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Review

Digital Technologies, Internet of Things and Cloud Computations Used in Agriculture: Surveys and Literature in Russian

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Abstract: Development of agriculture in Russia and Belarus is based on the practical implementation of "smart" systems in agriculture based on the use of modern wireless, intelligent technologies and Internet of Things. This review presents research articles (mainly, in Russian) published in the period of 2013 – 2022 on the use of cloud technologies and Internet of Things for the development of agriculture in Russia and Belarus. An analysis of the use of cloud technologies and Internet of Things in the modern world is given on the basis of research articles and reviews published in English in the period of 2017 – 2022. The main directions of digitalization of modern agriculture are listed. The uses of cloud technologies and Internet of Things in agriculture are described along with promising directions for further research and applications.

Keywords: modern agriculture; smart farming; cloud computing; internet of things; survey

1. Introduction

The following stages of agricultural development are distinguished in the science literature: traditional agriculture or Agriculture 1.0 (including the beginning of the XX century); Agriculture 2.0, with extensive use of mechanization, fertilizers and plant protection products (since the 50s of the twentieth century); Agriculture 3.0 with a higher degree of automation and the use of information from sensors in real time (since the early 1990s); Agriculture 4.0 based on the process control using elements of artificial intelligence and Internet of Things (since the early 2010s). It is also called "digital" or "smart" agriculture. The practical implementation of "smart" systems in agriculture ("smart farm", "smart field", "smart garden", "smart greenhouse" and "smart agricultural enterprise") is possible through the use of the modern wireless, intelligent technologies and Internet of Things. In [1], twelve technologies related to Industry 4.0 are identified, namely: Internet of Things, cyber-physical systems, digital twins, robotics, edge computing, cloud computing, big data analysis, data science, additive manufacturing (with 3D printing), augmented reality, cyber-security and real-time optimization.

Internet of Things (IoT for short) is a computer network of Internet-connected physical objects capable of collecting and exchanging data using built-in technologies for interacting with each other and the external environment. Farms using the IoT aim to minimize operating costs while providing better production results, such as higher yields, reduced livestock losses and lower water consumption. The structure of Internet of Things by CISCO, consists of the following seven levels; see [2] and Figure 1.

- *Physical Devices and Controllers Layer*. This is the lowest layer that is responsible for data. At this level there are sensors, microcontrollers, microprocessors and actuators, i.e., devices that collect data and transmit it for further processing. This level guarantees the correctness and high accuracy of the collected data, collecting which simplifies further processing.

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- *Connectivity Layer.* This layer is responsible for communication protocols. Communication between sensor devices and microcontrollers is done via RFID (Radio Frequency Identification), BLE (Bluetooth Low Energy), NFC (Near Field Communication), Zigbee, etc. It is also possible for sensors to connect directly with microcontrollers via a cabled connection. The microcontroller and microprocessors use protocols such as MQTT (Message Queuing Telemetry Transport), CoAP (Constrained Application Protocols) to transmit data to the gateway. The gateway uses HTTP (HyperText Transfer Protocol), MQTT, or CoAP to further store the data into the cloud or on a server.
- *Edge Computing Layer.* Edge computing may be referred to as fog computing in CISCO terms. The main purpose of edge computing is to perform raw data processing. These calculations are performed by a gateway device that performs low-level data mining to discard unnecessary data and transform heterogeneous data into a form such that simplifies decision-making for machine learning and data mining algorithms.
- *Data Accumulation Layer.* Data from the gateway devices are collected and stored in the cloud for further processing.
- *Data Abstraction Layer*. Various data mining algorithms are implemented to get more intelligent information.
- *Application Layer*. This layer is where dashboards of smart applications (such as mobile) that receive data from the cloud are deployed. Based on consumer requests, the cloud service provider operates on data so that the user can get useful information. Some smart devices can deploy the built-in application and receive data from the cloud to execute machine learning algorithms.
- *User and Business Layer*. This level deals with the user management and business management aspects of a fully deployed application.

In the agricultural practice, IoT systems may consist of a network of smart devices and a cloud platform to which they are connected. An adjacent to them is a system for storing, processing and protecting the data which are collected by sensors. The implementation of digital technologies in the agricultural production involves most continuous data collection from a large number of sensors, unmanned vehicles and aircrafts. The obtained information about the processes is big data having properties of variability, high dynamics, scale, multidimensionality, and asymmetry. A universal rule in Internet of Things technologies and related big data aggregation processes is that the huge data is collected in one place, the smarter the system becomes and the more valuable information can be obtained for consumers.

For storing and processing the collected data, the use of cloud technologies (i.e., distributed computing technologies that use network access methods to shared computing resources) is promising. Cloud infrastructure includes computer networks, servers, data storage, and operating systems. Cloud service providers typically provide their services using one of the following technologies [3]:

- SaaS (Software-as-a-Service). All the necessary software is located on cloud servers and is leased. There are also services such as data, file and record storage, web-based email services, and various project management-related tools that can be customized depending on the agricultural company.
- PaaS (Platform-as-a-Service). Clients are provided with an environment for developing their own applications, including an operating system, databases and processing tools.

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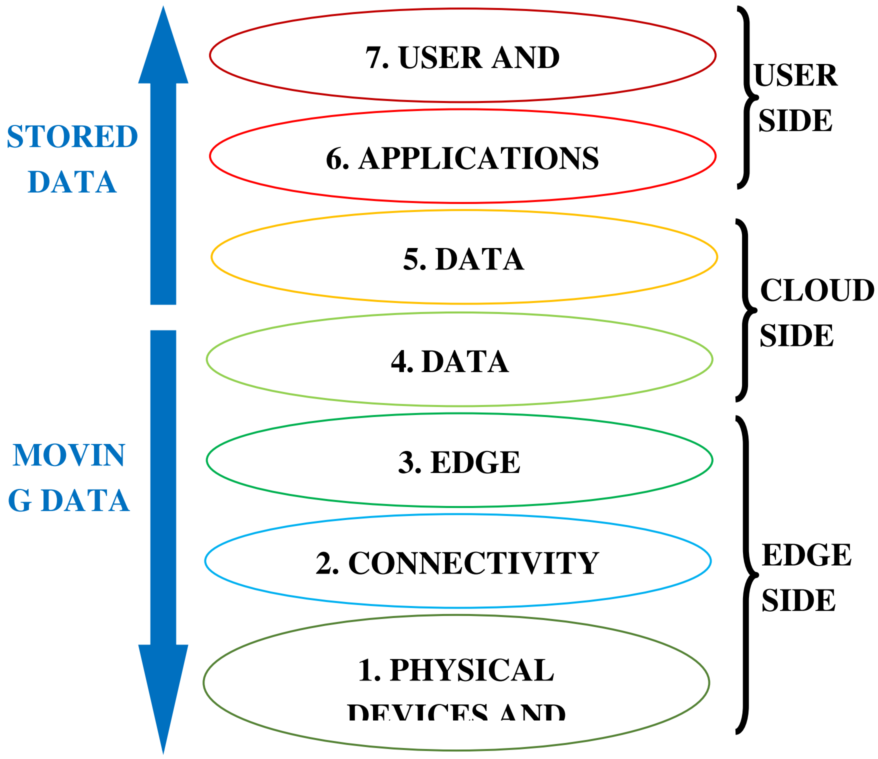

Figure 1. CISCO 7-latyered reference model [2].

- IaaS (Infrastructure-as-a-Service). Capacity and resources for the data storage, installation of operating systems and application development are provided. The main goal of the IaaS is to an eliminate dependence on platforms and a resource-intensive installation, providing them as a part of a cloud service.

In the modern agriculture, there are stable trends in the development of digital platforms in the agro-industrial complex implemented on PaaS technologies. In this case, most data from the sensors is stored in the cloud, which frees the agricultural company from the need to have big servers to store data for the observation period. The combination of cloud and edge computing is of interest. In this case, the direct control of the technological process based on sensor data is carried out from a server located on the territory of the farm. From time to time, the edge database will be synchronized with the cloud database and control algorithms will be updated to improve the quality and efficiency of decision-making. Ensuring the necessary level of information subsystems and resources security, integrity and confidentiality of data is achieved by using closed cloud services. Cloud technologies make it possible to combine agricultural companies into a single integrated information and communication system using elements of artificial intelligence to develop control algorithms based on big data analysis. Control algorithms based on self-learning neural networks will be continuously adjusted and refined as new data becomes available. The presence of a single information base will make it possible to develop recommendations for different agricultural companies, taking into account the observed trends (predicted weather conditions, the spread of diseases, pests, etc.) and the accumulated experience of other companies. The implementation of Internet of Things in Agriculture achieves the greatest effect when the processes of the intra-agricultural production cycle are connected with other parts of the value chain. Complex highly automated production and logistics chains are created, covering wholesale and retail trading companies, logistics, agricultural producers and their suppliers into a single process with an adaptive management. Such chains can reduce the cost and retail prices of food products, thus increasing their availability to consumers and productions and sales capacity.

2. Related Survey Papers

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In Subsection 2.1, we present recent survey papers on developing smart agriculture and applications of Internet of Things in it. In Subsection 2.2, we present surveys on digital technologies and the use of sensor data in smart agriculture. In Subsection 2.3, cloud, fog and edge technologies are presented along with communication protocols used in smart agriculture. Farm management information systems (FMIS) are described in Subsection 2.4. Perspectives of using the blockchain in smart agriculture are discussed in Subsection 2.5. Reviews of publications on new technologies in Agriculture 4.0 are presented in Subsection 2.6. Research gaps affecting the use of IoT and cloud computing in smart agriculture are described in Subsection 2.7.

2.1. Smart Agriculture and Internet of Things

Advances in the IoT and artificial intelligence technologies have revolutionized agriculture by providing intelligent systems that can monitor, control and visualize various agricultural operations in real time and with intelligence comparable to that of humans in calculation and analysis [4]. "Smart agriculture" is a term in the agricultural sector aimed at optimizing the activities of farmers in order to increase production productivity and intellectualize the farming system [5]. The expected benefits from the introduction of smart agriculture technologies are an increase in production, a reduction in costs by reducing the need for fuel, fertilizers and pesticides, a reduction in labor costs and an improvement in the quality of the final product [6].

Internet of Things is a promising family of technologies that can offer a variety of solutions for an agricultural modernization. In particular, the IoT data management and analysis can be used to automate processes, predict situations and improve many actions in real time [7]. Collecting data from multiple stages in supply chains allows for the creation of transparent data-driven food production systems [8]. In [4], it is noted that the digitalization of agriculture using artificial intelligence and the IoT has left the concept stage and has reached the implementation stage. Various components and new technologies, such as sensors, applications, programs and equipment are included to Internet of Things in agriculture.

Four levels of the Internet of Things are distinguished in [9]. The first component is a sensor that collects data in real time, followed by a communication device that processes data transmission (the second level). The third level is responsible for analyzing the data, and the service layer is responsible for performing any necessary actions.

The review paper [10] provides various definitions of the IoT, considers technologies that support Internet of Things and classifies the functional areas of the application of Internet of Things. The most widely studied issues in the field of Internet of Things are Internet of Things Applications in the agricultural sector followed by the IoT applications in the food industry and in other sectors such as energy, healthcare and industry [11].

The agricultural Internet of Things is used in a wide variety of areas of agriculture. More and more review papers are devoted to the applications of Internet of Things in the agricultural sector; see [4, 7, 10-19]. It is noted in [5] that most studies are devoted to crop production and, to a lesser extent, animal husbandry, the most popular direction is irrigation. At the same time, most of the studies focused on improving the productivity of the agricultural sector by solving technical problems in terms of mathematical and simulation modeling, while other studies focused on identifying and analyzing the risks associated with the deployment of IoT throughout the supply chain [11].

The review paper [12] examines the application of smart agriculture technologies in crop production, animal husbandry and harvesting, and describes the advantages and challenges of implementation in the proposed solution for each study reviewed. The article [9] lists the areas of use of Internet of Things in smart agriculture from irrigation and fertilizing to farm management systems and blockchain, along with security issues, challenges and several future research trends. The article [4] examines the potential applications of the IoT and AI (artificial intelligence) in the development of intelligent agricultural machines, irrigation systems, weed and pest control, fertilization, greenhouse cultivation, storage facilities, plant protection **unmanned aerial vehicles (UAVs)**, crop health monitoring, etc. Among the applications of Internet of Things in Agriculture 4.0, the paper [20] lists soil sampling and mapping, irrigation, fertilization, disease control, greenhouse management, vertical farms, hydroponics and phenotyping.

The study [13] focuses on outdoor crop cultivation and farm managers as the main users and decision-makers, while the study [9] focuses on crop tracking, field survey and analysis providing farmers with data on appropriate farm management strategies. A review of publications on the integration of the Internet of Things and vertical farms was carried out in [14]. Publications were reviewed according to the following criteria: crop-plant type, farm size, sensing data, used hardware (sensors, actuators, etc.), power supplies, velocity or frequency of data collection, data storage methods communication technology, data analysis methods and algorithms. The introduction of vertical farms and vertical gardens can be beneficial in maintaining a sustainable environment, as well as improving urban food security.

The implementation of modern digital technologies in a combination with Internet of Things in the supply chain of agricultural food products is considered in [7, 8, 11, 15]. As food supply chains become more complex, so does the importance of transparency in food production [8]. The application of Internet of Things in the agricultural food supply chain can not only provide a truly transparent supply chain but also reduce food and water losses, carbon emissions, pesticide use, and improve soil management, food quality and safety, inventory management and income [11]. In [15], a systematic literature review on the application of blockchain technology to the agricultural food value chain was carried out. The article [16] provides an overview of publications on the integration of blockchain and IoT in the development of intelligent applications in precision agriculture. The IoT applications in the agricultural and food sectors increase the fault tolerance, maneuverability and flexibility of the system; contribute to the environmental, social and economic aspects of sustainability [11].

2.2. Smart Agriculture Technologies and Data

Smart agriculture is not a single technology, but a collection of different technologies [17] that can be used individually or in combination, depending on the needs of the process. In [10], Internet of Things technologies (sensor, identification and recognition, hardware, software with cloud platforms, communication and networks, software and algorithms, data analytics and data storage, positioning and security) are considered and divided into four areas as follows: applications, middleware, networks and objects.

The ever-increasing interest in the IoT technologies in scientific publications was observed in the article [7], which provides an overview of the contemporary IoT technologies, used in agricultural sector, their potential value to farmers and the challenges faced by IoT in its adoption. The article [21] presents an overview of more than a hundred articles on information and communication technologies used in Agriculture 4.0. This study was conducted on how digital technologies affect (functionally, economically, environmentally and socially) on the agricultural production, transform the supply chains of agricultural food products, and also consider the problems that arise during their implementation. A review paper [8] describes assistive technologies of Internet of Things that can increase the transparency of the food production.

