Digitalization of crop production: development trends

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Abstract. It is shown that digital technologies, which are the basis of modern management systems and optimization of technological processes in agriculture, allow agribusiness to obtain the necessary information for decision-making, optimize resources and reduce the cost of production. The main trends in the development of digitalization of crop production—production management, satellite technologies, intellectualization of agricultural machinery—are considered. To reduce the technological gap between Russia and the world's leading countries in terms of labor productivity in agriculture through the development of digitalization of technological processes, agriculture needs direct support from farmers who master technologies and equipment with a high intellectual component that can ensure the competitiveness and investment attractiveness of the industry.

1. Introduction

The use of modern management technologies based on advanced digital models of agricultural production organization and broad intellectualization of agricultural processes are becoming an integral part of modern agricultural business in Russia [1-2].

Their use in the practice of agribusiness allows you to obtain previously unavailable data and necessary information for making management decisions, optimize resources and reduce the cost of production. Digital data acquisition and processing technologies include: sensors, communication equipment, information storage and aggregation systems, and various analytical applications for optimizing process control [3].

The analysis of domestic and international experience shows that the use of digital technologies is one of the important factors that ensure the growth of labor productivity, resource conservation, sustainability of food and agricultural raw materials production, reduction of product losses in the process of production, transportation, storage and sale.

The departmental project "Digital agriculture", developed by the Ministry of agriculture of the Russian Federation, through the development of digital technologies and platform solutions, provides for ensuring a technological breakthrough in the agro-industrial complex by 2024 and increasing labor productivity at agricultural enterprises using digital technologies by 2 times [1].

The purpose of the study. To analyze the main directions and experience of digitalization of management of production and sale of crop production, the use of satellite technologies to improve the efficiency of land use and intellectualization of agricultural machinery.
2. Materials and methods

The theoretical basis of the research was scientific research works [2; 4-24], dedicated to the methodological aspects of the use of digital technologies in crop production, as well as the departmental project "Digital agriculture", which involves the introduction of integrated digital solutions for the agro-industrial complex. As a methodological basis for conducting research, General scientific research methods and information and logical analysis of scientific and technical information reflecting the issues of digitalization of crop production were used.

Main results. Currently, agriculture is becoming a high-tech sector of the economy, where big data flows are processed from various sensors installed in the field, on a livestock farm, tractors, combines and other agricultural machinery, from weather stations, satellites, unmanned aerial vehicles and other systems. Analytical processing of these data allows you to obtain qualitatively new information that allows you to automate technological processes, find patterns for making management decisions to improve the efficiency of agricultural production, create added value that improves the work of agribusiness.

Digitalization and automation of the maximum number of agricultural processes is the development strategy of the world's leading agro-industrial companies. With the help of IT technologies and automation, it is possible to solve many problems that constantly arise in the long chain of production and sale of agricultural products. The solution of such problems is associated with a significant increase in the volume of received and processed data, an increase in the reliability of conclusions that underlie the adoption of technological and managerial decisions.

The basis of the "digital agro-industrial complex" is the intellectualization of all technological processes of agricultural production-from obtaining statistical indicators to moderating the entire value chain, improving the quality and marketing of products, and evaluating profits.

The emerging breakthrough in the digitalization of agricultural production is due to the following factors [4-6]:

- The development of sensors and devices that transmit and process current indicators that characterize the state of each control object (soil parameters, plants, microclimate, animal characteristics, etc.);
- Integration of the received data with various intelligent it applications that process them in real time, allowing you to develop sound recommendations for decision-making by agricultural specialists;
- The increased productivity of computers, the development of software, cloud, network and Internet technologies that allow you to automate most agricultural processes based on the creation and analysis of digital models of the functioning of all interrelated links involved in the value chain of products;
- Growth in the number of users connected to a single network, exchanging data through the cloud;
- The use of seamless communication channels to convey information.

Considering the multidimensional directions of digitalization of the agro-industrial complex, we can identify the main trends associated with the development of the following enlarged blocks:

- Plant production management;
- Development of satellite technologies for land use and land management;
- Intellectualization of agricultural machinery.

