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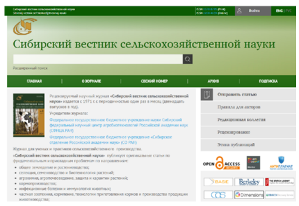

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Платформенный подход к обработке данных мониторинга и полевых опытов СФНЦА РАН для реализации цифрового земледелия

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Представлена концепция платформенного подхода для создания интеллектуальной системы цифрового земледелия с использованием современных информационных технологий. Описана возможная архитектура платформы, состоящая из пяти блоков, позволяющая собирать, хранить и анализировать данные о ключевых параметрах природной среды и посевов культур, а также обмениваться информацией и знаниями с целью повышения производительности и эффективности решений в земледелии. Показана целесообразность синергетического использования сенсорных сетей Интернета вещей, дистанционного зондирования, машинного обучения и аналитики больших данных для создания прогностических моделей, рекомендаций и систем поддержки принятия решений. Изложены основные признаки и их параметры, необходимые для разработки предиктивных моделей урожайности сельскохозяйственных культур, а также используемые для этой цели основные методы машинного обучения. Описан алгоритм разработки рекомендаций по выращиванию культур с помощью моделирования на основе машинного обучения, который состоит из создания набора данных, предварительной обработки данных, обучения модели и оценки результатов. Приведена структура системы поддержки принятия решений, состоящая из четырех основных компонентов: базы данных, моделей и аналитических инструментов, архитектуры и сети, пользовательского интерфейса. Описаны основные подходы и инструменты по разработке имитационных моделей. Платформенный подход реализуется с использованием двух подтипов платформ: хранения и управления данными и анализа данных. Для хранения данных используется распределенная файловая система Hadoop (HDFS) и другое, а также базы данных MySQL, PostgreSQL и другое. Для анализа данных применяются платформы потокового анализа Apache Kafka, Apache Flink, Apache Storm и др. Применение этих платформ позволяет анализировать данные в режиме реального времени и облегчает их обмен между разнородными устройствами и системами, а также обеспечивает интеграцию с Интернетом вещей и дистанционным зондированием.

Ключевые слова: цифровое земледелие, платформенный подход, наука о данных, мониторинг, дистанционное зондирование, машинное обучение, СППР, Apache Kafka

A platform-based approach to processing SFSCA RAS monitoring and field experiments data for the implementation of digital agriculture

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The concept of a platform approach for creating an intelligent digital farming system using modern information technologies is presented. The possible architecture of the platform, consisting of five blocks, is described, which allows collecting, storing and analyzing data on key parameters of the natural environment and crops, as well as exchanging information and knowledge in order to increase productivity and efficiency of solutions in agriculture. The expediency of synergetic use of sensor networks of the Internet of Things, remote sensing, machine learning and big data analytics to create predictive models, recommendations and decision support systems is shown. The main features and their parameters necessary for the development of predictive crop yield models are described, as well as the main machine learning methods used for this purpose. An algorithm for developing recommendations for growing crops using machine learning-based modeling is described, which consists of creating a dataset, preprocessing the data, training the model, and evaluating the results. The structure of the decision support system is presented, consisting of four main components: database, models and analytical tools, architecture and network, user interface. The main approaches and tools for developing simulation models are described. The platform approach is implemented using two subtypes of platforms: data storage and management and data analysis. For data storage, the Hadoop distributed file system (HDFS), etc., as well as MySQL, PostgreSQL databases, etc. are used. The data analysis platforms Apache Kafka, Apache Flink, Apache Storm, etc. are used for data analysis. The use of these platforms allows for real-time data analysis and facilitates their exchange between heterogeneous devices and systems, as well as provides integration with the Internet of Things and remote sensing.

Keywords: digital agriculture, platform approach, data science, monitoring, remote sensing, machine learning, DSS, Apache Kafka

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INTRODUCTION

Digital farming is currently understood as the use of modern environmental monitoring and data analytics technologies, as well as data- and knowledge-based solutions, to improve and optimize the farming systems, enhance the quality of crop products and increase crop yields, efficiently manage biotic and abiotic stressors, and reduce the consumption of non-renewable resources [1–3]. Key digital technologies for the development and implementation of smart farming systems include artificial intelligence (AI), big data, cloud computing, smart sensors, the Internet of Things, satellites, and drones [4–6].