Various research reviews of scientific publications consider various technologies used in agriculture, such as: positioning systems (due to GPS), remote sensors (including UAVs), data analytics, decision support tools, automation and robotics [17]; unmanned aerial and ground vehicles, image processing, machine learning, big data, cloud computing, and the Wireless Sensor Networks (WSN for short) [6]; the WSN cloud compution, big data, embedded systems, security protocols and architectures, communication protocols and Web services [22]; Internet of Things, blockchain, big data and artificial intelligence [21]; robotics, drones, remote sensors, and a computer vision with machine learning and computing software [9]; Internet of Things, cloud computing, machine learning and artificial intelligence [12]; IoT-based tractors, robots and cloud computing [20]. The technical details of artificial intelligence, IoT and the problems associated with the implementation of the digital technologies are discussed in the paper [4].

It was noted in [11] that many studies emphasize the integration of technologies such as blockchain, big data, cloud computing, machine learning, image processing technologies, RFID, WSN, etc., with IoT for applications in agriculture and food production. Many of the studies reviewed in [11] have focused on improving the system as a whole by reducing power consumption, latency, increasing bandwidth, etc. Agricultural cloud-based IoT solutions for monitoring and managing sensor networks, drones, autonomous vehicles, robots, agricultural machinery, greenhouses and food supply chains are considered in [7]. The paper [17] provides an overview of the use of edge and fog computing in animal husbandry, crop production, fish farming, forestry and farm fencing, environmental monitoring, and food supply chains. The article [20] provides an overview of how various technologies such as IoT, UAVs, Internet of Underground Things (IoUT for short), big data analytics, deep learning techniques and machine learning techniques can be used to manage various operations related to an agricultural farm. For each of these technologies, a detailed review of its use in Agriculture 4.0 is carried out. The article [22] reviews the latest research on the application of IoT and UAV technologies in agriculture. The basic principles of the IoT technology are described, including smart sensors, networks and protocols, the IoT applications and solutions used in smart agriculture. It is noted that the integration of heterogeneous data from different sensors used in smart farming systems is essentially difficult due to software and hardware compatibility issues.

Agricultural 4.0 technologies are based on the following four stages [20]: data sensing, data collection, data transmission and data processing. The problems of collecting, processing and storing and accessing data from sensors and other Internet of Things devices in smart agriculture are considered in studies [4 - 6, 11, 14, 18]. The parameters monitored by sensors in IoT-based smart agricultural applications are discussed in [5], where it is noted that the most commonly used sensors are temperature, humidity, soil and sunlight intensity sensors. Most researchers (see [4, 14]) note that the data collected by sensors is huge (and this amount is increasing day by day), distributed (tied to location and time), heterogeneous (can be structured, semi-structured or unstructured).

Internet of Things, being a network of small and remotely located objects, has very limited resources in terms of data processing and storage. The quality and cost of devices and sensors, and the reliability of the system, are the main challenges for smallholder farmers seeking to implement advanced technologies [4]. In addition, since the IoT devices are heterogeneous, there is a problem of device compatibility and synchronization for better performance [4], since primary analysis or pre-processing of data may not be sufficient to store data from different sources [14]. Sometimes data storage and processing must take place in real time, which requires additional computing resources [6]. There is an urgent need to upgrade the IoT devices to improve their reliability, endurance, intellectualization, etc., while reducing costs and operational difficulties. The solution may be a cloud service for Internet of Things applications, since it can provide huge computing power, a huge amount of storage and is highly scalable [4]. Cloud also takes into account many other elements, such as energy efficiency, optimization of hardware and software use, scalability, performance and flexibility [18].

2.3. Cloud Technologies Used in the Agriculture

We next describe different aspects of cloud, edge and fog computing which are used in smart agriculture.

2.3.1. Cloud computing

The cloud with practically unlimited computing power and storage capacity is a technology that can withstand the Internet of Things workload [7]. An IoT server can be implemented using a cloud computing infrastructure which has advantages due to a low implementation cost and scalability. Cloud computing in smart farming applications can be used to collect and store information from remote sensors, to process data (such as data analysis, visualization and decision-making) and display the results to users [22].

Using cloud-based IoT systems, it is possible to store big data from many sensors in the computer cloud. One can also host applications that are necessary to provide services and manage

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the IoT architecture. These resources are reliably accessible from anywhere at any time, and the information can be provided in a form that is easy for farmers or agronomists to understand [6]. Farmers can access all the information available on the market related to farming practices and equipment, as well as advice from different analytical organizations [20]. Cloud computing is intended to become a central system of the knowledge management systems and decision support systems infrastructure, and can be indispensable in systems with requirements for processing big data, especially in real time [6, 12].

Reviews looking at IoT applications in agriculture note that most of the systems reviewed depend on at least one cloud service [17]. The most popular methods of data storage were the use of a server database, a remote data management platform and a cloud server [7, 14]. Any IoT device includes an Internet-connection interface to transfer data to the server [22]. The most common platforms for Internet of Things are based on cloud computing [10]. As a rule, the initial data processing is carried out on a local server and the main cloud services were used for second-level uploading, storage, processing, analysis, decision-making, and alert generation [9, 17].

The paper [12] presents a diagram of the IoT-cloud-network for agriculture designed to implement machine learning models for collecting and analyzing farm data. It is noted that the cloud-IoT needs a further research due to the presence of limitations, such as scalability, reliability, confidentiality, security, heterogeneity of equipment used, energy optimization and cost.

2.3.2. Fog computing

The huge amount of data generated by IoT devices can incur high transmission costs to the cloud, both in terms of money and latency [7]. In the case when farmers work with highly automated equipment or UAVs, a low latency and reliability are paramount to their safety and to ensure an immediate response to different events [6]. To minimize a latency, costs, and improve a quality of service, edge and fog computing, MEC (Mobile Edge Computing), MCC (Mobile Cloud Computing) and cloudlets has been promoted which are an extension of the cloud computing paradigm [10, 18, 20]. They process data at the edge level of the network on a router and/or the IoT gateway to improve the performance of the IoT system (e.g., a response time, bandwidth, energy efficiency), as well as to provide a greater security and privacy. Such computing systems include several mechanisms similar to cloud computing but deployed at edge nodes located between the IoT devices and cloud infrastructure. They can be considered as a part of the IoT middleware. In such a way, these paradigms can complement cloud computing.

Local fog nodes are in a close proximity to edge devices and can provide their compute and storage resources for increasing supported system reliability, security with fault tolerance, scalability, multi-tenancy, advanced analytics and automation, cost-effectiveness. As a result, local fog nodes allow to reduce the amount of data transferred to the cloud [6, 18]. In [12], it is studied the advantages of a transport network in which vehicles play the role of fog servers, which reduces latency and improves the quality of service for data transmission. The IoT gateways as fog servers collect data from sensors and include data aggregation, filtering, encryption and video stream encoding services. They can also predict and/or categorize events based on machine learning algorithms deployed in clouds. Thus, an optimal balance can be achieved between edge storage with processing and the part of the workload that needs to run in the cloud [7]. In [18] it is concluded that it is important for developers to correctly determine from the very beginning where data processing will take place since this affects the choice of nodes, the amount of data to be transmitted and the communication protocols used.

2.3.3. Edge computing

To use smart agriculture technologies, and in particular cloud computing, it is necessary to maintain a constant Internet connection. In rural areas, there may either be no Internet connection at all, or the connection is unstable and often interrupted [17]. A technology that can reduce this problem is edge computing, which proposes to move computing and data storage to the edge of the network to provide a sufficient quality of service for compute-intensive, latency-sensitive, and

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bandwidth-intensive services. While in the early years of IoT communications, disparate endpoints of IoT devices did not perform a large amount of data analysis and processing, now they interact with each other and process more data at an edge of the network [16]. With an increase in the technical capabilities of edge nodes (CPU-memory), data processing is carried out directly at the edge nodes of the network and only the results are sent to the cloud [18].

Recent research shows that edge computing architectures are the optimal solution for minimizing latency, increasing privacy, and reducing bandwidth costs in the IoT-based systems. In the paper [23], an overview of edge computing technology and its reference architectures are given and a proposal for a multi-level architecture with a modular approach is presented. It is tested in terms of reducing the cost of a bandwidth between the edge and the cloud, by creating an IoT platform in an intelligent agro-industrial complex. The proposed reference architecture allows a decision-maker to manage complex systems such as smart cities, smart energy, healthcare or precision agriculture. The article [23] considers the AREThOU5A project for irrigation water management on a farm, provides a diagram of its system architecture, with a server subsystem deployed in the cloud and responsible for storing raw measurement data, performing data processing procedures and administering the email notification function.

The review [17] of the applications of edge computing in agriculture indicates that edge computing in agriculture is more common than it may seem, since it is sometimes a subcomponent in other areas of research, for example, in IoT. However, the systems being developed are often at the prototype stage and the critical issues of interoperability with scalability have not been sufficiently addressed. The edge computing infrastructure used was specialized and robust platforms for edge services, rather than individual implementations, needed to be developed to achieve a meaningful farm impact.

Various approaches to the description of the architecture of Internet of Things are discussed in [18], where the hardware technologies and communication protocols used, their advantages and disadvantages were described. The study [18] was continued in [19], where the following research questions were studied. Which storage and processing architectures are best suited to Agriculture 4.0 applications and respond to its peculiarities? Can generic architectures meet the needs of Agriculture 4.0 application cases? What are the horizontal development possibilities that allow the transition from research to industrialization? What are the vertical valuations possibilities to move from algorithms trained in the cloud to embedded or stand-alone products? It concludes that there is no universal and unique architecture for the IoT applications in smart agriculture that meet all the needs of all use cases.

The papers [18, 19] provide an analysis of the most popular cloud computing architectures, their combinations with fog and edge computing, as well as a comparison of architectures according to criteria such as proximity to the user, latency and jitter, network stability, high bandwidth, reliability, scalability, cost-effectiveness and availability. It was also noted that although the development of fog and edge computing and their analogues for MEC wireless networks makes it possible to process capabilities closer to users, improving response time, the procedures that can be performed on edge devices are limited by the computing and power capabilities of these devices. Traditional centralized cloud computing will continue to be an important part of computing systems and cannot be completely replaced by fog and edge computing since some resource-intensive tasks can only be handled at the cloud level, which has computing power and storage capacity. In Agriculture 4.0, this is especially true for the processing of satellite images and the training of artificial intelligence algorithms.

2.3.4. Communication Protocols for Cloud and Edge Computing

A comparison of the technologies used and the protocols of Internet of Things at the application, data transmission, the Internet and the network interface layers, was carried out in the review [10]. The article [2] analyzes the scientific literature on the IoT communication technologies in smart agriculture. Wired, wireless and hybrid technologies are used to transmit the collected data from the sensors to the control center. Wireless communication technologies IoT (Wi-Fi, ZigBee, LoRa, RFID, mobile communications and Bluetooth) used to connect to various devices in different layers of agricultural production are analyzed. Different technologies are compared in terms of technical characteristics and cost. Only one publication used wired CAN data transmission technology. The results show that each technology has its own advantages and limitations, and different wireless communication technologies are suitable for different scenarios.

Different technologies of data transmission (such as mobile communications and 2G/3G/4G/5G technologies, Zigbee, Bluetooth and LoRa) were considered in [11, 14, 20]. The most commonly used data transmission technologies for collecting sensor data were Zigbee and Wi-Fi [14]. Wireless protocols such as ZigBee and LoRa are advantageous for agricultural applications compared to other protocols due to their low power consumption as well as the desired communication range [11].

The unprecedented data collection and management capabilities offered by the IoT are based on several factors of the underlying architecture and technology of the communication network, one of the most important of which is the protocol that is used between IoT nodes, gateways and application servers. The paper [24] offers an overview of research on Internet of Things protocols with focusing on their main characteristics, performance and frequency of use in agricultural applications. Protocols for the data exchange between Internet of Things devices MQTT, CoAP, XMPP, AMQP, DDS, REST HTTP, and Web Socket are considered. They were compared in terms of efficiency indicators (a delay, bandwidth and power consumption). It was shown that the most popular for communication between the device and the IoT gateway is the MQTT protocol, which is a leader in almost all performance indicators. The MQTT protocol for the IoT was also discussed in [2] with the issues of authentication and security during data transmission and the problems of protecting IoT devices from physical and logical attacks.

The transmission of messages from IoT to the cloud requires a comprehensive protection, even when using the Transport Layer Security (TLS) protocol. In the article [24], a system is proposed that standardizes the transmission of messages from the device to the cloud platform and vice versa and provides end-to-end security. The conducted experiments demonstrate the effectiveness of the developed system and guarantee a unique identification of devices in the domain. It is noted in [2] that when designing a communication network, one should use the same protocol from IoT devices to the gateway, from the gateway to the cloud (the IoT platform), from the cloud to the end-user device and vice versa in order to control these actuators. This structure is optional and different protocols may be used in different parts of the communication network architecture depending on the requirements of the IoT platform, the hardware and software requirements of the gateways, etc. In the context of the IoT protocols and standards, open-source software and hardware were preferred [11] since it can solve interoperability issues with respect to protocols and devices.

2.4. Farm Management Information Systems (FMIS)

In the papers [13, 20, 26-28], farm management information systems are considered. Such systems are evolved from simple record-keeping software to complex cloud-based systems that can manipulate large amounts of data and provide decision support capabilities. The development of an IoT platform for agriculture aims to move from serving only a certain livestock or crops to a universal platform that can support any livestock or crop. This would make it easy to modify a system that can support a wide range of applications from managing and monitoring crop and livestock production to selling products to consumers and local stores [20]. Such a system would not be affected by any regional and geographical constraints and could be an intermediary for multiple IoT applications in agriculture.

In [26], a review of publications was carried out in order to determine and describe the current state of FMIS developments. As a result of a detailed analysis, 81 features of FMIS and 53 obstacles to the implementation of FMIS were identified. Some obstacles were obvious such as issues of system integration and the cost of FMIS. Other obstacles identified were less obvious such as a low level of understanding of FMIS and a lack of necessary skills on the part of the main FMIS user. Key associated aspects were also described such as agricultural domains (fields, greenhouses, orchards, farms or the overall system), modeling technologies (types of diagrams used), FMIS delivery models

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(as an application or as a platform, web or desktop) and identified stakeholders (from buyer and farmer to government and research institutes).

Academic and commercial FMIS in terms of their functionality were examined in [13]. The main system architectures and areas of use, implementation and profitability, as well as FMIS solutions for precision agriculture as the most information-intensive application area were analyzed. This review of commercial solutions included an analysis of 141 international software packages, which were divided into 11 functions using cluster analysis. Academic FMISs are more complex systems that take into account standards application, automated data capture and interoperability between different software packages. The FMIS commercial applications are focused on everyday farm office tasks related to budgeting and finance (such as record keeping, machinery management and documentation, taking into account new trends that require new functions related to traceability, quality assurance, and sales).

