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DIGITAL TECHNOLOGIES IN AGRICULTURAL PRODUCTION: IMPLEMENTATION BACKGROUND, CURRENT STATE AND DEVELOPMENT TRENDS

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Abstract. Digital technologies have been deeply integrated into our lives and found their application in all areas of human activity, including agriculture. Technological progress, the development of infrastructure in the IT industry, wider access to the Internet, a high level of education and growing computer literacy of the population contribute to the popularization and introduction of digital technologies in agricultural production. The review of the use of digital technologies in the agricultural sector has shown that existing software tools help plan the work of an agricultural organization, monitor the state of production, manage the farm, and sell products on virtual trading platforms. Most software products are able to store data in the cloud, and farmers can access the system via their personal account from any device with Internet access. There are also a number of programs on the market that allow farmers to plan, analyze and control the crop or livestock production. Leading manufacturers of agricultural machinery and equipment are actively integrating digital technologies into their products. It is now possible to manage a fleet of vehicles used in the fields, and implement unmanned control. Use can be made of tractors equipped with automatic systems for driving along rows or laid paths, turning, and monitoring process parameters. The authors propose a set of digital control means to be used in agricultural production, based on the application of technologies of the Internet of things, cloud data storage, big data processing, and artificial intelligence. It is the technologies that digital agriculture will be based on, which use robotic monitoring tools to collect information and transmit it to “cloud data storage”. It is processed there and directed to the control system, which develops the optimal solution and transmits the control signal to the robotic actuators. In this regard, the development of agricultural machinery should be focused on the robotic tools designed for monitoring and performing technological operations. The most difficult task is to develop a control system, since it must have elements of artificial intelligence and replace humans in agricultural production.

Key words: digital agriculture, big data, agrobot, Internet of Things, unmanned agricultural machinery, robotic technical means.

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ОРИГИНАЛЬНАЯ СТАТЬЯ

ЦИФРОВЫЕ ТЕХНОЛОГИИ В СЕЛЬСКОХОЗЯЙСТВЕННОМ ПРОИЗВОДСТВЕ: ПРЕДПОСЫЛКИ ВНЕДРЕНИЯ, ТЕКУЩИЙ УРОВЕНЬ И ТЕНДЕНЦИИ РАЗВИТИЯ

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Аннотация. Научно-технический прогресс, государственные программы по цифровизации отрасли, развитие инфраструктуры ИТ-отрасли, и растущая компьютерная грамотность населения способствуют популяризации и внедрению цифровых технологий в сельскохозяйственное производство. Анализ текущего уровня использования цифровых технологий в сельскохозяйственном производстве показал, что цифровое сельское хозяйство должно базироваться на технологиях, в которых роботизированные средства мониторинга собирают информацию, передают в «облачные хранилища данных», где она обрабатывается и передается в управляющую систему, которая вырабатывает оптимальное решение и передает управляющий сигнал на исполнительные роботизированные средства. Авторами предложена схема системы цифрового управления техническими средствами в сельскохозяйственном производстве, базирующаяся на применении технологий интернета вещей, облачного хранения данных, обработки больших данных и искусственного интеллекта. В сельскохозяйственной машине система управления технологическим процессом должна управлять совокупностью систем управления исполнительных устройств. Авторами представлен алгоритм, по которому работает система управления каждого исполнительного устройства (рабочего органа) сельскохозяйственной машины, оказывающего влияние на параметры протекания технологического процесса. Указаны тенденции развития цифровых технологий в сельскохозяйственном производстве: разработка системы управления технологическими процессами, средств мониторинга и роботизированных технических средств для выполнения технологических операций. Сложнейшей задачей является разработка управляющей системы, так как она должна обладать элементами искусственного интеллекта и заменять функции человека в сельскохозяйственном производстве.

Ключевые слова: цифровое сельское хозяйство, большие данные, агробот, интернет вещей, беспилотная сельскохозяйственная техника, роботизированные технические средства.

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Introduction. Today the area of available agricultural land on the planet is shrinking, and the ecological situation is deteriorating. Moreover, energy resources are scarce. However, in order to feed the constantly growing global population under these conditions, new approaches to agricultural production are required. For this purpose, new technologies, innovative farm machines and equipment, as well as highly productive varieties and breeds of animals are being developed. At present, further improvement of agricultural machinery and equipment does not ensure a significant positive effect. However, labor productivity and efficiency of production can be further increased through the development and application of systems of "digital agriculture" [1, 2, 3].