Within the concept of digital, or "smart," farming, large volumes of data are collected from various sources. This data is a valuable resource that can be used in data-driven services and decision support systems (DSS). However, one of the main challenges associated with large volumes of data is its significant diversity in terms of format and meaning, as well as the consistency and compatibility of the technologies, procedures and protocols used [7–9]. Moreover, various services and technologies in the smart farming ecosystem have limited interoperability due to the lack of standardized methods for integrating data and systems. These issues create significant challenges in data exchange, the application of processing technologies and their integration, and the provision of various information services [10, 11].

To address these challenges, a platform-based approach is being developed – a design method intended for creating efficient, reliable and sustainable intelligent systems [12–14]. A platform approach typically takes into account several mandatory requirements for the integration, processing, and use of information. These requirements include compatibility, reliability, scalability, real-time data processing, security and privacy, and standardized rules [15, 16].

Processing and analyzing large volumes of data is a complex task that is gradually shifting from classic "batch" processing (extract, transform, and load) to real-time processing. For example, environmental monitoring has recently adopted open-source technology in the big data environment, using a distributed platform for processing data streams in real time. These platforms receive datasets from various sensor systems, as well as data from heterogeneous automated meteorological systems, regardless of their type, and send them to the Apache Kafka topics using the Kafka Connect API for processing by the Kafka stream processing engine [17, 18].

An environmental monitoring system [19] plays a key role in digital agricultural management, ensuring sustainable agriculture and helping to address key challenges and factors affecting productivity. An intelligent monitoring system is essentially the foundation of digital agriculture. Not only can it maintain agricultural productivity with limited resources, but it also helps monitor climate change, nutrient and water dynamics in the soil, and control the development of weeds, pests and diseases [20, 21].

The purpose of the study is to develop a conceptual framework for a platform-based approach to collecting, storing, and analyzing environmental monitoring and field experiment data to achieve digital farming objectives.

MATERIAL AND METHODS

The research methodology was based on an interdisciplinary approach, embodied in the principles of objectivity and systematicity. The following information processing methods were used during the study: content analysis, abstract-logical analysis, generalization, and conceptualization.

To develop a platform approach for creating an intelligent system, an analytical review of scientific publications in the bibliographic databases Web of Science, Scopus, Science Direct, Springer Link, Google Scholar, Elibrary.ru, and CyberLeninka was conducted, describing both the theoretical principles and functional capabilities, as well as the results of the practical application of modern approaches in data science. Methods for collecting, storing, and analyzing data to support decision-making in agriculture were analyzed. The analysis also included a review of open-source information on tools in this field available online.

RESULTS AND DISCUSSION

The Digital Agriculture Management System (DAMS) is a data- and knowledge-based decision support system that integrates the following main blocks:

– technologies for in situ monitoring and remote sensing of crops and natural objects;

– machine learning algorithms and intelligent analysis of monitoring results and long-term field experiments;

– modeling of spatial objects and land classification using GIS;

– web platforms with publicly accessible real-time databases;

– modules for planning and supporting agricultural technologies;

– assessment of the impact on the sustainability and economics of crop production [22].

DAMS is based on ground-based, proximal and remote monitoring of soil, air and crops, carried out using a variety of sensors (invasive and portable) and digital images obtained from unmanned aerial vehicles (UAVs) or satellites at regular intervals, as well as from external databases, such as weather and climate [23]. Data collected from various sources, including long-term field experiments, are compiled on a specialized platform of the Siberian Federal

Scientific Centre of Agro-Bio-Technologies of the Russian Academy of Sciences (SFSCA RAS) (see Fig. 1).

The platform approach concept is a design method for data processing that will enable researchers to have a standard and reliable solution for collecting, storing, analyzing, and sharing information and knowledge to improve the productivity and efficiency of digital farming solutions.

The platform structure includes the following blocks: data collection, data processing and quality monitoring, modeling and predictive analytics, crop cultivation recommendations, DSS.

Data collection. The selection of representative features and the collection of data on their parameters are crucial for their intelligent analysis. Most often, various types of agricultural models use the features that reflect the agrometeorological resources of the area during the growing season or year, soil characteristics, crop conditions at different stages of plant growth, and the management actions applied to crops.