Decision-making systems for agriculture include data collection, data processing, optimization methods for decision-making. The process of building a decision-making system is considered in [27] on the example of the development of a plant watering system. This paper emphasizes the need for a higher-level FMIS that uses not only data from one producer, but also data from other local, regional or national producers for data analysis and decision-making. The difficulties in the implementation of such an information system for agricultural service providers are listed in [27]. The structure of the information system for smart agriculture using cloud technologies has been developed. The object-communication model for data management is presented in the form of entity tables. This model enables data sharing across production systems, rapid (controlled) third-party access and rapid integration of analytics and decision support tools. Decision-making processes are implemented into the entire scheme including product decisions, supply to the market, procurement of resources, etc.

2.5. Blockchain in Agriculture

Centralized IoT data access systems face problems of system failures with a complete loss of an access to data, big data access problems and security problems. Blockchain is a technology that provides an ability to make public transactions available to different groups of users without a need for an official third party to monitor transactions. With a help of blockchain, it is possible to create intelligent systems capable of verifying, protecting, monitoring and analyzing agricultural data [16]. The data obtained indicate that a blockchain technology, together with advanced information and communication technologies, as well as the Internet of Things, can improve the management of the agricultural food value chain in four main aspects as follows: a traceability, information security, production and sustainable water management [14]. Six challenges were identified in the implementation of advanced technologies in the agricultural production including a storage capacity, scalability, leakage of confidential information, high cost, regulation, bandwidth and latency of data transmission with a lack of staff skills. It is noted in [14, 23] that blockchain is a promising technology that ensures data security and confidentiality.

Blockchain is a decentralized way of storing data in the form of a chain of interconnected blocks [19]. Blockchain allows one to record information as follows: transactions between the provider and the farmer, as well as information relating to crops, materials and chemical products; farm, cultivation practices and management, animal feeding and additional information such as weather conditions, animal welfare, disease and treatment; a factory and equipment, processing methods, batch numbers and financial transactions with producers and distributors; warehousing, storage conditions (e.g., temperature and humidity), transportation methods, a transit time and all financial transactions between distributors and retailers; food items information, such as quantity available, quality, expiration date, time spent on the shelf or in the stock. Blockchain tools can increase transparency, traceability and resilience in farm-to-fork food supply chains. This provides a secure and reliable access to high-quality data in cloud and fog computing [8].

Reviews of publications on the integration of blockchain and the IoT for smart agriculture are presented in [16, 29] in order to answer the following two questions: how the integration of blockchain and the IoT improves data collection, data validation and data management; how the IoT

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architecture integrated into the blockchain can improve the capabilities and real-time decision-making process of participants in the agricultural value chain to transform conventional or traditional agriculture into a smart farming system. In [29], the application of a blockchain technology for agriculture is considered based on data collection, data verification, data security, data storage and data transmission/exchange through the external interface of the software application. The data that can be included in blockchain is environmental (using sensor data), production data (data from the value chain), administrative data (financial, government), external supply chain data (trade, delivery). An IoT-integrated blockchain architecture is proposed, which consists of a presentation level, a business level, a functional level, an integration level and a blockchain data level (integration of information systems and databases are at the business level, data processing at the functional level, data storage and security at the blockchain data level, information display through the presentation level).

The architecture of the IoT network based on blockchain design patterns, which combines the Internet of Things, fog computing, artificial intelligence (AI for short) and blockchain into a consistent model, is given in [16]. Blockchain is used not only to store and verify data from different IoT devices, but also as a monitor and transaction verifier for heterogeneous fog and cloud networks. Data is manipulated on the IoT device and does not need to be transferred back to the computer cloud. It was shown that a blockchain technology can make the IoT communication more secure, transparent and tamper-proof in precision farming systems. The advantages of blockchain over the cloud as data storage are decentralization, protection against data changes, resistance to unauthorized data distribution, transparent transactions, less expensive infrastructure and the possibility of edge/fog computing on the IoT endpoints. The main functions and strengths of the common blockchain platforms used to manage various subsectors in precision farming (such as crop cultivation, grazing and food supply chains) are discussed. Security and privacy issues are presented with open blockchain issues that hinder the development of the blockchain systems in precision agriculture.

2.6. Reviews of Projects in Agriculture

Reviews of research papers demonstrating the use of new technologies in Agriculture 4.0 are presented in [4, 6, 20, 30]. In [30], it is shown that many technical leaders (such as Dell, IBM, Microsoft, CISCO, Google, Intel, Qualcomm, etc.) are making efforts towards the potential use of the Internet of Things in agriculture. In particular, 17 academic and 17 commercial developments of the IoUT systems are described. Eight platforms for storing, analyzing and processing data in precision agriculture are presented. A list of companies and manufacturers of drones and sensors, providers of services for processing drone data, the use of drones for processing fields and platforms for managing them is given. The above companies are located predominantly in the United States, Canada, Australia, Switzerland, Hong Kong, the United Kingdom and South Africa. Brief characteristics of the developed applications using Internet of Things, UAVs and the Internet of Underground Things for agriculture (such as soil sampling and mapping, irrigation, fertilization, disease control, greenhouse management, vertical farms, hydroponics and phenotyping) are given. Most of them use cloud computing for their work. In most developed countries, tractors with a built-in navigation system and sensors that track all elements in the field are already common on farms; tractor manufacturers such as John Deere and Case IH have already begun offering autonomous tractors to farmers [4].

Applications, software and hardware play a crucial role in ensuring the intellectualization of the agricultural systems. The developed applications are responsible for collecting data for further analysis, such as Nutrient ROI calculator, Sirrus, FieldAgent, OpenIoT, Farmbot, SmartFarmNet, iSOYLscout, AgVault 2.0, AgriSync, FARMapper, are considered in [9]. There is also an overview of agricultural projects developed in Italy, Spain, Austria, the USA, India, Pakistan, Brazil and other Asian countries. The survey paper [11] reviewed 30 articles with hardware implementation and 6 articles with real applications of the Internet of Things in agriculture, such as automated irrigation, monitoring of soil parameters and product traceability systems. For example, the IoT Agriculture (AIoT) pilot project in China, which uses the IoT technologies to ensure food safety, is considered.

Most of the publications reviewed related to China and India, followed by Spain, Italy, France, the Netherlands, the USA and South Korea, as well as some European countries, while none of the survey articles described Russian developments in agriculture.

Vertical gardens (VG for short) is a method of growing plants in vertically stacked layers in closed, including high-rise, buildings. The vertical cultivation concept uses indoor cultivation systems in a controlled environment, where each individual environmental factor can be monitored and permanently controlled. In [14], 30 implemented projects (in period of 2014 - 2018) on the vertical cultivation of plants using Internet of Things technologies are considered. It was found that VG using the Internet of Things are most common in the United States (41.2% of the projects considered) and in China (23.5%, respectively). Due to their high level of technological readiness, VGs are popular in the USA and Europe. Interest in VG adoption is expected to increase in the future in Turkey, Singapore, Japan, South Korea and Malaysia.

The application of edge computing to agricultural applications, such as dairy cattle breeding, crop production, aqua-farms, protection of forests from fires, supply chains, safety from wild animals and environmental monitoring, is considered in [17]. This paper lists the developments of scientists from the USA, EU, India, China, Canada, Brazil, South Korea and Malaysia. A review of 94 scientific publications on communication technologies of the Internet of Things in smart agriculture from three databases (Science Direct, IEEE Xplore and Scopus) is presented in [5]. The geographical distribution of the selected articles shows that the most productive are the authors from India with 25 study examples. It is followed by China (15 articles); the USA and Korea (five articles and four articles); Mexico, Spain, Italy, Pakistan, Viet Nam and Malaysia (three articles each); United Kingdom, Tunisia, Indonesia, Brazil and Turkey (two articles each); and Portugal, South Africa, Australia, Ireland, Macedonia, Greece, Thailand, Egypt, Nigeria, Norway, Colombia, Algeria, Saudi Arabia, Romania, Russia, Kuwait and Bangladesh (one article each).

In the paper [13], it is reviewed a commercial Farm Management Information Systems (FMIS for short) developed in France, Germany, Italy, the United Kingdom, the USA, Canada and Australia. In the literature review on FMIS, presented in [26], out of 38 publications selected for analysis, there was not a single one from Russia.

The use of blockchain in agriculture can increase the transparency of food production and supply and improve their quality. The advantages and challenges of integrating blockchain and the IoT are described in [16], which lists five blockchain platforms for smart agriculture (Provenance, AgriDigital, IBM Blockchain, Food-coin and AppliFarm), and considers the application of blockchain to the management of agricultural production in China, Sweden and Africa.

The paper [6] provides an overview of European projects in the field of smart farming. The first part presents the results of research by scientists, who apply innovative technologies to grow various crops in Europe, classified depending on the country, the technologies used, the type of a field work and the type of crops. Realized projects tested in these fields or greenhouses in Europe were also considered, including one study [31] on the deployment of IoT in a tomato greenhouse in Russia, using wireless sensors, cloud computing and artificial intelligence to monitor and control plants and conditions in the greenhouse, and predict the growth rate of tomatoes. In the second part of paper [6], an analysis of the 18 most significant projects in the field of intelligent agriculture, funded in European countries, is carried out.

The paper [12] discusses the application of smart farming to a crop production, an animal husbandry, and post-harvest processing. This review examines research on the identification of diseases on cucumber leaves in the Cyprus region, on the development of a 3-D method for the visual detection of sweet pepper peduncles in Australia, on the use of smart sensors in poultry houses and farms in Europe, on solving specific problems in fish farming (biomass monitoring, feed delivery control, parasite monitoring and crowding management) in Norway, and on determining the best time to harvest coconut for aromatic coconut producers in Thailand.

In the paper [30], it is described a technological equipment and different approaches used in precision farming and the IoT. It is shown seven case studies from different countries (Italy, Greece, France, the USA, Japan, Argentina and Tanzania). An example of a Mediterranean farm (a commercial winery) in France is presented, in which digital and precision farming tools are used for winemakers and wine-consultants. A study on precision farming in perennial crops in Greece highlights the use of remote sensing and near-range sensing in a variety of settings. The application of variable rate nitrogen fertilizers based on prescription maps and sensors "on the go" is an example of corn cultivation in Northern Italy. A smart irrigation is a theme of the United States. This case study highlights technological advances in a cotton irrigation to optimize yield and sustainability. In Japan, the production of rice based on proximal sensors and IoT is described. Some other case studies (in Argentina and Tanzania) discuss an overview of the implementation of smart farming technologies and techniques used in these countries. The results of this research show the potential of precision farming and the economic profitability of the latest technologies, as well as improving an environmental sustainability. It is emphasized that in some tested countries, there is a lack of technology (for example, new machine systems and knowledge in the field of data analysis). Therefore, the transition to an IoT system will require significant investments. Precision farming and Internet of Things are not only technologies that can help increase yields, but they are mainly dedicated to optimizing resources and the sustainability of humanity and agro-ecosystems.

2.7. Research Directions

The authors of articles [5, 10, 12, 15, 16, 20, 21] identify research gaps affecting the use of the IoT in smart agriculture and suggest research directions to improve current food production. In particular, it is proposed to consider cloud-based smart farming, the inclusion of a cloud platform in a smart farming system, the introduction of foggy technologies on farms and the use of edge nodes for training in computer learning as topics for further research [12]. Recommendations to overcome the limitations in the implementation of the Internet of Things in agriculture related to the cost of equipment, sensor compatibility, structure and fault tolerance of the communication network, reliability, integrity and volume of transmitted data, etc. are proposed in [5]. The need to develop a universal Internet of Things platform with an integrated farm management information system that uses data from not one farm, but the entire region, taking into account the entire supply chain, is emphasized in the articles [17, 20, 27].

3. Publications on Realized Projects

Many publications describe different developments in smart agriculture, which were tested and then used on the farms in different regions and countries.

3.1. Information Systems and Different Platforms Used for Farm Managements

Information systems and data transfer platforms from IoT devices for a farm management are discussed in the papers [28, 32-37] based on cloud technologies. Common requirements for the development of FMIS in agriculture are described in [32]. In [28], an information system for managing a farm using cloud computing, big data and the Internet of Things was developed. This development was carried out on the FIWARE platform, using the FMIS, to which a financial analysis tool for the farm was additionally developed. The developed application has been successfully tested on winter wheat crops in Germany for a season. All the tasks that the farmer performed during this season were recorded, including the use of equipment and resources such as seeds, pesticides, fertilizers, etc. In addition, all financial transactions related to the harvest (e.g., purchase of fuel and salaries of employees) were available. To validate the financial analysis, which is performed on the basis of standard values, farmers were asked to provide their own estimations of the typical costs of each task performed in terms of the equipment and labor. The application focuses on the financial analysis of the farm based on all the transactions of the farm, as well as the assessment of profitability. A variable cost was calculated, which was directly assigned to a specific field or a crop, and a fixed cost, which is recorded for the farm and then distributed to the fields or crops.

The article [33] developed a scalable IoT-based monitoring system with forecasting capabilities for agriculture. The proposed IoT system was designed and experimentally tested by monitoring a

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temperature and humidity in a commercial tomato greenhouse in Mexico for six months. Predictive modeling of the greenhouse microclimate based on data using an artificial neural network was implemented. The obtained results showed that the ANN model can be successfully used to predict a temperature for 24 hours with a simple three-layer ANN of 8 neurons in a hidden layer. The temperature forecasts were accurately fulfilled 24 hours in advance with an error of 1°C. The results obtained confirm that the proposed IoT framework can make it easier for farmers to monitor their crops and increase the production of crops.

The article [34] presents agricultural information (i.e., a cloud-based autonomous information system for agriculture), which provides information as a service for managing various types of IoT data. The proposed system is autonomous, designed for various branches of agriculture (plants, animals and equipment, weather parameters, soil, the presence of pests, productivity, the need for fertilizing and irrigation), is based on cloud computing and fuzzy logic. The system supports the QoS (Quality-of-Service) and has a graphical user interface. A web application and a mobile application were also developed. The performance of the proposed system in a cloud environment was evaluated based on the CloudSim toolkit, which showed an improvement in cost, network bandwidth, execution time and latency. The system collects information from various users through pre-configured IoT devices (mobile phones, laptops and iPads). agricultural information was tested in an Indian village with a farmer satisfaction.