It should be noted that when creating and implementing digital technologies in crop production, both separate blocks and their integration can be used, for example, in precision farming technologies, creating various modules for complex digital solutions for the agro-industrial complex: "Smart field", "monitoring of agricultural machinery", "Sharing of capacities and equipment", etc.
Plant production management. Digital planning involves the rational construction of a production management system, designed to eliminate the negative impact of the human factor associated with limited knowledge, inadequate motivation and responsibility of management personnel on the results of production.

Currently, 40% of top managers of agricultural enterprises are concerned about the need to analyze big data, the quality of processing of which affects the validity of conclusions based on which decisions are made [7].

The developed software allows you to give advice to specialists on improving the production and processing technologies of plants in comparison with the indicators of previous years. The recommendations are based on modern methods of information processing aimed at determining the optimal time for planting seeds, fertilizing, watering, harvesting, calculating the time of loading and delivery of products to consumers.

According to experts J'son & Partners Consulting major agricultural enterprises can be pioneers in the implementation of automated enterprise management systems based on the use of technologies of Internet of things, Autonomous akrobatov, the development of innovative methods and software required for processing large agricultural data as well as in the organization of training, training personnel and organizing the implementation of advanced achievements of foreign companies.

Medium-sized private agricultural enterprises with sufficient flexibility in the selection, testing and active use of new technologies in the production process can also act as a promising segment for the use of AIoT solutions in the domestic agricultural sector.

An example of a complex automated information system for decision support in the management of technological processes of crop production, based on a set of mathematical models, is presented in (figure 1) [6].

![Figure 1. Model support of integrated AIS management.](image)

The basis for data mining is the database of the field history module, which was created using the "BigData" technology.

As a rule, the first digital technologies were introduced by large enterprises, such as the agricultural holding "Rusagro", which processes almost 1% of all agricultural land in the country. The beginning of digitalization is associated with the introduction of a resource management system. Tasks for 1.5 thousand employees are formed in the Enterprise Resource Planning System - SAP ERP (enterprise Resource Planning of SAP).
The company analyzes the data received from the satellites, with their own weather stations and weather services, sensors in fields are aggregated and represent large data characterizing dynamics of development of crops, agricultural techniques, the characteristics of fields seeds, soil conditions, applied technology and weather conditions. The collected data is used by the company to analyze and adjust production programs.

For agricultural producers, real-time data monitoring and analysis systems are of particular interest. For example, in the Russian project "Agrosignal", all the work of equipment is shown on the monitors, so any failures can be easily noticed and quickly eliminated. Special attention is paid to monitoring the development of crops, which covers more than 150 farms that process more than 2 million hectares of land. The control system plans production processes, adjusts plans in the course of their implementation, and automatically registers deadlines for work with the help of connected sensors and devices. Practical application of the developed system has shown that productivity can be increased by 2 times, saving of material values up to 50 %, and productivity increases by 10-15 % [7].

Another example of the use of digital management technologies is the Kuban agricultural holding, which employs 5,000 people. The holding is engaged in crop production, animal husbandry, grain storage and processing, seed production and other activities.

Digital monitoring of agricultural machinery, developed by the company to determine the route of movement, fuel consumption, technical condition of machines, allows you to save up to 30% of fuel, automate the processes of harvesting, plowing, fertilizing, etc. Obtaining and processing field diagnostics data using high-resolution cameras, meteorological sensors that measure air temperature, humidity, rain, as well as the speed and trajectory of air masses, atmospheric pressure, as well as a database of plant diseases actually leads to the need for the use of big data processing technologies (big data).

The main task of the holding's management is to ensure control over the work of all enterprises included in the holding: agricultural enterprises, livestock farms, feed and horse farms, feed quality control laboratory, service centers and other enterprises. Detailed cartograms of fields, monitoring data of their state obtained using satellite technologies and data from unmanned aerial vehicles, analytical processing and packet transmission of information are used to solve control and management problems [8].

This technology allows the holding's specialists to more accurately predict weather conditions, obtain results of soil fertility testing, and more quickly manage plant development and production efficiency.

To automate production management processes, link production operations with enterprise resources and ensure efficiency growth in crop production, Kuban Agroholding is one of the first companies in the Russian agricultural sector to implement an industry-specific ERP system based on the specialized Oracle JD Edwards Enterprise One software package with applications for agriculture. On an area of more than 100 thousand hectares, the processes of managing and controlling the cultivation of cereals, legumes, sunflower and sugar beet are automated.