Purpose of the study. To analyze the prerequisites, the current level of implementation and trends in the development of digital technologies in agricultural production and methods of using technical means in agricultural production based on modern digital technologies.

Study objectives:

1. Identify the introduction of digital technologies into agricultural production.
2. Analyze the current level of the use of digital technologies in agricultural production.
3. Analyze trends in the development of digital technologies in agricultural production.

Material and methods. The study was based on information materials presented on the websites of Rosstat, the Ministry of Agriculture of the Russian Federation, leading manufacturers of agricultural machinery and equipment, as well as an overview of research ongoing towards the use of digital technologies in agricultural production.

Results and discussion. Recently, the use of digital technologies in agriculture is increasingly growing. Greenhouse farms were the first to apply digital technologies in crop production. Today there are greenhouses with fully automatic microclimate control and partial robotization of production processes [4]. Irrigation and nutrient application are easy to automate, however, such operations as planting and harvesting require more complex solutions, which often turn out to be economically impractical [5, 6].

Robotic milking systems are one of the clearest examples of using digital technologies in livestock production. Their use makes it possible to increase milk yield, minimize animal injuries, reduce the amount of manual labor, etc. However, such equipment is expensive and requires specially trained and highly qualified personnel to maintain it.

Our analysis shows that the introduction of digital technologies into agricultural production is hampered by a number of factors[1]:

- low interest of agricultural producers in long-term investments due to the unstable situation on the agricultural market, exchange rate and other factors;

[1] Arkhipov A.G., Kosogor S.N., Motorin O.A. et al. Tsifrovaya transformatsiya sel'skogo khozyaystva Rossii [Digital transformation of agriculture in Russia]. Moscow, FGBNU "Rosinformagrotech", 2019.

- lack of a unified approach to standardizing processes, forms and formats for collecting, storing and transferring information;
- lack of a regulatory framework and weak federal and regional interdepartmental communication;
- lack of a unified digital platform for agricultural producers and regional authorities;
- lack of personnel capable of applying digital technologies;
- lack of degree training programs to prepare specialists for the use of digital technologies in agricultural production.

Despite the obstacles, the digitalization of agricultural production is inevitable. One of the most important prerequisites for this process is the state policy of the industry digitalization [6, 7]. In recent years, state programs have been developed on digitalization of the economy and forecasts of the country's technological development[2,3,4,5,6].

Other important pre-requisites for digitalizing agricultural production are:
- technological progress, development of infrastructure for the Internet access and the IT industry;
- increased level of education and computer literacy of the population, especially in rural areas.

In the 21st century, the IT industry is developing rapidly, therefore, more and more people have the Internet access. Moreover, technologies are developing at such an accelerated pace that the Internet access via telephone lines was shortly changed by fiber-optic communication technologies, which significantly increased the speed of the Internet connection. At present, the emphasis is already made on wireless communication: about 3.5 billion people on the planet have the Internet access via a smartphone. This is important due to the fact that many technological operations, including those in agricultural production, can be controlled using smartphone applications.

According to Rosstat, in 2017 the share of households with access to the Internet in Russia was 75%. Moreover, the urban population is provided with the Internet by 78.5%, while the rural population – by 63.6%[7]. To ensure the massive introduction of digital technologies into agricultural production, it is important for the rural population to have the Internet access. In 2013, 47% of the rural population of Russia was provided with the Internet access, which indicates a fairly rapid growth in the Internet accessibility. Therefore, in the next few years, high-speed Internet will be provided not only to the urban population, but also to about 90% of the rural population, which will have a positive effect on the introduction of digital technologies into agricultural production.

Technological progress and the development of the IT industry contribute to the rapid development of digital technologies; however, it is important not only to make conditions, develop software products and provide access to the Internet, but also to solve the problems of controlling production processes. This requires specialists capable of working with digital technologies. The younger generation should be trained in educational institutions to acquire the knowledge and skills that will enable them to work with digital technologies. And those specialists, who are already working in agriculture, require advanced training courses to remain attractive for employers and stay relevant in the context of the global digitalization of the economy. In this regard, many agricultural universities include new subject courses in their curricula – "Automated control systems for equipment", "Navigation systems for vehicles", "Satellite navigation systems", etc.