A system for smart agriculture IoT-Agro is proposed in [35]. A web-based www.iot-agro.com platform has been developed for coffee growers. This platform allows to track the ecological variables of the coffee zone by plot, farm and region; to make their own decisions on the management of coffee tree crops based on real data; and to plan pre-harvest activities based on an estimate of coffee production per year, avoiding monetary losses in production. This IoT-Agro evaluates coffee production based on weather data and crop management data (fertilization, control and cleaning) using learning models. An experiment was conducted on the coffee farm "Los Naranjos", located in the district of La Venta (the municipality of Cajibio, Cauca, in Colombia). The application has been tested by stakeholders, from farmers and operators to researchers. Storing climate data at the data analytics level helps farmers access actionable insights; perform technical calculations on irrigation needs and early warnings to predict plant diseases; estimate the yield of their crops using artificial intelligence models; plan the time of harvest taking into account climate change. Farmers can adjust crop management plans: fertilizing, nutrition, planting, irrigation. Storing data at the top level allows them to carry out regional planning to ensure economic stability, promote markets, adjust supply and influence prices for the benefit of producers.

In the paper [36], it was proposed a MooCare model designed to help producers manage dairy cattle in order to increase productivity. Using IoT devices, MooCare automates and personalizes animal feeding. The model allows for on-premises deployment to a farm or cloud compute resource that is accessible from the Internet. This model contains the following functions: obtaining data on a cow productivity (based on the animal identifier and milking sensor), predicting the milk production of the animal (using the ARIMA model to determine the predicted value), supplying the concentrate individually to each cow depending on its milk production (regulated by the actuator) and sending warning notifications to the producer using threshold values. The estimates include modeling based on cow lactation data from a real farm located in the southern region of Brazil. The computational results showed that the model can provide an adequate forecast of a milk production, the reliability of the forecast was 94.3%.

A flexible platform for a soilless cultivation in fully re-circulated greenhouses using moderately salty water has been proposed in [37]. This system was implemented in a real prototype in a greenhouse in southeastern Spain as a part of the EU Drain-Use project. Two cycles of tomato cultivation were used. The first to test the correctness of the architecture, and the second to analyze the improvements of the system compared to the harvest in the open field. Savings of more than 30% on water consumption, and up to 80% on nutrients were obtained.

The article [38] proposed an irrigation strategy based on a zonal irrigation, fuzzy logic, wireless communication and the IoT to monitor irrigation and maintain soil moisture in ideal conditions for a

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plant growth while consuming minimal water and energy. The developed zonal irrigation system was applied to irrigate tomato plants in a greenhouse in Algeria. The experiment lasted for eight days. The area of six square meters in question was divided into two zones. In each zone there was a wireless unit with a solenoid valve and a soil moisture sensor and a sensor unit for measuring the ambient temperature. The Raspberry Pi was used and served as the HMI server and host. The system sends sensor data to the server via a radio frequency communication. A fuzzy logic controller (FLC for short) processes this data and makes a decision to control irrigation. The developed system can monitor and control greenhouse irrigation from anywhere and at any time using a Human Man Interface (HMI) developed as a part of IBM's Node-RED. Experiments have shown that combining a fuzzy logic controller with a zoning strategy is superior to other algorithms in terms of minimizing water and energy consumption.

In the article [39], an IoT system was developed with a new nitrogen, phosphorus and potassium (NPK) sensor with a light-dependent resistor and light-emitting diodes. The data collected by the developed NPK sensor from selected agricultural fields is sent to Google's cloud database to support fast data retrieval. Fuzzy logic is used to detect nutrient deficiencies from the sensed data. A warning SMS message is sent to the farmer about the amount of fertilizer to be used at regular intervals. A hardware prototype of the sensor and Python software for the Raspberry Pi-3 microcontroller were developed. This model was tested in India on three different soil samples (red soil, mountain soil and desert soil). The analysis of the developed NPK sensor in terms of throughput, end-to-end latency and jitter was performed using the Qualnet simulator. Experiments have shown that the developed IoT system can increase crop yields.

As a rule, a developed system has a multi-level architecture (four levels in [33] or three levels in [35] and [37]). The three levels in IoT-Agro architecture are as follows: agricultural perception, edge and data analytics. The agriculture perception layer consists of IoT-enabled devices (sensors, actuators, weather stations, tags and RFID readers) that monitor real-time weather conditions and product health across the entire value chain (cultivation, harvesting, post-harvest, drying and storage). This layer provides data to the analysis components in the data analytics layer. The edge layer is close to the endpoints for on-premises real-time computing and data processing to reduce the burden on the data analytics layer and improve the reliability of agricultural IoT data. This layer includes interconnected edge devices, physical or virtual objects (e.g., routers, switches, wireless access points, repeaters, embedded systems and servers) geographically distributed across farms to collect all data from the agricultural perception layer. The data analytics layer consists of data centers and traditional cloud servers with virtually unlimited compute and storage resources. At this level, IoT-Agro services are deployed based on data analysis. The open-source software platform described in [37] consists of local, edge and cloud layers. At the local layer, cyber-physical systems interact with crop growing devices for real-time data collection and monitoring. The edge layer of the platform is responsible for monitoring and managing main tasks of precision agriculture at the edge of the network to improve the reliability of the system in case of network access failures. The cloud platform collects current and past records and hosts the data analysis modules using the FIWARE platform. The architecture of the system in the form of modules reduces the design time for the configuration and maintenance.

The article [23] presents a proposal for a multi-tiered global edge computing architecture with a modular approach to reduce bandwidth costs between edges and clouds. The reference architecture was tested by creating an IoT platform in an intelligent agro-industrial complex in the community of Castile and León, to optimize the management of agricultural enterprises. The test results demonstrated the advantages of the developed architecture in the following aspects: real-time data analysis at the level of on-premises devices and edge nodes, rather than in the cloud; reduce operational and management costs by reducing traffic and data transfer to the cloud; a better application performance due to lower latency levels at the edge of the network than in the cloud. A higher level of security and privacy was reached when incorporating blockchain technologies into the layers of an IoT architecture and business decisions.

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A large amount of data coming from IoT sensors requires high processing speed and real-time decision-making. For IoT cloud processing in smart agriculture, Lambda or Kappa architectures is commonly used. However, they are not specialized for smart farming. The article [40] presents an optimized version of the Kappa architecture, with the aim of improving a memory management and data processing speed for a fast and efficient IoT data management in agriculture. The parameters of the proposed Kappa architecture were configured to process data from the analysis of animal behavior in a precision animal husbandry. It was shown that the combination of the Apache Samza computing system with the Apache Druid database provides a higher performance. The results of this research showed the effect of adjusting the parameters on the speed of treatment.

In [32], a common architectural framework for modeling agri-food systems based on the IoT, combining technical and business aspects was developed. The application of the proposed framework to 19 use cases in different regions of Europe was described; its effectiveness for modeling the IoT-based architectures in a wide range of different agricultural areas was demonstrated. Experimental developments on the use of various communication protocols for transmitting data from sensors to the network in IoT systems for various agricultural applications are described in the articles [41, 42]. The article [41] presents an adaptive network mechanism for a smart farm system using LoRaWAN and IEEE 802.11ac protocols. The system has the ability to configure the protocol depending on the state of the network. For example, IEEE 802.11ac was suitable for transmitting data that requires high speeds, such as images or videos. In contrast, the LoRaWAN protocol was suitable for sending data that has small data packets, such as sensor read data. An adaptive mechanism that combines the advantages of both protocols ensures the reliability of the system when performing the monitoring task. The proposed mechanism was implemented at the application level and tested by collecting data in a greenhouse in South Korea. The obtained result showed that the proposed system improves a network performance and provides reliability in terms of average latency and the total amount of sensor data collected.

The article [42] developed and implemented a flexible IoT security middleware that can be used in end-to-end cloud and fog communications, from smart devices at the edge of the network to cloud-hosted applications. The task of middleware for communication protocols between two different network segments (from cloud to gateway and from gateway to edge) has been solved, which ensures a high security. The developed software is able to cope with intermitted network connectivity, as well as device limitations in terms of a computing power, memory, and energy and network bandwidth. To provide a security in case of interruption of communication, the "resume session" algorithm has been developed. If a recently disconnected device wanted to resume a previous interrupted connection, one can reuse encrypted sessions from the recent past. It was described the "optimal scheme decider" algorithm for selecting the best end-to-end security scheme option suitable for securing an IoT-based application, depending on user requirements and resource constraints at the network edge. Prototypes of the client and server were used in the conducted experiment. The server is hosted in the main cloud and gateway and listens for client requests from the gateway and IoT nodes. The client part of the system provides an interactive interface, in which one can choose from five different levels of a security. The results of the experiment showed that the implemented middleware provides a fast and resource-dependent security through the use of static pre-shared keys for various requirements of IoT-based applications, achieving a compromise between a higher security and a faster data transfer.

3.2. Using Fog Computing in IoT Systems

Management systems based on cloud computing are sensitive to the stability of the Internet connection. With the increase in the amount of data generated by IoT devices, the Internet availability and bandwidth constraints are affecting the operation of cloud applications. Intelligent agricultural applications that analyze and manage agricultural yields using IoT systems can suffer from outages due to disconnections from cloud services that typically occur in rural areas. The use of fog computing allows the IoT system to process data faster and cope with intermittent connectivity. Moving computing to fog nodes located at the edge of the computer network increases availability and reduces data processing latency. In [43], a management-as-a-service architecture based on fog computing is proposed for dynamic processing of Internet of Things events. The proposed architecture is based on the fog computing paradigm to meet the requirements for an availability and performance. It consists of a rules engine and a complex event processor. The rules engine allows one to define dynamic management rules in the cloud. The controller is a fog-based complex event processor that provides scalable and reliable communication, global and adaptable control. The proposed solution can be used in environments, where there is no access to the Internet. The possibilities of the proposed architecture are demonstrated by examples, in particular, for "smart" agriculture, a system for controlling the heating and ventilation in a greenhouse (in Brazil) was considered. It was shown that the cost of infrastructure when applying the proposed architecture is about half the price of a cloud-oriented system. In addition, the use of the MQTT communication protocol allows different types of devices to be used in practice.

A fog must send a large amount of data to the cloud, and this can overload the channel with unused data traffic. The article [44] proposes an approach to reduce the amount of data that a fog stores and transmits to the cloud by filtering fog data. The conducted experiment uses two real-world datasets in the context of smart agriculture, where the first contains the values of a temperature and humidity, while the second contains a soil moisture and temperature conditions. As a result of the experiment, it was found that with the maximum reduction of data, a fog needs to store and transmit to the cloud only 3%–6% of the original data generated by sensors. In the paper [45], it is proposed a combination of cloud and fog computing, in which basic computing and decision-making based on sensor data are performed on devices at the edge of the computer network, and the results of the analysis are then transmitted to the cloud. This achieves an increase in the speed of calculations and a decrease in the cost of data transfer. The architecture of the IoT service platform has been developed and the proposed platform for watering and fertilizing plants has been modeled based on the analysis of leaf image data. Soil temperature, humidity and pH sensors were used, and cameras were also used to take pictures of the condition of the leaves based on Raspberry Pi. The MQTT protocol was used for communication between the devices, and then the data was transmitted to the fog node via the Wi-Fi protocol. If damage is detected, the system, taking into account the temperature and humidity data, decides to start the automatic water and nutrient supply mechanism.

The field irrigation management system receives soil moisture data from sensors installed at several points in the sowing field. There may be problems with the connection or failure of the sensors, which leads to failures in a data transmission. The paper [46] presents an intelligent irrigation system using fog computing and deep neural networks. Deep learning methods can predict soil moisture data using a weather, yield, and irrigation data. Various architectures of deep neural networks for building models and for predicting soil moisture were proposed. Two computational experiments were conducted to calculate irrigation forecasts using data from experimental coconut and cashew fields in Paraiba (Brazil). Soil moisture data from sensors and weather data from a public weather station were used. The computational results showed that predictive models were quite effective and contribute to saving irrigation water.

In the article [47], the following two problems were discussed: (i) the application of fog computing in the management of perishable products supply chains using blackberry fruit; and (ii) data, compute, and storage requirements for fog nodes at each stage of the supply chain. The advantages of implementing fog computing for monitoring and control in the transportation of blackberries from a manufacturer located in Mexico to a seller in the USA were discussed. A three-level model was proposed. The level 1 is sensors (a temperature, humidity, carbon dioxide and brightness) in the truck and RFID tags on each box with berries. The level 2 is fog computing, were smart readers with microcontrollers act as mobile fog nodes. The truck is also a fog node, including RFID tags, smart readers, an on-board decision support unit (ODSU for short) and an event notification unit. The ODSU receives filtered sensor readings from a smart reader and matches them against the product's default temperature and humidity profile. If the parameter values exceed the maximum possible values or fall below the minimum threshold temperature and humidity levels, the ODSU triggers an alarm or makes an automatic adjustment. The event notification unit is

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triggered by the ODSU after corrective actions were taken in the case of violation of the threshold value and sends alerts in the form of messages and emails to the driver and manager. The level 3 is cloud computing, where data transfer to the cloud is carried out using GPRS or a cellular communication network when the truck is in an access zone. If the data uploaded by the mobile fog unit includes the history of sensor readings exceeding the threshold, then the shelf life of the boxes (pallets) and the number of pallets have been expired. At the third level, the history of supply chain operations is stored and analyzed, and calculations such as determining the quantity of products to be delivered to downstream retail stores (distribution) centers and determining the optimal routes at each level of the supply chain are carried out.

3.3. Integration of Blockchain in IoT Systems

The use of the Internet in the IoT in agriculture poses a wide range of challenges, such as a security (e.g., protecting from cyber attacks), data privacy risk (data poisoning and withdrawal attacks), etc. [23]. Integration with blockchain brings the following improvements to the traditional greenhouse: availability, scalability, increased bandwidth, privacy and off-chain data storage. The paper [48] presents an approach to optimizing the greenhouse system using blockchain. A conceptual architecture of the optimal microclimate in the greenhouse has been developed. The proposed system consists of three layers: the blockchain layer, the IoT layer and the greenhouse layer. The IoT layer provides information from various sensors (a temperature, humidity and carbon dioxide (CO_2)) in the greenhouse. The blockchain layer is based on a smart contract-based prediction, optimization and control. The optimal smart contract processes the received data in three stages. At the first stage, the Kalman filter is used to estimate the next value using historical greenhouse data. The prediction module based on the Kalman filter helps to fine-tune and adjust the environment before it becomes harmful to plants. At the second stage, the predicted data is transferred to the optimization module, where the optimal parameters are calculated based on certain conditions and system constraints, such as a power. At the third step, optimal settings to improve performance are used to adjust and control the actuators in the greenhouse using a cascade fuzzy controller as a control algorithm. All this ensures a better plant growth based on the optimal greenhouse setup and resource utilization. The actuators are a CO_2 generator, a natural vent, a forced vent, a fogging system, a heater, a chiller, an air circulation fan and a dehumidifier. A farmer can interact with the greenhouse system through a web application developed on the basis of the proposed architecture. To evaluate the performance of the greenhouse system, a greenhouse emulator was developed and implemented. Greenhouse sensor data is collected, and then the greenhouse interface processes it to control the actuator and stores the data on the blockchain network. The results obtained show that the proposed approach to optimization leads to an increase in yield and a decrease in the energy consumption.