The “agrometeorological resource” feature group contains weather information collected using field weather stations and includes data on air and soil temperature, air and soil humidity, wind speed and direction, precipitation amount, and temperature fluctuations. Weather data can also be used from various sources, such as digital global databases of meteorological parameters. An example is the online resource "Weather and Climate" (http://www.pogodaiklimat.ru), a Russian climate database containing a long-term weather archive from around the world.

The group of features “soil” includes the following variables: soil type and structure of the soil cover, occurrence in relief, location as a geographic object, pH value, nutrients (nitrogen, phosphorus, potassium, magnesium, sulfur, zinc, boron, calcium, manganese), soil moisture, structural state, etc. Soil information is obtained by digitizing paper soil maps, using remote sensing data from satellites and UAVs, and using agrochemical surveys or sensor systems. Validation of these variables is achieved through agrochemical and agrophysical laboratory analysis.

The "crop condition" feature group contains information about the crop: biomass, growth during cultivation, stand density, projective cover, and other parameters, determined through field surveys and vegetation indices (VI). The NDVI is commonly used, calculated based on the two most stable (independent of other factors) sections of the vegetation's spectral reflectance curve. In the red region of the spectrum (0.6–0.7 μm) lies the maximum absorption of solar

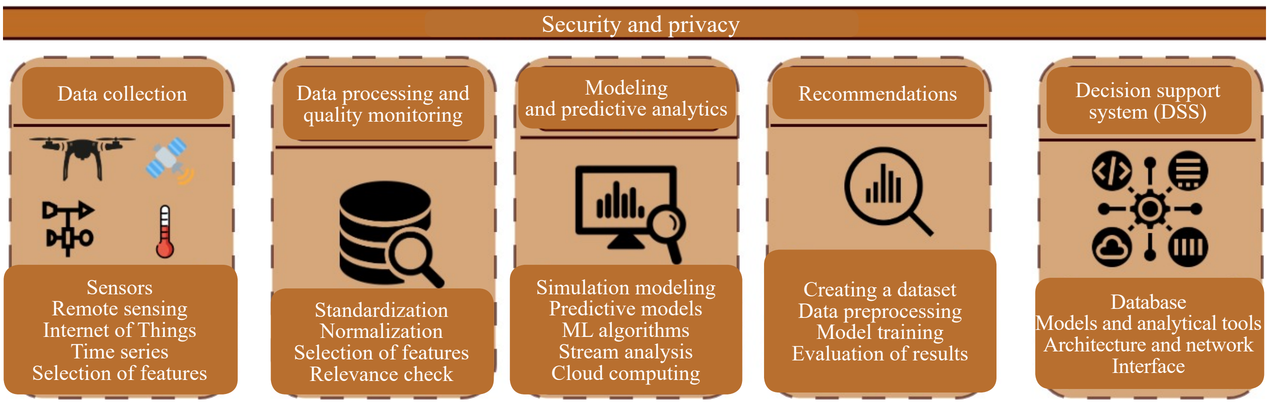

Рис. 1. Структура платформы мониторинга и анализа данных для разработки основ цифрового земледелия в СФНЦА РАН

Fig. 1. The structure of the data monitoring and analysis platform for developing the foundations of digital agriculture at the SFSCA RAS

radiation by plant chlorophyll, and in the infrared region (0.7–1.0 μm) lies the region of maximum reflection of leaf cellular structures. The relationship between these indicators allows for a clear distinction between vegetation and other natural objects and analysis of its condition. This group also includes other VIs that indicate crop health, such as leaf area index, nitrogen status of plants, and the development of diseases and pests.

In the group of features "control actions" the data on crop yields (time series) obtained in the field experiments are used, as well as data on the phytosanitary and agrochemical condition of the soil and crops, crop rotation over time on the site, the use of fertilizers and plant protection products (pesticides), soil cultivation methods, sowing dates and parameters of other agrotechnical indicators.

Data processing and quality monitoring. The data collected from various sources is typically presented in different formats, which are incompatible for storage in a single database. Furthermore, some of this data may contain incomplete data, missing values, outliers, and outliers. To address these issues, various preprocessing methods must be used during the data preparation stage. These methods include standardizing data according to a specified format, identifying and removing duplicate data, eliminating gaps in generated data, and validating data sources and content. These methods help ensure data consistency, completeness, and accuracy.