Specialists require not only the ability to work with digital technologies, but also an understanding of the specific features of a particular profession. In the future, a crop farmer must understand the basics of agronomy and be able to manage the entire production process using software products.

Various software solutions that facilitate the work of agricultural commodity producers are already appearing on the market. One of these programs – FarmLogs – is used to plan the work of an agricultural organization, monitor the state of production, manage production processes, and sell products on trading floors. The program stores all data in the cloud space, which can be accessed through a personal account from any device with the Internet access (a personal computer, laptop, tablet computer, or smartphone). Another similar program is Agrivi farm management, used by a manager or specialists to plan or analyze the farm activities and directly control the production processes.

Software products are important for agricultural production, but it is difficult to achieve high results without using executive technical devices based on digital technologies. Most agricultural machinery manufacturers carry out R&D designing modern machines with digital control systems.

For example, the cab of the Rostselmash Acros 585 combine harvester has undergone significant changes as compared with the Don-1500: now it features improved visibility, reduced negative impact of noise and vibration on the operator, and increased comfort. One of the most important changes is the introduction of digital technology into the combine systems and controls to monitor the harvesting process – mechanical controls are replaced by joysticks and touch panels. All this, of course, has a positive effect on increasing the operator's labor productivity, reducing his/her fatigue, and, as a result, on the quality of technological operations.

Today, John Deere is considered the leader in the implementation of digital technologies in agricultural equipment. John Deere Precision Farming Systems (AMS) can monitor fields, analyze the data obtained, develop optimal solutions, and manage technological operations. Systems have been developed to automatically drive in rows or a given trajectory and turn around. All these innovations free the operator from solving most of the tasks and concentrate on monitoring and, if necessary, making adjustments to the technological process. At the same time, the positioning accuracy is quite high and can reach 2.5 cm.

Many tractor and agricultural machine producers manufacture their products with ISOBUS protocol support.

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[2] Decree of the President of the Russian Federation dated 01.12.2016 No. 642 "On the Strategy of Scientific and Technological Development of the Russian Federation"

[3] "Digital Economy of the Russian Federation" program (approved by the order of the Government of the Russian Federation on July 28, 2017 No. 1632-r.

[4] Departmental project "Digital Agriculture": official publication. Moscow, FGBNU "Rosinformagrotech", 2019.

[5] "Forecast of Scientific and Technological Development of the Russian Federation for the Period up to 2030" (approved by the Government of the Russian Federation on July 10, 2018).

[6] Order of the Ministry of Agriculture of the Russian Federation of January 12, 2017 No. 3. "On Approval of the Forecast of Scientific and Technological Development of the Agricultural Industry of the Russian Federation for the Period up to 2030".

[7] Results of Federal statistical survey. URL: https://www.gks.ru/free_doc/new_site/business/it/fed_nabl/tab1.htm. (Access date 10.03.2020)

The "language of communication" ISOBUS allows the tractor to interact with the aggregated machine. Thanks to ISOBUS, it is possible to quickly connect, using a nine-pin cable, the electronic systems of the tractor to the control systems and actuators of seeders, balers, potato harvesters, etc. This makes it possible to automatically adjust the working tools of agricultural machines, constantly monitor the technological process and make the necessary adjustments in real time.

Many scientists and companies are currently developing innovative agricultural technology of the future, the use of which is often economically impractical today, but the situation should change in the near future. There are three promising areas for the development of digital technologies in agricultural production:

- development of robotic plant growing enterprises;
- development of robotic livestock farms;
- development of robotic greenhouses and climate systems for growing plants in urban environments. In the field of designing robotic crop enterprises, agricultural robots are being developed. In Australia, a professor at the University of Sydney, Salah Sukkari, has developed the "Ladybug" agrobot designed to work in vegetable fields. The unmanned vehicle is capable of monitoring the condition of fields, making technological maps, and using a mechanical arm to remove emerging weeds. The battery life of the agrobot can be up to 72 hours.