The paper [49] proposes a secure privacy preservation infrastructure (SP2F) for intelligent agricultural UAVs. The proposed SP2F framework has two main mechanisms, a two-level privacy mechanism (for data authentication and a mitigation of data poisoning attacks) and a deep learning-based anomaly detection mechanism. Experiments were conducted on two public IoT-based datasets, namely: ToN-IoT and IoT Botnet, for two scenarios as follows: pre-application (with the original datasets) and post-application (with transformed datasets) of two-level privacy. It was obtained that the proposed SP2F design is easy to implement and deploy, and can effectively detect most attacks in a complex and heterogeneous network of intelligent agricultural UAVs. The proposed approach significantly improved the overall performance of the proposed SP2F platform. The incorporation of blockchain-based network storage and IPFS-based external storage into a fog and cloud infrastructure provides verifiability, traceability and scalability across the computer network.

It should be noted that there are no reviews that include a description of the use of cloud technologies and the Internet of things in agricultural production used in the Russian Federation, while Russia is one of the world leaders in the production and export of several agricultural products. In this review, we are going to fill this gap and offer a reader a review of the literature on the digitalization of agriculture in the Russian Federation.

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4. Literature on Cloud technologies and Internet of Things in the Russian Federation

In this section, we present a survey of publications about using cloud technologies and the Internet of Things in agriculture in Russian Federation. Articles from the scientific electronic library eLIBRARY were selected for our analysis. This library is integrated with the Russian Science Citation Index (RSCI) and is the world's leading electronic library of scientific publications in Russian language. Based on the selection for the keywords "cloud technologies" in the section "Agriculture and forestry", 371 scientific articles were received, of which, after analyzing their context, 98 publications were left. Of the selected articles, only three papers were published in English while the remaining papers were published in Russian. The numbers of surveyed publications in Russian language per year are presented in Table 1 and Figure 2.

Table 1. The number of publications in Russian per year.

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Number of publications	1	3	3	3	4	10	20	21	16	17

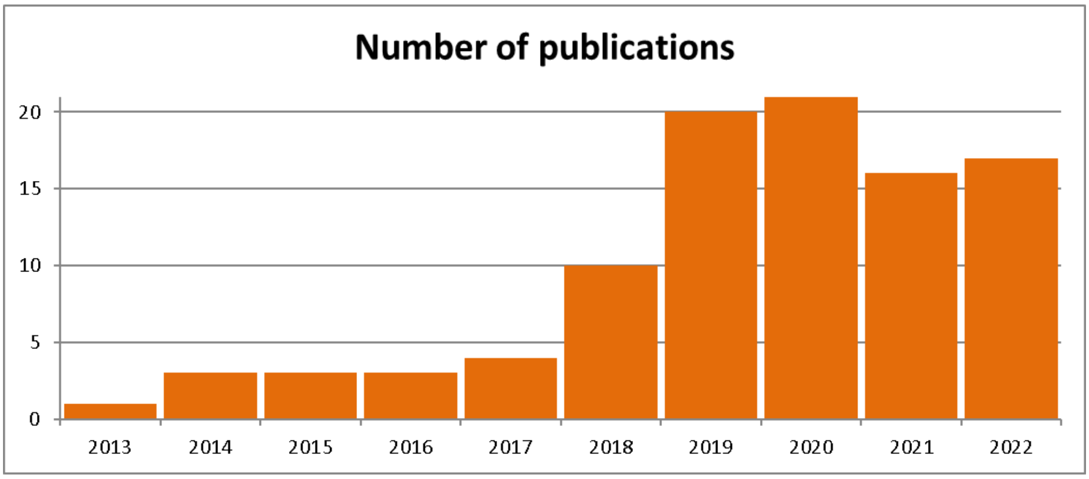

Figure 2. Distribution of papers on agricultural production in Russian per year.

We categorized the found articles according to the areas of agricultural production that were studied in the papers in Russian. The following areas were identified: digital platforms, economics and accounting, animal husbandry, crop production, greenhouses and weather forecast, water management and irrigation, machinery management, mapping and geodesy; see Figure 3. The number of articles for each of the industries is shown in Figure 4.

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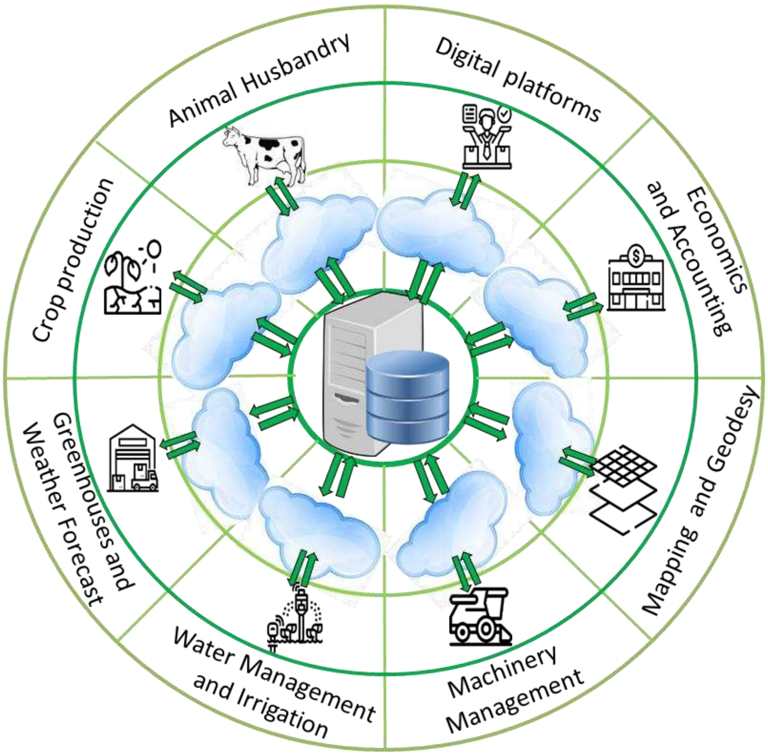

Figure 3. Research areas.

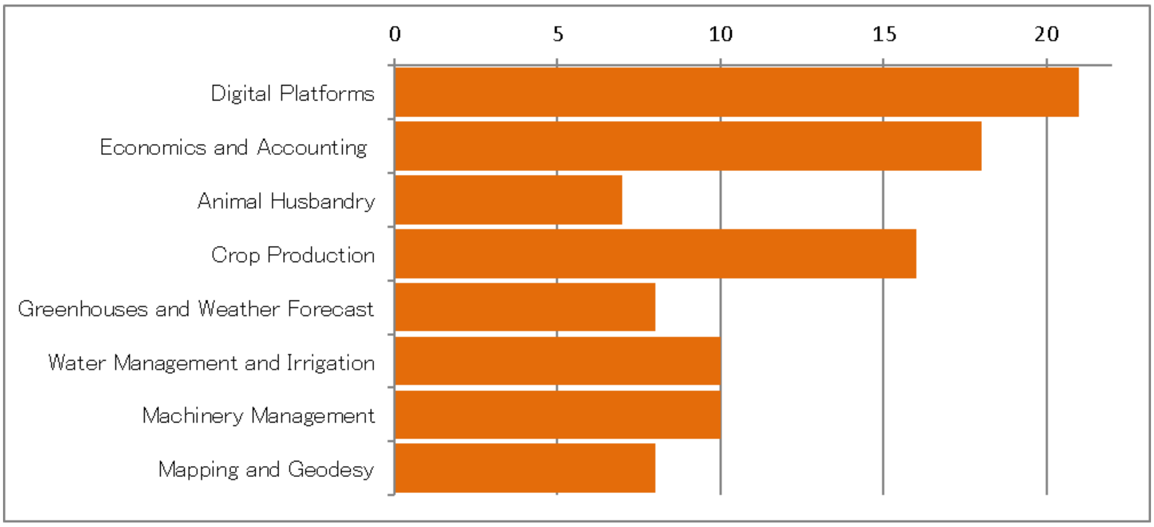

Figure 4. Distribution of the surveyed papers by the agricultural research area.

5. Smart Agriculture in the Russian Federation

5.1. Development of Agriculture in the Russian Federation

Over the past ten years (2012 – 2022), the development of agriculture in the Russian Federation has gone through the following stages.

- 2012 – 2013: The period before the introduction of temporary restrictions on the import of a number of products from the EU, the USA and some other countries, is characterized by peak values of imports.
- 2014 – 2016: The accelerated growth in production volumes for most commodity items, import substitution.
- 2017 – 2019: The further increase in production volumes, a significant increase in the supply of Russian agricultural raw materials and food abroad.

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- 2020 – 2021: The change in the structure of consumption, a decrease in the purchasing power of the population caused by the corona-virus pandemic. Significant growth in food exports from the Russian Federation.
- 2022: The increase in world food prices (especially for grain and oil), which is partly due to the situation in Ukraine.

If in the period from 2012 to 2016, exports of agriculture products amounted to about 20 billion dollars per year. Then, by 2020, it had grown to 30 billion dollars. In 2021, it was amounted to 37.1 billion dollars. In 2022, it was amounted 41.6 billion dollars. In the structure of exports, almost a third part is grain, 20% of fat-and-oil products, 18% of fish and seafood.

The agro-industrial complex of Russia is currently actively developing. Agricultural production shows a significant growth. The gross production of grain crops, yields and the value of grain and wheat exports are shown in Table 2.

Table 2. The gross production and export of crop production.

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Grain and leguminous crops, million tonnes	61	94.2	70.9	92.4	105.2	104.7	120.7	135.5	113.3	121.2	133.5	121.3	153.8
Wheat, million tonnes	41.6	56.3	37.8	52.1	59.7	61.8	73.3	86	72.1	74.5	85.9	76	104.4
Barley, million tonnes	8.4	16.9	13.9	15.4	20.4	17.5	18	20.6	17	20.5	20.9	18	23.5
Rye, million tonnes	1.6	3	2.1	3.4	3.3	2.1	2.5	2.5	1.9	1.4	2.4	1.7	22
Corn, million tonnes	3.1	6.9	8.2	11.6	11.3	13.1	15.3	13.2	11.5	14.3	13.9	15.2	139
Yield, c/ha	18.3	22.4	18.3	22	24.1	23.7	27	29.1	25.4	26.6	28.6	27.2	32.3
Grain export, million tons	14	18.8	23.2	19.6	30.7	31.6	34.9	44.5	56.2	40.5	57.5	43.1	55.5
Wheat export, million tons	11.9	15.2	16.1	13.8	22.2	21.2	25.3	32.8	43.9	31.8	38.3	32.9	44.3

In wheat exports, the Russian Federation has been a world leader since 2016, and since 2021 it has ranked first in the world in grain exports, occupying 5% of the world market and 20% of the world wheat market.

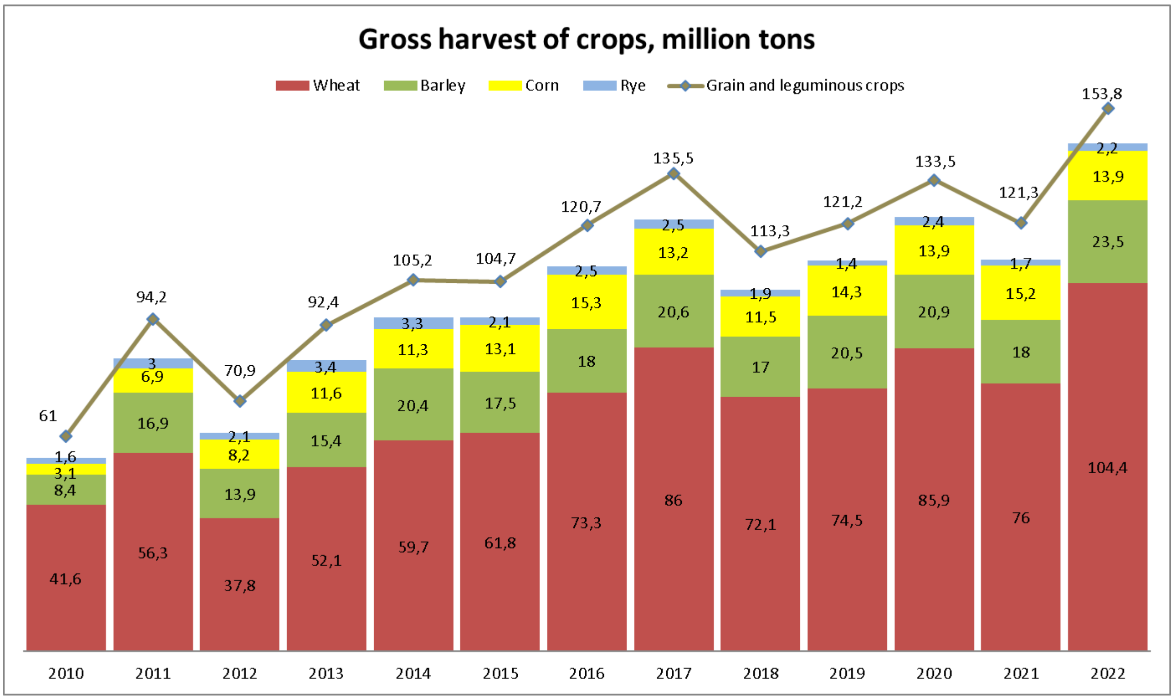

Figure 5. Gross harvest in Russia from 2010 till 2022.

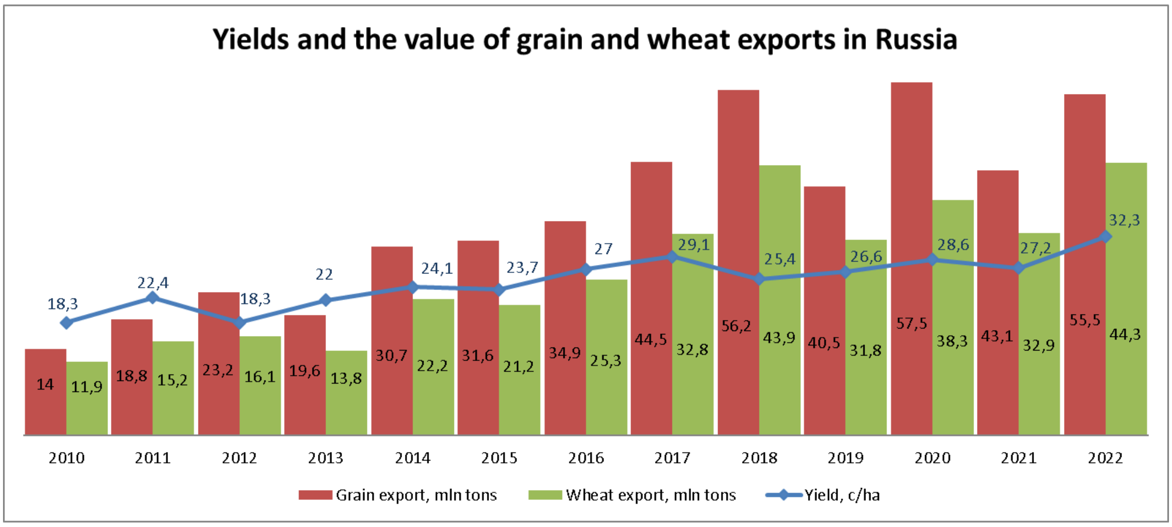

Figure 6. Export from the Russian Federation in 2010–2022.