The key goal of data processing and monitoring is to achieve balance to reduce class bias, perform data transformations, and remove irrelevant features. Various feature selection methods have been developed, such as filter-based feature selection and wrapper-based feature selection [24]. In predictive analytics, features and their variables are also evaluated using various statistical criteria, such as information gain assessment, information gain coefficient, Gini coefficient reduction, variance analysis, χ-square, Relief F algorithm (an algorithm for selecting features of rank importance), principal component analysis, etc.

Furthermore, data quality assurance is also an important task. A large number of tools have been developed for this purpose. For example, in [25], the authors identified 667 such software tools. For a detailed study, the authors selected 13 tools (8 commercial and 5 open source) that provide functions such as data profiling, data quality assessment using metrics, and automated data quality monitoring. Based on their analysis, they found that these tools are widely used in research, but none of them fully implement the functions listed above. Therefore, it can be concluded that data quality monitoring tasks in global data science are still underdeveloped.

Modeling and predictive analytics. Modeling is the study of natural objects using their models. This involves constructing and studying models of real-life objects and phenomena (living and nonliving systems, various processes—physical, chemical, biological, social), studying constructed objects and systems to determine and refine their characteristics, rationalize their creation methods, etc. There are several types of modeling:

– subject: the model reproduces the geometric, physical, dynamic or functional characteristics of the object;

– analog: the model and the original are described by a single mathematical relationship;

– symbolic: diagrams, drawings, and formulas act as models;

– model experiment: it is not the object that is being studied, but its model.

In digital agriculture, modeling is a fundamental paradigm. Modeling technology is a comprehensive method for predicting possible outcomes or assessing the consequences of decisions by creating computer models of complex systems and simulating their behavior, as well as the processes of possible changes in the systems.

In recent years, simulation modeling has become widespread as the most promising direction [26]. Approaches to the development of simulation models of systems can be divided into the following groups:

– programming the model using universal languages, such as Java, JavaScript, Python, C++, C#, R, etc. The dynamics of the system are described by equations that are coded into the program, then the equations are calculated and the relationship between the output values and the input values is established;

– creating a model using specialized modeling languages, such as GPSS, SIMULA, SIMSCRIPT, MIMIC, CSMP/360, etc. The dynamics of the system are reflected by the interaction of the model elements in time and space;

– conducting simulation experiments using specialized software products, such as Aimsun, AnyLogic, Arena, AutoMod, GPSS World, VisSim, MvStudium, etc. The simulation environment provides the ability to visualize the simulation process, allows for scenario analysis, and the search for optimal solutions;

– integrating of simulation tools into standard mathematical computer systems, such as the Simulink package, Matlab, Mathcad, and Mathematica. These software environments provide tools for working with formulas, numbers, graphs, and text, as well as for managing variables and data input and output.

Various CASE (Computer-Aided Software Engineering) tools are also used for business process modeling, database design, code generation, and documentation. These tools are a set of software tools that automate software development and maintenance processes [27].

In predictive analytics, there are currently two main approaches used to forecast crop yields, as well as other objects and processes. The first approach uses mathematical models called process models or crop growth models (mechanistic models). These models can be used to represent a variety of interactions between plant physiological processes and the environment to assess biomass production potential and provide an abstract understanding of the dynamic behavior of physiological stages of plant development. Despite their effectiveness, such models are typically too expensive and labor-intensive, making them impractical for large-scale applications in agriculture.

The second approach uses data-driven models. This approach, sometimes called empirical, is comparatively easier to use than crop growth models. It considers crop yield data over several years, obtained through field experiments or remote sensing. Based on these data, a set of traits most likely to influence yield is identified. Taking these effective traits as independent and yield as the dependent variable, various forecasting modeling options are applied. These methods are relatively less expensive and easier to implement, and they require no prior information on the various physiological processes involved in plant growth.

Currently, the second approach utilizes various machine learning (ML) algorithms, a subfield of artificial intelligence. ML is a scientific technology that enables computers to learn and improve, either independently or with minimal human intervention, by processing data obtained through interaction with the real world. It incorporates adaptive mechanisms that enable learning from examples and experience and demonstrates the ability to automate the construction of analytical models.