Adigo has developed the FIELD FLUX agrobot, which is capable of conducting high-precision soil analysis and determining the amount of nitrogen without human intervention. Sampling is carried out with a special "tentacle".

In France, the VITIROVER agrobot was designed to work in vineyards. The robot accurately recognizes weeds and cuts them. It is equipped with a night vision system, so it can work around the clock. The agrobot performance rate is a hectare in six days.

There is a wide variety of other robots for agricultural production, but at the moment the most promising are unmanned tractors and combines, which are being developed by many organizations, including Russian ones.

Avrora robotics is developing an unmanned tractor for agriculture, the main advantages of which are versatility, platform independence, and modularity. It is able to independently aggregate with various agricultural machines and implements.

Another Russian company, the Cognitive Technologies Group of Companies, together with Rostselmash are working on the development of unmanned self-propelled agricultural vehicles with the C-Pilot computer vision system.

The American company John Deere is developing an all-electric unmanned tractor "GridCON". A special feature of the tractor is that it is powered not from storage batteries, but via a 1000 m cable. Tractor power is 100 kW (134 hp), while it is possible to increase it to 200 kW (268 hp). The working speed of the tractor can reach 20 km/h, and it can be remotely controlled. At the same time, the intelligent system can not only control the tractor, but also monitor the cable position in order to avoid the tractor hitting it. John Deere is developing other autopilot systems that are installed on the company's existing equipment.

Another US company, CASE, has developed an unmanned tractor. The robotic tractor was designed in collaboration with CNH Industrial based on the Magnum Case IH. The autopilot system takes into account not only the tractor dimensions, but also the agricultural equipment to be aggregated. The tractor is equipped with sensors, gauges, and cameras that recognize stationary and moving objects. The tractor can be controlled using a personal computer or mobile device. The company plans to start mass production of unmanned tractors in 2020.

Dutch company Precision Makers has developed the Greenbot unmanned robot that can plow, fertilize, sow or mow around the clock.

Japanese company Kubota Corp. has developed a prototype of the unmanned tractor FarmPilot, intended for use in rice fields. It is capable of working the soil at different depths, sowing, variable-rate fertilization, etc.

Unmanned aerial vehicles (drones) are becoming more and more widespread in agriculture. They monitor fields, take pictures, sow seeds, apply mineral fertilizers and plant protection agents, control crops, etc.

The tasks of robotizing equipment employed in the field are quite complex, despite the fact that in animal husbandry this process is simplified as the machines operate in an artificially made closed system (a farm building), where a lot of negative factors occurring in nature are excluded.

Milking robots have long been commonplace in dairy farming. The recognized leader in robotic equipment for animal husbandry is Lely, which manufactures robots for milking, feeding, housing and caring for animals. The Swedish company DeLaval has developed two farm management systems: ALPRO for all milking parlors and rotary systems and DelPro for robotic milkers and cowsheds with tie-up housing of animals. Afimilk's electronic herd management system is used to manage cow movements, identify animals, measure milk yield, etc. At the same time, further introduction of digital technologies is predicted, so the next 20 years may see the domestic livestock industry move towards the robotic farms in which all technological operations will be robotized, and people will perform the functions of technical personnel serving robotic equipment.

Another area of research that has been gaining popularity in recent years is the cultivation of plants in artificial agroecosystems. In modern greenhouse facilities, most of the processes are automated, but the issue of full automation is important not only in terms of economic feasibility, but also in view of the fact that plant protection products are often used in greenhouses, and due to the closed system, this can negatively affect health of the personnel. Growing plants in climatic chambers is also an important area for the study and improvement of modern technologies and technical means [8]. Such cameras can be installed in buildings, including residential ones, which is an urgent task for regions with a harsh climate. A separate innovative format, which will soon possibly replace the existing greenhouses, is vertical farms for growing plants. They can be located in cities, do not require large areas due to the multi-tiered growing system, and are more energy efficient.

The introduction of digital technologies into agricultural production implies a fundamentally new approach to the management of agricultural production processes. Decision-making is already carried out on the basis of the use of Big Data processing technologies. A schematic diagram of a digital control system for technical means in crop production is shown in Figure 1.