5.2. Some Features of Digitalization of Agriculture in Russia

The peculiarities of Russian agricultural enterprises, which complicate the process of its digitalization, are that computing and information resources are geographically distributed, while highly localized and changeable. The prevalence of the Internet and other communication facilities in rural areas remains relatively low, which is insufficient for development of the IT infrastructure for distributed agricultural production management systems. Some publications note the shortage of specialists who provide the operation of databases of such systems and the algorithmization of control scenarios (devices, installations and processes). All these peculiarities lead to the fact that less than 8–10% of farms in Russia currently use digital platforms [50]. In addition to the geographical remoteness of agricultural enterprises, the specificity of Russia is determined by the presence of numerous small farms and peasant households along with large agricultural holdings. The latter have greater opportunities for digitalization and automation of agricultural production [50-53].

The National Program "Digital Economy of the Russian Federation" was approved in 2017, and the National Project "Digital Economy" has been operating since 2019. It involves, among other things, the transformation of priority sectors of the economy and social sphere, including healthcare, education, industry, agriculture, construction, urban economy, transport and energy infrastructure, financial services, through the introduction of digital technologies and platform solutions. The National Project includes such federal projects as "Digital Technologies" and "Artificial Intelligence". The goal of digitalization of agriculture is to ensure stable growth in productivity while reducing costs and energy consumption, increasing the efficiency of land use, reducing production costs and increasing added value, improving the quality and efficiency of management decision-making, as well as improving working conditions and increasing the prestige of agricultural professions.

After the adoption of the National Program in 2017, the number of publications devoted to the problems and achievements in digitalization of agriculture increased significantly [54-56]. It is noted in [57] that the active implementation of digital technologies is one of the key factors in increasing the competitiveness of the agro-industry, which makes it possible to ensure high rates of production development and an increase in employment and in personnel motivation for agricultural work. The following areas of application of digital technologies in agriculture are highlighted in [58]: Integrated production management; digital technologies in crop production, animal husbandry, energy supply, storage and processing of agricultural products; digital engineering of rural settlements.

5.3. Digital and Cloud Technologies in Russian Agriculture

The article [59] states that "Agriculture 4.0" is a sub-item of "Industry 4.0" and uses the same current advances in communication technologies such as cloud computing, Internet of Things, blockchain technology, etc., combined with other complex technologies such as artificial intelligence, robotics and big data. According to [60], the main digital and information technologies that implement the concept of the IoT in industry are as follows: miniature sensors; cyber-physical systems (CPS); wireless technologies and IP mobility; Network Function Virtualization (NFV); smartphones and human-machine interface; cloud and fog computing technologies; big data processing technologies; artificial intelligence and machine interaction (M2M); augmented reality (AR) and 3D printers. The implementation of digital technologies in agriculture implies the integrated use of modern developments, including the Internet of Things, cloud data processing, 3S technologies, remote survey, geographic information systems (GIS and GPS), the development of tools for collecting, analyzing and transmitting ultra-high-detail data, etc. Management of technological processes of agricultural production is based on the analysis of large data sets (such as data on production volumes, data from weather stations, agro-ecological surveys, field passports, data on field contours, crop rotation, acreage and crop, data on the state of the herd, veterinary condition, product traceability, telemetry data on the state of agricultural machinery, agrochemical surveys and product quality control parameters).

Nowadays, in agriculture in the Russian Federation, elements of the "precise" farming system (parallel driving systems, fuel consumption accounting, differentiated application of fertilizers and plant protection products) are implemented, a lot of projects are implemented to digitalize animal husbandry (herd management systems, automated animal feeding, traceability of animals and products) [61]. The importance of work on information support for monitoring the resource potential of fields and precision farming using GIS is increasing, which is due to the geographically distributed structure of production and the economic need for more accurate agricultural production. Research using advanced information technologies (neural networks, genetic algorithms, artificial intelligence methods, cloud technologies) is promising [62].

The article [63] examines the strategic directions of digitalization, adapted to the activities of an agricultural enterprise, which are possessed by scientific achievements in the field of robotics, automated control systems, precision farming, and remote sensing of the earth and satellite cartography. It has been substantiated that the use of innovative technologies in agricultural production has undeniable prospects that will allow obtaining positive dynamics in the production and sale of products, reduce operating costs, storage and transportation costs, as well as increase the innovative component in the added value of the product. The agricultural sector is fully capable of using technologies such as the Internet of Things, cloud services (agro-scouting, accounting, management of an agricultural enterprise through mobile devices), big data, blockchain, artificial intelligence, ERP systems (integration of disparate data in a single system).

The article [64] lists the types of digital technologies that are used in agriculture. Computational decision-making tools, cloud technologies, various types of surveillance equipment, micro-robots, digital communications (mobile, broadband, LPWAN), geolocation (GPS, RTK), GIS, yield monitors, UAVs, automatic control and guidance, variable speed technology, on-board computers, radio frequency identifiers, automated milking, feeding and monitoring systems are listed. Technologies that are especially in demand in agriculture at present include [65]: The GIS technologies (geographic information systems and technologies for remote sensing of the Earth); precision agriculture technologies; Big Data technologies; Internet of Things technologies; artificial intelligence technologies (digital twins), etc.

The basis for the use of modern digital technologies is cloud and fog computing technologies [56, 60]. In [66, 67] the cloud computing markets in Russia and abroad are considered, the leaders in the cloud services market are listed. There is a sharp decline for the software market in 2013, while the volume of transactions for the cloud computing market continues to increase [66], which indicates an increase in customer interest in transferring their data to cloud storage and using software from the cloud by SaaS-model. In [68], the main directions in the application of cloud technologies are identified and the development of cloud infrastructure is assessed. The types and models of cloud services presented on the Russian market, the main trends and prospects for the development of the Russian cloud computing market are analyzed. In [69], it is noted that the most commonly used model of access to cloud technologies is the SaaS-model. The paper [52] examines the experience of

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strategic planning of the digital transformation of the EU economy, including agriculture. In "smart agriculture", the deployment of edge capacities connected to equipment on farms allow collecting agricultural data in real time, provide farmers with advanced services such as crop forecasting and farm management, as well as optimize food supply chains, which require providing access to a distributed cloud storage infrastructure. A number of provisions and recommendations on the digitalization of agriculture, arising from the studied experience of the EU countries, have been formulated. Particular attention is required in the use of digital technologies by farmers and small producers. They are the most vulnerable link in the digital transformation of the agricultural business. It is necessary to reduce the digital divide between large and medium-sized producers and expand the training of farmers in the best practices of digitalization using online resources and platforms.

Note that initially the articles focused on the analysis and implementation of western technologies and world experience, and it was proposed to adapt and implement western cloud platforms and information systems at domestic agricultural enterprises [51, 66, 70-73]. In the last two years the emphasis has been on accelerating own development using cloud technologies and on creating cloud data centers in Russia to ensuring food security and increasing the competitiveness of domestic agricultural products.

6. Developments in Agriculture in the Russian Federation

6.1. Digital Platforms

For effective management of production processes in agriculture, it is necessary to have objective and reliable information about the characteristics, parameters and state of technological processes, constantly monitor the parameters and physical quantities of soil and climatic resources, cultivated plants, farm animals, machines and the environment [62]. An important component of the development of the agro-industrial complex is the development and use of automated information systems for information support of decision-making at all stages of the production process [74]. These systems represent a digital platform consisting of software and hardware, devices and specialized professional information systems.

Authors of the papers [50, 75, 76] point to the need to unify the management of agricultural enterprises at the federal and transnational levels, and numerous attempts were made to develop appropriate digital platforms. In [77], a reference model of agriculture was developed, consisting of unified databases of primary and technological accounting information, typical sites of enterprises with cloud storage based on powerful database management systems. The paper [78] considers a mathematical model for the synthesis of optimal industry digital platforms, which ontologically generalizes disparate reference models in agriculture, construction, logistics, and pharmaceutical industries with their integration into a unified state digital platform. In [79, 80], in order to develop a model for the formation of an optimal digital platform in the agro-industrial complex, a number of cloud digital sub-platforms are identified that are common to most agricultural organizations (such as a service for collecting and storing operational primary accounting information in a single database, maintenance of a unified database of technological accounting, applied service, which is a software implementation of functional control tasks with a single description of algorithms). In [81] a sketch of the project of the Regional center for information services for expert systems for agricultural technology management is presented.

As a part of the implementation of the State program for the development of agricultural business in the Republic of Belarus, the following projects have been developed and implemented: a national AIS for the formation, maintenance and use of a unified register of varieties of agricultural plants approved for use in the territories of the EEC member states; AIS "Gostekhnadzor" for collecting, accumulating and processing information on state registration of tractors, trailers for them and self-propelled machines, conducting state technical inspection; AIS "Monitoring of maintenance of milking parlors at dairy complexes"; database and information retrieval system of the machine and

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tractor fleet; state information system "AITS" of identification, registration, traceability of farm animals, identification and traceability of animal products.

A unified IoT platform Aggregate has been developed to automate many aspects of agricultural enterprises to improve efficiency and financial performance [82]. This platform provides monitoring of vehicles and agricultural machinery (cars, tractors, combines), management of sorting, storage and processing of raw materials (automatic recognition of forklift trajectories to determine operating intervals and calculations of the weight of the supplied raw materials), monitoring of storage conditions of raw materials. In all cases, when developing AIS, cloud data centers can be used as a data warehouse and for analysis and forecasting based on the available information [61]. As noted in [83, 84], the most promising is the use of a hybrid model of cloud storage and a local database. Information is accumulated in farm databases, and then exported to special cloud storages, where it is consolidated. Pivot tables, responses to user queries and charts obtained from a common database can be used to monitor the status of farms in the region and effectively manage their activities. Such a data warehouse project using cloud technologies was developed for the management system in the Ministry of agriculture of the Irkutsk region. The article [81] proposes the use of expert MIS, in which knowledge bases are formed in regional data processing centers, stored in cloud information systems and transferred to local MIS upon request. The structure of the expert information system for managing agricultural machinery is substantiated, which ensures the greatest efficiency at the lowest cost of implementation.

The paper [53] describes the benefits of implementing cloud technologies and the Internet of Things in agriculture and provides a diagram of an end-to-end automated production and value chain that includes market companies, agricultural producers and their suppliers. In [56, 60], it was concluded that one of the main means of industrial IoT functioning is cloud and fog computing technologies, and in [60] a conceptual model of the industrial IoT was proposed, in which cloud computing is performed through distributed computing using the blockchain technology. The use 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 typical structure of a cloud platform for processing and analyzing remote sensing data is highlighted in [67], each layer of which has its own character of functioning, autonomy, standardization and horizontal scalability. In [85] it is proposed to create a Unified geographically distributed remote sensing information system with the integration of all remote sensing information resources into a single geoinformation space. After decryption, the information should fall into the cloud GIS, which combines a single database of technological accounting, a single database of primary accounting and a database of data of all material, intellectual and human resources of the agro-industrial complex. The resulting system is the Unified administrative management system, which includes data on land plots and their land users.

In [86], the integrated cloud service "ANT", created on the "GeoLook" platform and intended for agricultural enterprises, is considered. This is a tool kit for precision farming. The basis of the service is the electronic contours of the fields. Each user can create them in the service or upload existing ones in the database. By adding data from agrochemical measurements, the information system obtains accurate maps of the distribution of elements in the soil, identifies heterogeneous soil areas and determines their need for fertilizers. Agricultural units of differentiated fertilizer application receive individual tasks from the system. Meteorological data and the serviceability of equipment are also monitored in order to minimize the human factor and errors in the preparation and conduct of operations. The system allows you to keep records, optimally plan work, predict yields, use interactive dashboards to monitor the progress of sowing and harvesting in real time, track deviations from the plan and see the causes of deviations and factors affecting the final results.

The adaptation of the IBM Watson Decision Platform for Agriculture to improve the efficiency of agriculture in Russia is discussed in [71]. The main element of this platform is the PAIRS Geoscope system from IBM Research, which quickly processes massive complex sets of geospatial and temporal data collected by satellites, drones, millions of IoT sensors and weather models. The platform allows integrating of The Weather Company data, remote sensing data (for example, satellite) and IoT data from tractors. It can be used to analyze hyper-local weather forecasts for real-time recommendations based on specific fields or crops.

Information systems are developed in various regions of Russia to take into account the soil, climatic and agro-technological features of the territory. Irkutsk State Agrarian University has developed a cloud-based multifunctional platform "Smart Farmer 4.0", designed for small businesses and farms. Applications have been created: "Agro-industrial cluster", "Optimization of the use of land resources in the region", "Ecological and mathematical modeling of food production", "Drought", "Natural elements", "Risk management of agricultural production plans», "Modeling of crop bio-productivity" and "Planning of agro-technological operations" [83, 84]. It is proposed to use Mail.Ru Cloud Solutions as a cloud storage platform for the project.

The concept of a single digital platform is based on cloud data storage, which is the link between all components. The use of a single digital platform brings benefits to the farmer (increases the efficiency of agricultural production, reduces costs and risks, reduces dependence on key specialists, simplifies document flow and access to state support), the state (increases the effectiveness of state support, simplifies monitoring and control, increases the relevance of industry indicators), to banks (simplifies the lending process, it becomes possible to monitor the loan portfolio).

6.2. Economics and Accounting

Works on economic research of digitalization in agriculture usually use products based on the "1C: Enterprise" platform: [55, 87-90]. Authors [55] consider the possibilities of the "1C: ERP AGRO-INDUSTRIAL COMPLEX" system to solve the problems of the transition from traditional management to the digitalization of business processes in the agricultural sector by the implementation of the national project "Digital Economy". The article [87] describes the creation of a "digital twin" of the enterprise on a digital platform developed by the company "Farming Technologies". The software integrates with the accounting system "1C: Enterprise", and allows, on the basis of forecasting a possible economic effect, to produce agricultural products with a given cost. The paper [88] examines the experience of the transition to cloud technologies of agricultural organizations of the Republic of Sakha (Yakutia), highlights the main problems and difficulties that accounting professionals may face. It is proposed to develop a single automated cloud system based on the platforms "1C Enterprise 8: Accounting of an agricultural enterprise" and "1C: Enterprise 8and accounting of a peasant farm".