To analyze the level of soil fertility, an "agronomist's staff" is used, with sensors and GPS and GLONASS systems. The main indicators to be determined include humidity, organic matter content, hydrolytic acidity, salt extract pH, levels of nitrate and ammonium nitrogen, mobile forms of phosphorus and potassium. According to experts, thanks to the digitalization of management, the company was able to become one of the most efficient largest land users in the country.

Other domestic companies are also engaged in the development and promotion of digital agricultural production management systems. For example, the online field monitoring and agricultural management service developed by Exact Farming determines weather data, vegetation index, crop rotation status for past years, soil fertility, reflects the progress of field work, information about products in warehouses, and also increases the accuracy of risk forecasting, which is a more reasonable proof of the need for loans.

The company Alan-it is a developer of a set of software tools for crop production, including an accounting system and built-in business Analytics. The complex allows you to keep records, optimize
the planning of agricultural work, predict yields, monitor the progress of sowing and harvesting operations in real time and assess the causes of deviations from the plan that affect the final results. This makes transparent the entire process of production in crop production, allows the management staff to increase the efficiency of applied agricultural technologies.

To develop management decisions in the field of agricultural production, the same company has developed a cloud-based geoinformation and analytical service that provides specialists with information about the state of each field in a certain period of time and allows them to predict the dynamics of plant development.

According to the research center FNAC VIM gardening is one of the most labor-intensive subsectors of agriculture, the mechanization level which is 15-20%, which hinders the introduction of modern highly effective technologies of production of fruit and berry production, leads to a simplification of agricultural technologies, reduced productivity and loss of crops up to 40-50% [9].

For the implementation of modern technologies for the cultivation of berry bushes in FGBNU FNAC VIM, the structure of the production process management system in intelligent technologies for the cultivation of shrub berry crops is justified, including:

- A unit for monitoring the parameters of the production process (plant life parameters with a set of sensors for collecting information about the state of plants and the environment).
- Information and analytical unit for information processing and analysis
- Control actions implementation unit, including controllers of stationary irrigation systems and controllers of machines for performing technological operations, including top dressing and local application of fertilizers and plant protection products, working with satellite positioning systems.

The requirements for the automated production process management system (ASUPP), which provides control and accounting of external climatic factors, growth indicators and the state of berry bushes in critical phenophases of their development, are developed. A graphical representation of environmental data is available on the Internet. In the course of work, the user is given the opportunity to enter and adjust the production conditions, thereby adapting the system for the formation of optimized management decisions.

The IoT solution presented by Cognitive Technologies (Cognitive technologies), designed to control the path of grain from the field to the Elevator and reduce the loss of grain, which reaches 1 million tons during transportation and insufficient accounting, is noteworthy for managing grain sales [4].

For this purpose, digital chains are built to support the logistics of supply and sales of products with parallel processes of digitalization of transport and logistics, exchange of information received from vehicles with operators of digital platforms [10].

Among digital technologies for these purposes, the technology of radio frequency identification (RFID) has become widespread, containing a microchip that stores a unique identifier, as well as an antenna capable of transmitting this information to special radio readers. RFID technology allows you to effectively solve the problems of accurate accounting, receiving and shipping products, significantly reducing the cost and complexity of inventory. The use of RFID technology in the software and hardware complex Cognitive Agro Control, allows you to organize online exchange of basic data during grain harvesting, their transfer to the server of the harvesting control center, conduct statistical analysis.

Projects based on RFID technology are being actively implemented in practice. Thus, 79% of the surveyed companies have already invested in such projects, and the rest plan to do so in the next 1-3 years. [11-12].

With the help of digital technologies in agriculture, it is possible to create automated chains that include retail chains, wholesale companies, logistics, agricultural producers and suppliers of products in a single process with adaptive management.
According to experts of J’son & Partners Consulting, the most promising model in this direction is the direct sales model, in which agricultural producers, through the use of Analytics, "see" the end user, the required volume of supplies and the structure of demand. At the same time, the principles of automatic exchange of information between participants in the supply chain allow you to minimize the cost of the warehouse and logistics infrastructure of the entire chain.

To solve the problem of operational planning in the context of daily supply adjustments, you can switch to digital planning systems that cover the entire chain of purchase, production, logistics and sales. Such a system will allow specialists to plan production and deliveries in real time, taking into account mathematical models of demand and sales of products.