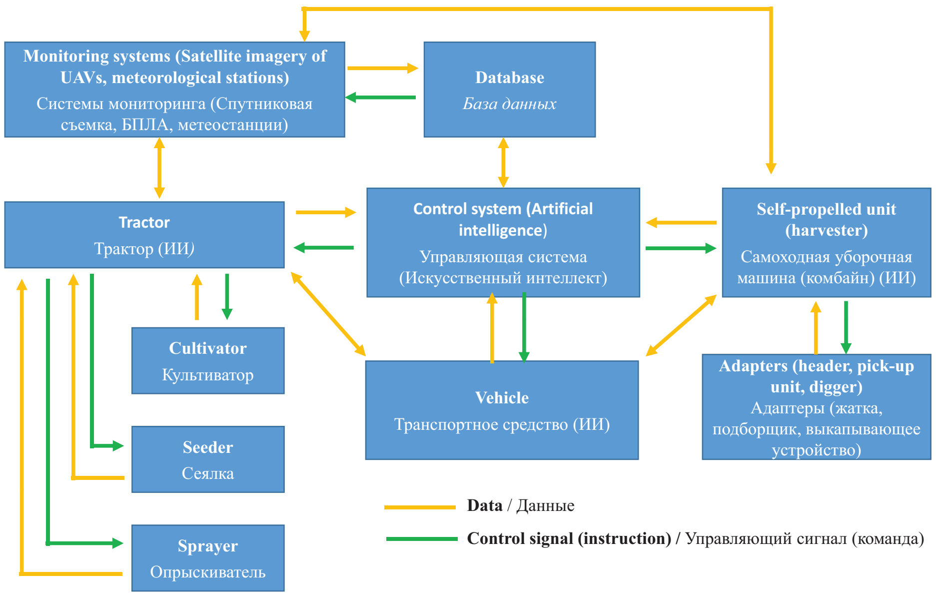

Fig. 1. Schematic diagram of controlling technical means in crop production

Рис. 1. Принципиальная схема управления техническими средствами производства в растениеводстве

One of the initial tasks of the system is the collection and accumulation of a large amount of data, which makes it possible to reveal the influence of separate factors on the final result, and the more data we have, the more reliable relationships we can obtain [9]. To collect data, we propose to use various monitoring tools, including those using Internet of Things (IoT) technologies.

The proposed management system, constantly analyzing the available and newly received data and the results of previously made decisions, simulates production processes, evaluates the impact of new solutions on the productivity of crops and the quality of the resulting products (a digital twin can be produced for a separate section of the field, the entire field, or the farm), and issues controlling signals. In the process of analyzing data, simulating the situation and comparing the predicted results with real indicators, the system goes through a self-learning process.

The sources of data receipt can be various monitoring systems, satellite images, tractors, combines, vehicles, self-propelled agricultural machines equipped with monitoring tools, etc.

The proposed structure enables the control system to centrally influence the technological process and monitor its quality, while the working tools and their operation are adjusted automatically by agricultural machines due to the built-in systems. The quality of technological processes is controlled along two circuits: a control system of an agricultural machine and a control system based on information received in real time. This prevents a decrease in the technological process quality caused by possible failures in the operation of the agricultural machine and embedded systems.

The algorithm of the control system operation to monitor the technological process parameters of an agricultural machine is shown in Figure 2.

When a signal is received from the control system, the preset values of the parameters transmitted by the system are set. During the implementation of the technological process, the information about its course is constantly collected and processed. The current parameters are compared with the specified ones, and if they deviate, the control device is corrected to influence the technological process. Such a cycle occurs continuously throughout the entire time of the technological process. The resulting system is a real-time one.