In [91], a promising option for automating accounting in agriculture is proposed, based on the use of cloud computing and remote databases. The features of the application of accounting automation programs in agricultural organizations are highlighted. On the example of the agricultural sector of Udmurtia, the influence of accounting automation on production efficiency is shown. The articles [92, 93] present a cloud decision support system for lending to small agricultural enterprises of the Krasnodar Region, which implements the following models: optimization of the selling price of products, assessment of the effectiveness of the use of credit funds of mono-product and multi-product enterprises based on deterministic and fuzzy methods, assessment of the systemic stability of the enterprise.

In [94], a regional automated system for accounting and analysis of agricultural products based on cloud technologies was developed. The implementation of the software in 15 regional departments of agriculture of the Stavropol Territory showed that due to its use, labor costs associated with data consolidation and analysis were reduced. Studies to assess the economic efficiency of the use of cloud technologies in agricultural enterprises [63, 89, 95-100] show a reduction in labor costs for data consolidation and analysis [94], documentation and accounting [88, 90], improving production efficiency [57, 91] and reducing the cost of production up to 20 % [50]. In [95, 96], a methodology for assessing the effectiveness of investments in cloud technologies is proposed, key assessment indicators are identified. In most cases, the use of cloud data storage is economically feasible even for small agricultural enterprises, since the current prices of most providers of public clouds are small, although in each case an economic analysis of the company's costs for the implementation and use of cloud technologies should be carried out [97]. The article [89] proposes the AIS "Assessment of the implementation of cloud technologies at an agricultural enterprise", and the paper [63] presents a cost-effective project of the cloud data warehouse adapted to the activities of an agricultural enterprise. It is concluded that the total cost of leasing of cloud storage is significantly lower than the cost of implementing your own data storage system.

6.3. Animal Husbandry

Systems for monitoring animals, their behavior, physiological parameters and productivity are widely introduced in animal husbandry. Information systems for identifying and accounting for the animal productivity based on cloud technologies are being developed by the authors of [101, 102]. The service infrastructures are deployed on the basis of the "Mail.ru Cloud Solutions" platform of Mail.Ru LLC, and are delivered according to the SaaS model. Approbation of the software was carried out in livestock farms of the Stavropol Region. In [101], animal productivity accounting software was developed. Approbation was carried out on rams of the Russian meat merino breed and black-and-white calves. Data on the growth and development of animals with the use of the probiotic feed additive Diaretin-S were systematized. It has been established that the use of the Diaretin-S additive has a beneficial 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/head, for calves – 35-70 g/head.

In [102], an animal identification and trace module was developed for the automated veterinary information system AVIS. The module allows recording and tracing animals based on visual methods (using ear identification numbers), as well as radio frequency identification methods (by implanting a subcutaneous microchip); carry out the movement of animals between livestock points and owners; generate reports on transfer, input, disposal, etc. The developed software is widely used in the Stavropol State Veterinary Service. The database includes 827.1 thousand heads of small ruminants and 209.6 thousand heads of cattle, including 7.5 thousand heads identified using radio frequency technologies, placed on 23.2 thousand livestock facilities in the Stavropol Region. The use of the animal identification module made it possible to increase the speed of data processing, improve the quality of information, its suitability for analytical processing, and strengthen control over the movement of animals, which creates the prerequisites for the digital transformation of the management of the state veterinary service of the Stavropol Region. Note, that mobile operator VimpelCom also develops monitoring livestock farm systems [82].

The problems of managing dairy farms and remote control of milk quality are considered in [103, 104]. To solve them, it is proposed to use the IoT and cloud technologies. A four-layer IoT network structure for managing a dairy farm is proposed, which includes milk analyzers, a gateway, a cloud platform, and mobile applications for farmers and operators. The cloud platform server hosts databases and knowledge bases, a solver, and a website. The use of various cloud services was analyzed: AWS IoT, Google Cloud IoT, and Microsoft Azure IoT Suite. The selection of an appropriate network protocol was carried out according to four network indicators: transmission speed, distance, frequency and security. The 4th generation LTE network using CIoT-LTE-M technology was chosen as the network for transmitting information from dairy farms to the cloud environment [103]. A generalized algorithm for farm milk quality control has been developed, which includes receiving information from analyzers, transmitting it through a gateway to a cloud platform for storage and intelligent processing, and displaying the results through operator applications [104].

The development of remote monitoring systems is also carried out in beekeeping. In [105], the result of developing a system with a local monitoring system for bee hives and a remote data collection system, taking into account variable weather factors, is presented. The collected data is transmitted to the "Pchelodom" cloud system via a GSM module. ThingSpeak cloud was used for data upload and post-processing. For the mechanization and automation of technological processes in pig breeding, a wide range of equipment has been developed for automated preparation and normalized distribution of liquid feed mixtures and dry feed, an automated station for individual feeding of sows and a set of equipment for multiple feeding of animal by bio-phases [106]. All equipment operates in automatic mode with the possibility of remote control via the Internet.

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6.4. Crop Production

One of the most promising areas for improving the efficiency of agricultural production planning is the use of intelligent technologies to systematize agro-technological knowledge by creating a specialized software package for receiving, primary processing, formalization, storage and presentation of knowledge in the field of crop production. The lack of information for decision-making leads to the fact that up to 40% of the crop is lost in the process of cultivating [107]. The structure of such a database and its attributive information, which is necessary for decision-making in the production of crop products, is considered in detail in [108]. A conceptual diagram of the interaction between the database and the knowledge base is given. Representation of knowledge for decision-making is proposed to be displayed in the form of production structures. In such constructions, one can refer to mathematical models built into the knowledge base as procedures for calculations, or presented as separate software packages. The knowledge base can also store assessments of agro-technological parameters obtained by experts, for example, expert assessments of the impact of the timeliness of sowing work on various production parameters. In addition, it is proposed to use cloud technologies and remote sensing data while simplifying 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 (via cloud services), and forming educational and training components. In [109], a logical and structural diagram of a digital platform for crop production in the Novgorod region was developed. The main components of the digital platform are: a data cloud module (database), a module for filtering, sorting and analyzing data, an innovative project module, a module for professional competencies, and an application creation module. The cloud data module (database) is intended for collection (accumulation), aggregation and storage of crop production data in the Novgorod region.

The article [74] is devoted to the implementation of management decisions using robotic technologies, and it lists the developments of the Federal Scientific, Agricultural and Engineering Center "VIM" in horticulture and crop production: intelligent robotic systems for regulating microclimate and nutrition parameters, controlling fertilizer application and protective equipment plants, picking berries, etc.

Research is being carried out on the possibilities of increasing grain production using information systems for the choice of agricultural technologies, taking into account the agro-ecological, soil-climatic and production conditions of agricultural producers. The assessment of information systems developed for the farms of the Russian Federation was carried out according to the following indicators: taking into account the factors limiting grain production; availability of criteria for assessing agricultural technologies; type of information system. As factors limiting grain production, agro-ecological, soil-climatic and production conditions, as well as the level of intensification are determined [110, 111]. According to the results of the study, systems based on economic and mathematical models and implemented as web applications using cloud technologies are recognized as the most promising [110]. The generalized structure of such applications is given in [111].

In [112], an automated control system for agricultural technologies in industrial horticulture was developed with the possibility of conducting ground inspections using a mobile application. The system provides real-time processing of information flows reflecting the characteristics of the growth and condition of plants in critical phases of development. It is shown that the system automatically optimizes machine technologies for cultivating horticultural crops according to biological (implementation of the potential biological productivity of crops) and economic (improving the efficiency of the use of production resources) criteria.

In [113], an information and analytical web-based system for selecting technologies for the restoration and use of agricultural land was developed, which allows making timely scientifically based decisions to improve the state of degraded agricultural landscapes. The web system includes a database, a user authorization subsystem, cloud data storage and a backup subsystem. Two web interfaces have been developed: a user interface that provides access to viewing and searching for information, and an administrative interface. For each database entry, you can get general and detailed information about the object and recommended technologies for restoring soil fertility, call up GIS, satellite and other maps of the desired object, and view related materials.

The works [107, 114, 115] propose a method for building expert decision support systems (DSS) in precision farming. The methodology provides for the use of local DSS and a cloud-based knowledge base (KB). An analytical automated agricultural technology management system is located in the cloud data processing center, and a KB is being formed. The KB is formed on the basis of the strategic management algorithm by analytically solving the problem for a variety of different decision-making conditions. Each set of such conditions and obtained solutions is an elementary KB record. This KB is transferred to the local DSS. The proposed method has been tested for solving the following problems: the formation of strategies for applying mineral fertilizers and long-acting ameliorants in crop rotations of various types [114], managing the state of spring wheat by forming a sequence of technological operations in one growing season [107], choosing the optimal date for harvesting fodder from perennial grasses [115]. When solving the first problem, an algorithm was developed in [114] that minimize the risk of crop losses and overspending of mineral fertilizers and ameliorants. For different variants of the initial values of the parameters of the chemical state of the soil and different climatic conditions for each type of crop rotation, the optimal strategies for applying mineral fertilizers and ameliorants are determined. To select the best option from the KB e, the pattern recognition method is used. To form a KB cloud for managing the state of spring wheat, in [107], algorithms were developed for the formation of optimal programs that minimize the risks of losses in the spring wheat crop. The local DSS selects from the obtained KB the closest optimal programs for the application of mineral fertilizers and irrigation during the growing season. To make decisions about the optimal dates for harvesting fodder from perennial grasses, two variants of algorithms are used in the local DSS. The first is based on control models, and the second is based on the pattern recognition method. The algorithms were tested in [115] against a KB of 50 cases for an arbitrary set of input data of a local DSS. It was found that in local DSS, errors in decision-making on optimal harvesting dates within ±2 days are possible, which is due to errors in the approximation and identification of these models. The method of pattern recognition proved to be more accurate, which has greater flexibility, and its potential accuracy increases significantly with an increase in the number of cases in the KB. This is due to a significant increase in the probability of occurrence of cases close to the real conditions of the local DSS. Based on the results of testing the methodology, a method for controlling the formation of KB is substantiated, aimed at reducing the loss of optimality of strategies associated with the mismatch of initial conditions on local DSS and KB of information cloud.

Agricultural production requires the processing of significant amounts of information to solve various management problems. The development of neural network and cloud technologies makes it possible to process information in the cloud with the provision of access to computing power by the user. In [116], an intelligent technology for the formation of a fertilizer system, which is a cloud service, is considered. In [117], a SaaS cloud service is being developed to identify defective areas of agricultural fields using an artificial neural network (ANN). The article describes the construction of ANN of various models, as well as tools for creating an environment for performing calculations in the cloud. Neural network computing is implemented in the cloud with scalable computing power. The choice of parameters for recognizing problem areas of reclaimed agricultural land is substantiated. Recommendations are given on the implementation of preliminary processing of the initial graphic data, methods of training the constructed ANNs, development of the client and server parts of the system. The study showed that neural networks are able to successfully solve the problem of recognizing the image of agricultural fields with the identification of defective areas of various natures.

For agriculture, a promising direction is the use of GIS and GPS for both ground-based and aviation and satellite sensing. In [118, 119], the possibilities of remote ground and airborne sensing methods using controlled manned and unmanned aerial vehicles and satellites to improve the performance of phytosanitary monitoring of agro-ecosystems are considered. It is shown that monitoring by means of recognition of the phytosanitary state of agro-ecosystems, together with cartographic information obtained on the basis of GIS and GPS, makes it possible to make short-term, long-term and long-term forecasts for assessing the distribution of harmful organisms and the volume of plant protection from pests and pathogens in agro-ecosystems. The results are presented as applications for Smartphone and tablets.

Unmanned aerial vehicles (UAVs) make it possible to cultivate land plots of complex configuration, apply fertilizers differentially according to a given program, and automate the processing of plants with minimal human contact with pesticides, and work at night without compromising the quality of work. The experience of using agricultural drones for spraying plants at Belarusian enterprises (JSC Govyady-agro and Novitsky farm) is described in the article [120]. The advantage of this treatment is the deep penetration of the fertilizer into the plant mass due to the air flow from the UAV propellers.

6.5. Greenhouses and Weather Forecast

The highest efficiency in the use of digital technologies can be obtained in artificial ecosystems, where the conditions for growth and high productivity are controlled and the necessary technical means are available. Closed agro-ecosystems, including vertical farms, off-soil plant growing and robotic crop complexes, in the future will allow reaching self-sufficiency in food in areas such as megalopolis, settlements in the Far North and in deserts.

The following scheme of using digital technologies in artificial ecosystems: collecting data on ecosystem parameters (sensor network) → transfer to databases (cloud storage) → data processing and decision making (control signal generation) is considered in [121, 122]. On the basis of the Arduino platform, a "registrar" device has been developed that allows real-time recording of the object indicators and external factors and saves them in a cloud database. A description of the registrar design, which is based on a programmable controller with ATMega processor, is given. Software "Smart Greenhouse" has developed as an IoT code and firmware designer for accelerated deployment and implementation of IoT devices and networks [82].

The greenhouse is a closed-type agro-ecosystem in which processes are strictly determined by the growing plant technologies, taking into account the influence of the environment. A model of the "plant-environment-situation-control" system was proposed in [123], allowing to describe the processes in a greenhouse on the basis of experimental data. A software and hardware system for smart greenhouse has been developed, which allows you to control and manage plant growth during the growing season, taking into account the environmental conditions. The control device generates a control signal based on the rules of the expert and the current input information from the environmental sensors. Data is exchanged through the Blynk cloud data storage, from where the data is sent to the MATLAB script for machine processing, and then returned to the control device. Monitoring data is stored in the cloud storage throughout the growing season. It is noted that for the practical implementation of the developed system for smart greenhouse, it is necessary to use modern wireless and IoT technologies.

Greenhouses are one of the sites where IoT technology is most actively applied. To support this technology, "Ruselectronics" holding has developed «Smart Greenhouse» software, which is a constructor for the accelerated deployment and implementation of IoT devices and networks. The problem of adapting a communication standard to the conditions of agricultural production to ensure wireless data transmission over long distances is considered in [124]. The LoRa standard at a frequency of 433 MHz was reasonably chosen as the standard for transmitting data from bots and sensors. The selected standard is proposed to be used for data transmission in the intelligent control system of the plant hydro-melioration robot in artificial ecosystems "Hydrobot 1.0".

The developed intelligent robotic complex that regulates microclimate and nutrition parameters to control plant growth in closed artificial ecosystems is described in [74]. A greenhouse microclimate control device based on the Arduino Uno was developed in [125]. The functional requirements for the developed device are determined, the block diagram of the device is given, the user interface developed in the IoControl cloud service is presented. The developed device allows you to take readings from devices in the greenhouse, transfer them to a personal computer or phone via the Internet, and also control the actuators inside the greenhouse online using a cloud service. The user can view the data and remotely control the actuators, turning on and off the heating, irrigation, lighting and window opening systems.