Figure 2 shows an approximate diagram of an end-to-end automated value chain, including sales companies, agricultural producers and suppliers [4].

The analysis shows that all participants in the value chain of agricultural products in Russia will increasingly be involved in the development of sharing technologies of the Internet of things and big data aggregation. This is due to the fact that the more data is collected and analyzed in one place, the smarter the system becomes and the more valuable information can be obtained for managing the production and marketing of products.

An example of integrated solutions for smart agriculture is the development of Pessl Instruments (Austria), which helps farmers make more informed decisions to optimize the distribution of resources (seeds, water, fertilizers, etc.), make fields more resistant to agricultural risks (drought, excess water, frost, heat stress, crop damage by pests, fungal infections, etc.). The use of digital tools offered by farmers can provide farmers with a better end result. For the operation of digital management of agriculture, Pessl Instruments has developed 12 specialized stations and recorders [13].

In accordance with the concept of scientific and technological development of digital agriculture, digital technologies in the management of agriculture include the development of analytical tools and databases: annual reports of various fields of activity in the industry, on the state of food and resource markets, the results of intellectual activity of agricultural research institutes and agricultural universities, etc. [10].

Figure 1. Diagram of an end-to-end automated value chain.
To identify issues constraining the development of digital technologies, determining the priority directions of the state support of digitalization APK developed specialized indexes for evaluating the degree of penetration of digital technology in agriculture, provides for the integration of information resources of the Ministry of agriculture databases of Rosreestr, the Russian space Agency, the FTS and other departments that will generate more accurate predictions [14-16].

The agriculture Ministry has developed a state information system of traceability of seed, which should reduce the "gray" market of seeds reaching today 40 %, and by strengthening controls to improve the quality of seeds, the project of support to agricultural products for export based on paperless technology (digital platform "From field to port"). It is predicted that by 2021, 100% of agricultural products for export will be accompanied by paperless technology.

Development of satellite technologies for land use and land management

Digital technologies are used to solve problems of increasing the efficiency of agricultural land use: for land inventory, assessment of the state and development of agricultural crops, crop yield forecasting and other purposes. For this purpose, appropriate technologies, software and methods of using remote sensing data from spacecraft and aircraft have been developed [17].

The physical basis of aerospace monitoring of crops is the manifestation of structural and biochemical changes in plants in the spectra of their reflection of solar radiation recorded by digital sensors during the growing season. Satellite monitoring of crops taking into account meteorological conditions makes it possible to use space-based information to predict yield, since it is established that if the vegetation condition is good throughout the entire growth period, the probability of obtaining a good harvest also increases [18].

The measured reflection characteristics of vegetation covers are presented in the form of dimensionless vegetation indices (NDVI, EVI, etc.), in the form of parameters of radiation transfer models (leaf index (LAI), the share of absorbed solar radiation in the photosynthetically active region of the spectrum (FAPAR), etc.

One of the most common and used indices for solving problems that use quantitative estimates of vegetation cover is the vegetation index NDVI, which at a certain point in the image is equal to the difference in the intensities of reflected light in the red and infrared ranges, divided by the sum of these intensities.

Numerous studies show that the NDVI index can be used to predict crop yields with high confidence in the absence of adverse weather conditions for the subsequent period. The vegetation index NDVI changes throughout the season, its values are different during the growth, flowering and maturation of plants. The most accurate forecast of crop yield according to the NDVI index can be given at the time of passing the peak of the NDVI value, which usually falls on the earing phase (for cereals) or in the phase of maximum leaf development (for other crops).

Yield estimation works are carried out mainly in three directions: yield estimation by year-analog, using regression analysis based on remote and meteorological observations and on the basis of simulation modeling [19-20]. Such studies are carried out at the Institute of comic studies as part of the creation of a system for remote monitoring of agricultural land.

In the forecast for the analog year, it is assumed that if the crops of agricultural crops in the current year develop as well as in any previous season, then the yield should be close to the yield of this analog year.

The regression method for predicting yield is used to construct yield values based on Rosstat data for previous years with various predictors obtained on the basis of satellite data, which use the NDVI vegetation index calculated from the data of SPOT-VEGETATION (SPOT satellites) and MODIS (Terran Agua satellites), weather data on temperature and precipitation, maps of arable land and crops.