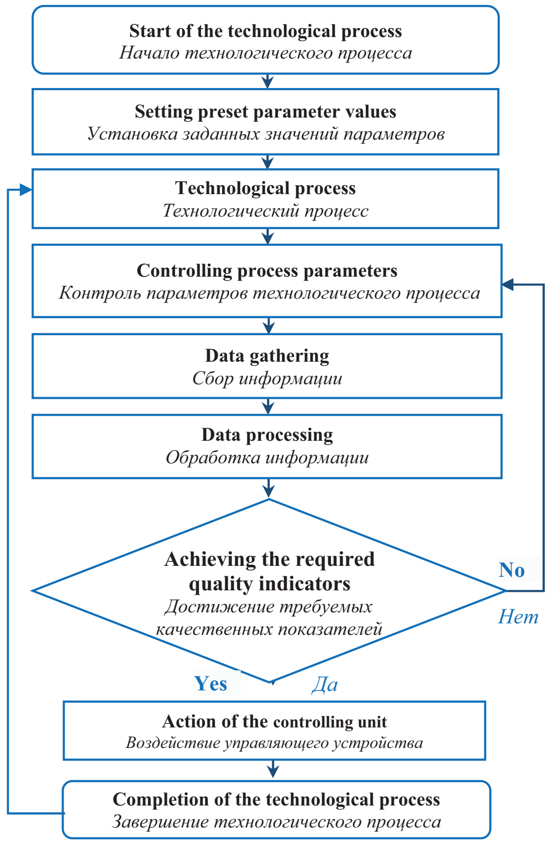

Fig. 2. Algorithm of the control system operation to monitor the technological process parameters (machines or equipment)

Рис. 2. Алгоритм работы системы управления параметрами технологического процесса (машинами или оборудованием)

According to the presented algorithm, the control system of each actuator (working tool) of an agricultural machine operates, which affects the parameters of the technological process. Accordingly, in the agricultural machine, the process control system will operate a set of control systems of actuators.

Accordingly, one of the requirements for all agricultural machines in the transition to digital agriculture is the ability to collect and transmit information about the state of certain environmental parameters and the technological process using the Internet of Things technologies [10]. Such information can be, for example, soil moisture, the actual depth and quality of its processing, the actual seeding rate, the condition of crops, etc.

Agricultural machines can independently transfer information to the database, but it is more rational to use self-propelled power tools (tractors, combines) and agricultural machines (a self-propelled mower or self-propelled sprayer) as information transmitters. In this case, in a machine-tractor unit, an agricultural machine transmits data to a self-propelled power plant, in which one part of the data necessary for optimal performance of the technological process is processed and analyzed, and the other is transmitted for processing to a cloud database [11]. Thus, self-propelled power and transport vehicles should also be able to receive information from agricultural machines, collect certain information about the state of the environment and the technological process parameters, partial data processing, and transfer to a cloud database.

If we consider the structure (figure), we will see that not only vertical (agricultural machine – database), but also horizontal links are made, for example, between the seeding unit and the vehicle through the tractor, enabling the devices to exchange information, for example, on the number of seeds and fertilizer in the sowing unit, determine the place and time of the "meeting" for loading.

The functioning of the considered system is possible provided all devices "communicate in the same language", which means that the transmitted data must have a single format, or be converted into a specified format before being transferred to a database or another unit.

The development of a control system is the most difficult task, since it must have elements of artificial intelligence and replace humans in agricultural production, so large amounts of data are needed to train it.

Conclusions

The introduction of digital technologies into agricultural production is urged by technological progress, the infrastructure development to ensure reliable the Internet access, the IT industry, government programs for the industry digitalization, as well as the level of education and growing computer literacy of the population.

The analysis showed that the most promising areas for the further use of digital technologies in agricultural production are the development of robotic plant growing enterprises and livestock farms, and the construction of robotic greenhouses and climate systems for growing plants in urban environments. The successful implementation of these projects requires control systems for monitoring technological processes, tools and robotic technical means for performing technological operations. Therefore, agricultural engineering enterprises should ensure their sufficient supply.

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Contribution

I.A. Starostin, M.E. Belyshkina, N.O. Chilingaryan, A.Yu. Alipichev performed theoretical studies, and based on the results obtained, generalized the results and wrote a manuscript. I.A. Starostin, M.E. Belyshkina, N.O. Chilingaryan, A.Yu. Alipichev have equal author's rights and bear equal responsibility for plagiarism.

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ИССЛЕДОВАНИЕ МОДИФИЦИРОВАННОГО РАБОЧЕГО ОРГАНА КОМБИНИРОВАННОЙ РОТАЦИОННОЙ КОСИЛКИ

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Аннотация. В настоящее время на рынке практически отсутствуют средства механизации, объединяющие операционно за один проход удаление (скашивание) растительности и выравнивающее рыхление верхнего почвенного слоя с измельчением расположенных в нем корневых систем. Цель работы – осуществить теоретический расчет модифицированной конструкции