The work [126] considers the applicability of neural networks for building a short-term forecast of air temperature. As a basic neural network, a non-linear autoregressive model with external input data was used. The training was carried out on the data obtained with an interval of 10 min. and observation time of 72 hours. The Neural Time Series utility of the MATLAB package was used. A check of the predictive properties of the resulting neural network, carried out on a sample of data not used in training, showed that in all cases the correlation coefficient of the input data and the forecast was more than 0.96, and the root-mean-square error did not exceed 1.5 °C. Despite the high accuracy of forecasting, it is noted that in order to build a functioning temperature forecasting system, it is necessary to periodically retrain the network to take into account the variability of parameters depending on the season. Such a retraining scheme can be easily implemented using cloud services and the Internet of things.

6.6. Water Management and Irrigation

The management of the reclamation regime of agro-ecosystems is considered in [50, 127-131]. The requirements for the use of digital technologies, such as IoT, have been formulated, and a list of priority tasks for automating the technological processes of reclamation agriculture has been developed in [127]. Automation of agricultural production management on reclaimed lands ensures the implementation of the established sequence of technological procedures with maximum speed and accuracy [128, 129]. The implementation of management decisions in automatic mode using intelligent algorithms will provide energy and resource saving by identifying patterns of controlled processes and using innovative data processing methods.

The works [50, 128-130] show promising areas for improving the digital development of agricultural production on reclaimed lands: cloud technologies and big data, software products based on neural networks and artificial intelligence, software-controlled complexes that provide the user with the resulting information for corrective actions; Internet of things and other innovative developments in the management automation, providing data collection, support and implementation of management decisions. Using these technologies, the work [131] defines the requirements for the functional structure and architecture of modern automated production process control systems that monitor and record the ameliorative state of agro-ecosystems, intelligent data processing, the formation of management decisions and their implementation automatically without human intervention. The advantages of using information and communication systems for the management and implementation of agro-technologies of reclaimed agriculture in the agricultural production, and the factors hindering their widespread implementation (lack of proper development of the Internet in rural areas and low motivation of agricultural producers to use digital solutions) are shown in [50, 127].

In [129, 131], an analysis was made of commercial automated process control systems that ensure the regulation of irrigated crop production operations, which showed a significant lag of domestic products from the best foreign samples. Water distribution management systems on inter-farm irrigation systems are considered in [75, 129, 132]. Processes of design and operation of irrigation systems are analyzed. The need to focus software on mobile devices, the development of cloud services and methods for processing large amounts of data is indicated [75]. Models, algorithms and procedures for managing water distribution in inter-farm irrigation systems that ensure guaranteed fair water distribution based on the principles of sustainability and uniformity of water supply, minimizing unproductive water consumption, and maintaining objective statistics on a wide range of management quality indicators were developed in [132]. The work is focused on the unification of irrigation systems by developing of the management decision support system (DMS). The advantage of using web-cloud technology, which provides the user with resources in the online service mode, as a software platform for DSS has been established. Based on the analysis of the proposals of leading companies in terms of cloud technology services, a DSS for water distribution based on Google services was developed.

The work [129] describes systems for operational monitoring of soil and weather conditions in the practice of agricultural production, which help not only to track changes in conditions and remotely control irrigation systems, but also make effective management decisions. It is noted that the processing of the primary information should be carried out online and used for operational management, adaptation and development of the control system by setting the parameters of mathematical models and for solving tasks of higher levels of the management hierarchy. Studies of water bodies were carried out in [133] and [134]. In [133], a series of interactive hydrographic maps of the city of Brest (Republic of Belarus) was developed, with visualization of data on the content of micro-plastic particles in 25 water bodies.

The most important aspects of the entrepreneurial activity of the managers of pond farms are maintaining the bioproductivity of ponds, increasing the profitability of production by reducing the cost, reducing the production cycle from planting material to obtaining marketable products. The work [134] describes the development of pond aquaculture, automation of management, improvement of water bodies using such achievements of Industry 4.0 as cloud technologies and neural networks. In the work, the Smart Fish Farm cloud services was used to record, store, process and analyze data, the water area of the ponds was determined using satellite photos and Google earth. It is noted that by using "smart" technologies, fish farms will be able to improve the environment, preserve the health of fish, reduce production costs, increase profitability (speed up the process of growing fish up to 15%, save on feed up to 20%).

6.7. Machinery Management

Precision farming includes not only crop production technologies, but the use of the latest robotic machines, and in an optimal way. It is required to optimize not only the monitoring and management of agricultural equipment, but also the compound of the machine and tractor fleet, as well as the content and order of technological operations. The problem of optimal selection of agricultural machinery is considered in [111, 135, 136]. The development of software for the choice of technologies and machinery in crop production is considered in [111]. The requirements for the developed software, its main components, their functions, rules of communication, using cloud technologies are given. The presented structural scheme provides for taking into account the restrictions imposed by the agro-climatic and production conditions of the agricultural producer (the scope of work and their timing, phytosanitary conditions, relief and contour of fields) for the choice of technologies and the rational compound of the machine and tractor fleet. In [135], a temporal data model has been developed that makes it possible to draw up daily work plans for the selected equipment, and to calculate the economic indicators of mechanized tillage. The developed data model is integrated with the geo-database and with the database of agricultural machinery of the farm.

In [137], the problem of optimizing the routes of agricultural machinery is considered. The organizational structure of the system as a cloud Internet service has been developed and described. The system allows you to take into account not only the distance between the start and end 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 the interaction of its elements is given. The server part of the system has an object-oriented architecture, which allows you to flexibly expand and change the application functionality. The user interface is used to enter data and display driving routes. Additional elements of the system are the GPS/GLONASS service and the "Yandex.Maps" server.

The Scientific and Practical Center of the National Academy of Sciences of Belarus for Agricultural Mechanization has developed equipment and software for a remote monitoring system for machine and tractor units, including a telemetry module, an identification module, fuel sensors, server and user software. The system is designed to determine the coordinates, direction and speed of the machine-tractor unit. In real time, the system allows you to determine the composition of the unit, the cultivated area and fuel consumption. A prototype of an on-board computer for tractors Belarus 3022/3522 with a navigation module was developed to determine the current coordinates while moving with an accuracy of up to 10 cm. The on-board computer allows you to control more than 15 tractor operating parameters and automatically guide the unit along a given trajectory with an accuracy of 1 cm. Studies have shown that the optimization of the operating modes of high-performance units will increase their productivity by 5-10% and reduce the specific fuel consumption by up to 10% [138]. An automated system for analyzing and monitoring the status indicators of heavy vehicles using machine learning has been proposed in [139]. The signals from the sensors are sent via the CAN bus to the on-board computer and are wirelessly transmitted to the server to monitor the parameters and determine the transition to a critical state.

A scheme for a digital control system for agricultural machinery based on the IoT, cloud, BigData and AI technologies is proposed in [140]. The authors presented an algorithm by which the control system for each actuator of an agricultural machine operates. The paper [82] lists the developments of Russian companies operating in the Internet of Things technology market for monitoring and managing technical means. In particular, Tibbo Systems, a leading Russian developer of software for control and monitoring systems, has developed a unified Aggregate IoT platform that provides monitoring of vehicles and agricultural equipment (cars, tractors, combines), management of sorting, storage and processing of raw materials (automatic recognition forklift trajectories to determine work intervals and calculate the weight of the supplied raw materials), monitoring the storage conditions of raw materials. The mobile operator MTS specializes in transport monitoring, and its developments can be useful for tracking agricultural machinery and commercial vehicles in the logistics of agricultural products. The mobile operator MegaFon has launched NB-IoT technology, which is also expected to be used in the agro-industrial complex. Digital video surveillance is also being developed to control geographically distributed agricultural production facilities. General methodological principles for designing cloud video surveillance and concepts for integrating video and the cloud are proposed [77]

6.8. Mapping and Geodesy

The use of web mapping and cloud computing technologies to simplify the work of agronomists is considered in [135, 142-148]. The paper [135] studies the integration of geo-information databases with agricultural machinery databases for making decisions on the optimal choice of equipment, the choice of technological operations, solving logistics and other practical problems. In [142], the main tasks of geodesy are considered, as well as cloud technologies and photogrammetry, and the principle of operation of the photogrammetric method is described. The benefits for agriculture from the use of cloud technologies associated with the creation of maps and plans based on photogrammetric images are given in [142, 143].

To assess agricultural land, the works [144, 145] develop spatial databases based on the object-functional approach. The necessity of practical implementation of agronomic geo-databases (AgroGIS) with a hierarchical structure based on databases of local and regional levels is shown. The filling of the geo-database at the local level is provided by the inclusion of objects associated with agricultural workers, land plots, agricultural implements, soils, technological maps, tractors [144]. The main components of the geo-database are proposed in [145] as separate sets of spatial classes (Climate, Relief, Soils, Vegetation, Hydrography, Agrolandscapes). Three different ways of user interaction with the AgroGIS database have been developed.

The studies of land resources of the regions are considered in the works [133, 144-147]. The studies were carried out on the example of the Brest region of the Republic of Belarus [146], the Volgograd region [144] and the southern seas of Russia [147]. Using story map templates from the ArcGIS Online cloud mapping platform, the information and analytical system "Land fund of the Brest region" and the "Atlas of the State of the Lands of the Brest Region" were developed [146]. They contain structured information about land types, analysis and assessment of their current state, dynamics of nature-forming land types in the Brest region, and a comprehensive geo-ecological assessment of the region's land resources. The paper [133] analyzes the experience of using GIS

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technologies in order to visualize data on the content of micro-plastic particles in water reservoirs of Brest (Republic of Belarus). The result of the study is a series of interactive hydrographic maps of the city. These maps are freely available on the Internet, can be viewed by other users, and can be used to create similar maps and map schemes using an ArcGIS Online account.

Within the framework of the GIS project, ready-made solutions for the cloud database and GIS applications of the local information system "Ecological Study of the Southern Seas of Russia" are presented [147]. When generating information for entering into the geo-database in [144], topographic maps at a scale of 1:1000000, satellite images prepared by Landsat-7 ETM+, Sentinel-2, and statistical calculation data were used. The work [148] provides research in the field of organic agriculture in the Republic of Belarus. The features of the production and circulation of organic products, the current state of development of the industry, as well as the prospects for the development of geo-information products as active means of electronic inventory of individuals and legal entities engaged in economic activities are considered. Geo-information products have been created and developed in the form of web-maps, web-passports, electronic databases, web-catalogs.

7. Discussions and Future Directions

Four areas of digitalization in agricultural technologies have been identified: monitoring the conditions and parameters of processes, the transfer and storage of information, artificial intelligence and cloud technologies, and the implementation of control decisions by robotic means. To introduce digitalization in agriculture, it is necessary to develop a special technological base, including: (a) smart systems for collecting, structuring and analyzing data (this includes cloud, fog and edge technologies, and expert systems); (b) hardware platforms with support for wireless communications and reduced power consumption of sensor devices; (c) embedded solutions for existing agricultural machinery or new models of hardware and software. Internet of Things and cloud technologies can be a key enabler for the implementation of smart agriculture.

The use of cloud technologies is based on the creation of AIS for tracking supply chains, accounting for agricultural products, collecting up-to-date statistics, etc. Cloud databases can act as a data warehouse that allows you to perform analysis and forecasting based on the available information. Farmers could send their data to the cloud and receive management decisions based on them using artificial intelligence methods.

An important direction in the use of cloud computing is also intelligent decision support systems. In this case, solutions are developed that optimize the execution of technical processes, taking into account production and economic criteria. These solutions are developed on a cloud platform with artificial intelligence, and then are transferred to robotic mechanisms for execution. Centralized integrated processing of information coming from sensors is carried out online and is used for operational management, adaptation and evolution of the control system with subsequent correction of the parameters of mathematical models and for solving problems of higher levels of management. This will increase production productivity, reduce the shortage of skilled labor, simplify the delivery of the final product to the buyer, provide manufacturers with the necessary information, predict natural disasters and take into account climate change, which will make it possible to minimize risks and losses.

Agricultural production is carried out under the influence of many uncertain factors that cannot be predicted and which a person cannot influence. It is necessary to take into account the uncertainty inherent in agriculture, both when setting tasks for planning agricultural production, and when searching for effective solutions to management problems that arise in the process of agricultural production. The use of stochastic approaches or fuzzy logic approaches may be unjustified, for example, due to the unknown distribution law. It would be appropriate in this case to use the stability approach [149, 150], which allows one to determine the range of changes in the given initial data that does not lead to a change in the optimal solution. For agriculture, this will mean, for example, determining the optimal list and order of agricultural operations, which will remain unchanged, despite the uncertainty of their durations. At the same time, the time schedule for the execution of works will vary, depending on the weather, sensor data and other uncertain factors. Combining this approach with Internet of Things and cloud computing will improve the quality and quantity of the agricultural production.

8. Conclusions

The agriculture is the backbone of the world economy, as it is of strategic importance for ensuring the food security of each country. The need to meet the ever-growing food demand to achieve "zero hunger" is leading to a shift from traditional to "smart" farming methods. Agriculture 4.0, or "smart" agriculture, is associated with modern technologies such as big data, machine learning, deep learning, artificial intelligence, internet of things, blockchain, robotics and autonomous systems, cloud computing, cyber-physical systems and digital twins.

The practical implementation of "smart" systems in agriculture is possible only through the use of modern wireless, intelligent technologies and Internet of things. In Russia, IoT technologies are developing in agriculture as rapidly as in the advanced countries of the world, and are at a high competitive level. To improve the efficiency of production, Russian agricultural enterprises, as a rule, develop their own automated information systems for managing agricultural production. Information systems are being developed in the regions of Russia, taking into account the soil-climatic and agro-technological features of the territory. However, the implemented developments are not unified, which complicates the transition to digital agriculture across the country. To include small and medium-sized agricultural enterprises in the digital economy, it is necessary to create a unified state digital platform for analysis and management decision-making.

The 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 changeable. The penetration of the Internet and other communication means in rural areas remains at a relatively low level. Traditionally, there are gaps in the education of rural workers in the field of digital technologies. All this leads to the fact that less than 8-10% of farms currently use digital platforms in Russia.

Aims of "smart" agriculture are associated with the need to ensure sustainable agricultural production, with the improvement of mathematical modeling of agricultural production and forecasting of economic indicators of agricultural production. Developments described in this work can be scaled up in the future, which will make it possible to move from the management of technical processes and equipment to the management of the profitability of the whole agricultural enterprise and, in addition to the economic effect, increase the prestige of the agricultural job.

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