The third method of yield forecasting is based on modeling the daily increase in plant biomass since the beginning of the growing season. This method allows you to estimate the yield in advance, in the middle of the growing season, and can be considered as a means of independent control of statistical information coming from the field and allows you to get forecast yield estimates for
individual fields. However, this method requires a large amount of field data to calibrate the models used [19].

Setting up bioproductivity models involves comparing the results of modeling with field data within the boundaries of each field and selecting a number of empirical constants. Such models have the greatest versatility and detail in accounting for meteorological conditions of crop formation, but they require a large number of meteorological and agrochemical characteristics, the control of which for each field is a difficult task [21].

Practical experience and methodological approaches to the use of yield forecasts in justifying the structure of sown areas of agricultural crops based on the three-year and four-year cyclical dynamics of grain yields, applied in the Kuban state agricultural enterprise, when testing the model based on data for 2012-2018, showed their acceptability as a tool to ensure a minimum error in the forecast of winter wheat and barley, rice and sunflower yields. Less successful were the forecasts for oats and soybeans, and for corn for grain-the results were unsatisfactory [22].

Unlike the forecasting method based on forecasting when the values of vegetation index reaches its maximum, developing approaches to shift the terms of the crop yield forecasting at an earlier time without any critical reduction in the accuracy of the forecast. Thus, the error in predicting soybean yield during early forecasting, performed according to the scheme shown in figure 3, was in the range of 5-12% for different regions, which corresponds to a fairly high accuracy of the developed model of early yield forecasting [23].

The Ministry of agriculture of the Russian Federation has created a unified Federal information system for agricultural land (EFIS ZSN), which will be filled with up-to-date and reliable data on the efficiency of agricultural land use, including information on the use of each land plot by regions of Russia, on agricultural culture, the state and development of vegetation, crop forecasting and other real-time indicators. Obtaining this information will be largely based on satellite technologies.

Along with monitoring the state of agricultural land, it is planned to create together with Roscosmos and Roshydromet a single database of space images and climate data. This will make it possible to introduce intelligent industry planning in 85 regions of the Russian Federation (100%) by 2021, based on the principle of growing the most profitable crops, taking into account the transportation of products to the place of processing or consumption.

The development of research on the use of space technologies is aimed at solving a number of problems that hinder the widespread use of these technologies in agriculture:

- High cost of purchasing and operating equipment;
• Insufficient reliability of satellite communications and GPS positioning accuracy;
• Insufficient quality of technical support;
• Duration of the device programming and calibration process;
• Complexity of data processing and insufficient training of agricultural personnel;
• Insufficient accuracy and reliability of the information received, as well as the frequency of data updates.

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The introduction of space technologies in agricultural production on a large scale will require active work on their promotion at the state level, the development of research on the development of methods to improve the accuracy of forecasts based on the development and use of modern spacecraft, equipment and software.

Intellectualization of agricultural machinery.

Currently, agriculture is equipped with a new generation of machines, the design of which is constantly becoming more complex, so the maximum use of the technical and technological potential of such equipment can be achieved by its intellectualization, the development of which goes in the following main directions:

• Equipping agricultural machinery with modern digital information systems and devices;
• Development of technologies for remote monitoring and diagnostics of equipment;
• Creation of unmanned vehicles and robotic systems.

The main goals that the intellectualization of agricultural machinery provides for are aimed at increasing labor productivity, the efficiency of using machinery, reducing material and time costs for the production of agricultural products and raw materials, and improving their quality indicators.

Based on modern information and automated systems of control of technological processes, the use of global satellite positioning systems GPS/GLONASS automatiziruete many technological operations tillage, fertilizing, sowing, care, harvesting, introducing precision farming technology, parallel driving, to solve problems of regulation of the working bodies of mounted and trailed machines, load optimization engine due to the control of technological, power and operational and other parameters. Digital systems of modern tractors and combines, including various sensors and signal conversion systems, are used to control the operation of the engine, transmission, working bodies, security systems, climate control, etc. [24-26].

On the basis of on-Board computers, information systems for monitoring technological and operational parameters related to the operation of agricultural units were created and implemented: regulation of the position of the working bodies of mounted and trailed machines, engine loading, control of oil pressure in the engine, coolant temperature, fuel consumption, etc.

An example of such a system, created in PJSC "Rostselmash" for installation on combine harvesters, is the Adviser system, which controls up to 40 parameters of the combine, including the parameters and modes of operation of the engine, the thrasher of the combine and the speed of its movement. The use of such intelligent systems makes it possible to increase the potential capabilities
of agricultural machinery, reduce the risks of equipment failures and related to the human factor, and create prerequisites for the transition from manual to automated control of the latest equipment [26].

The world trend of intellectualization of agricultural machinery at present is the use of remote monitoring systems of machines, including monitoring of technical condition and diagnostics [26-27]. The main task of such systems is to increase the productivity of the agricultural machinery fleet by optimizing the technological process based on the analysis of working hours, making appropriate adjustments to the settings of technological modes, collecting, recording and documenting data, increasing the operational reliability of machines, and switching maintenance from planned to state-of-the-art maintenance. These systems use satellite navigation GPS/GLONASS technologies, stationary computers, laptops, tablets or mobile phones.

Many domestic and foreign companies are engaged in the development of such systems: "Claas", "John Deere", "AGCO", "New Holland", "Case IH", "Rostselmash", "Fairway", "GLONASS Telematics", "Scout", etc.

An example of remote monitoring systems of machines allowing to track the performance of machines and control them in real time on the computer from the office and also provide remote diagnostics using the GPS signals and wireless data network can serve as a system TELEMATICS firm "Claas" (figure 4). With the help of satellites GPS determines the location of cars and mobile communications to a single server receives more than 200 different settings [26].

The use of TELEMATICS on combine harvesters during testing in Germany and the UK showed that it reduces the harvest period by three days, increases the productivity of machines by 10%, the utilization rate of working time – by 7%, reduces costs by 0.5%.

Another major global trend in the intellectualization of agricultural machinery is the creation of robotic systems and unmanned vehicles that will determine the competitiveness of the agricultural sector in the next 5-10 years. Therefore, many domestic and foreign firms are working intensively in this direction. Robotic systems are designed to automate repetitive monotonous and time-consuming operations, eliminate the work of the machine operator in dangerous conditions, and reduce the level of injuries in agriculture. Such robots for performing technological operations in the field, in gardens, greenhouses and other agricultural facilities have already been created.

The most active work on the creation of unmanned systems is carried out in the United States, Germany, Japan, China, the United Kingdom and other countries. Many large foreign companies are already preparing for the production of unmanned tractors. Such Russian companies as "Yandex", FSUE "NAMI", PJSC "KAMAZ", "Avrora Robotics", FNAC "VIM", "Cognitive Technologies", holding "shvabe", etc. have a great reserve in the creation of unmanned technical systems [26].

Conclusion. Despite the fact that the pace of digital development in the world has significantly accelerated, Russian agriculture is in the early stages of using digital technologies, although the conditions for the formation of a digital platform "Digital agriculture" have already been created.
Studies show that the solution of problems of increasing labor productivity in agriculture by 3-5 times, which are not solved using traditional models, can be solved only within the framework of models based on digital technologies.

The emergence of cheap sensors, mobile broadband, big data Analytics, cloud technologies, artificial intelligence systems and the Internet of things contributes to the development of the digital transformation of Russian agriculture.

The widespread use of digital technologies and systems in crop production will allow to optimize production, storage, transportation, processing and sale of products, to carry out production processes in optimal terms, with the lowest costs, to use agricultural machinery with intelligent systems and software products that ensure productivity growth, reduce production costs, and eliminate the negative impact of the human factor on production results.

The success of digitalization of management in the field of agriculture in Russia will largely be determined by the speed of transition from the introduction of disparate IT solutions applicable within a single agricultural holding or a single product manufacturer to the integration of all business processes with elements of predictive modeling. For a broad digital transformation of agriculture, it is necessary to:

- Improve the system of training for agriculture, focused on the adaptation of specialists to the requirements of the digital economy;
- Provide direct support to agricultural producers who are developing machinery and equipment with a high intellectual component that can increase the pace of digital technology development; competitiveness and investment attractiveness of the industry.
- To carry out continuous monitoring of indicators of digitalization of the agro-industrial complex of Russia for taking measures to eliminate negative phenomena in the implementation of the departmental project "Digital agriculture".

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