Predictive analytics is performed by two types of models: machine learning (ML) models and deep learning (DL) models. ML models typically use the following algorithms: Decision Trees – DT), Support Vector Machines – SVM, Markov chain correlation – MCC, K-Nearest Neighbors – KNN), Random Forest – RF, Naive Bayes classifier – NB, Gradient Boosting – GB, Adaptive Boosting – AdaBoost, eXtreme Gradient Boosting – XGBoost, Artificial Neural Network – ANN, Regression Models – RM, etc. DL models use Convolutional Neural Network

– CNN, Recurrent Neural Network – RNN, Deep Neural Networks – DNN, Spiking Neural Network – SNN, Long-Short Term Memory – LSTM, etc. [28].

Recommendations for growing crops. Crop recommendation can be generated using ML-based modeling and consists of four steps: dataset creation, data preprocessing, model training, and result evaluation.

The sequence of operations when creating a model are:

– data collection: current data on weather conditions, soil properties, vegetation indices, management effects, and historical crop yield data are used; cleaning: all errors and noise in the data are removed, and categorical data are converted to numerical form; normalization: the data is scaled so that all characteristics contribute equally to the model;

– feature selection and extraction: the most important (relevant) features of the data are identified to aid in forecasting, and new features can be created based on existing data;

– splitting data into training and test sets;

– training the model using ML algorithms (e.g. RF or XGBoost);

– evaluation of the performance indicators of the forecasting model (for example, RMSE, MAE, R^2, F1-Score, etc.);

– retraining test using performance evaluation parameters on the test dataset.

Determining the best model for predicting crop yields using ML with an appropriate set of features and characteristics of their parameters provides the opportunity to develop specific recommendations for crop cultivation.

Decision support systems (DSS). The decision support system consists of four main components [29]: a database, a model and analytical tools, a DSS architecture and network, and a user interface (see Fig. 2).

A DSS database is a collection of current and historical structured data from multiple sources, organized for easy access and analysis. This data component can be expanded to include knowledge in the form of rules. Large databases in DSS are often referred to as data warehouses. DSS typically utilizes data extracted from all relevant internal and external databases. Information management often refers to database management. Management decision support refers to the use of computerized tools to make sense of structured data or documents in a database.

In model-based DSS, mathematical and analytical models are the core component. Such DSSs have a specific set of goals, so selecting the appropriate models is a key design issue. Furthermore, the software used to create these models must manage the required data and user interface. In model-based DSS, the values of key variables or parameters are repeatedly modified to reflect potential changes in monitoring data. This requires continuous model updating. Knowledge-based DSS uses specialized models, such as ML methods, to process rules or identify relationships in data.

The DSS architecture and network define how the hardware and software are organized, how data is distributed within the system, and how the system components are integrated and connected. The DSS, if not for internal use, should be accessible via a web browser on the internet via mobile devices. It's important to consider not only technical issues, but also security concerns related to DSS architecture, networks, and the Internet. Network technologies and modern, accessible network platforms can become key drivers of DSS.

The user interface is the most important component. Tools for creating it are sometimes called DSS generators. Much of the design and development effort for a DSS should be focused on creating the user interface. With the massive growth of mobile devices, DSS user interfaces must be adaptable to search for input and deliver results on traditional computer screens as well as on a variety of mobile devices. In some cases, this device support may even extend to wearable devices.

To implement a platform approach to building intelligent systems, two subtypes of platforms are typically used: data storage and management, and data analytics. A data storage and management platform is integrated software and hardware for collecting, prioritizing, and managing data, while a data analytics platform is a platform used to perform data analysis to extract valuable information.

The most common platform for storing data is the Hadoop distributed file system (HDFS), but Amazon, Web Services, Google Cloud, PostGIS, and others are also used. The following databases are also used: MySQL, PostgreSQL, Google Cloud, Microsoft Access, Microsoft SQL, ArcGIS, and others.

Streaming data analysis platforms include Apache Kafka, Apache Spark, Apache Flink, Apache Storm, Amazon Web Services (AWS), Google Cloud, QGIS, and others.

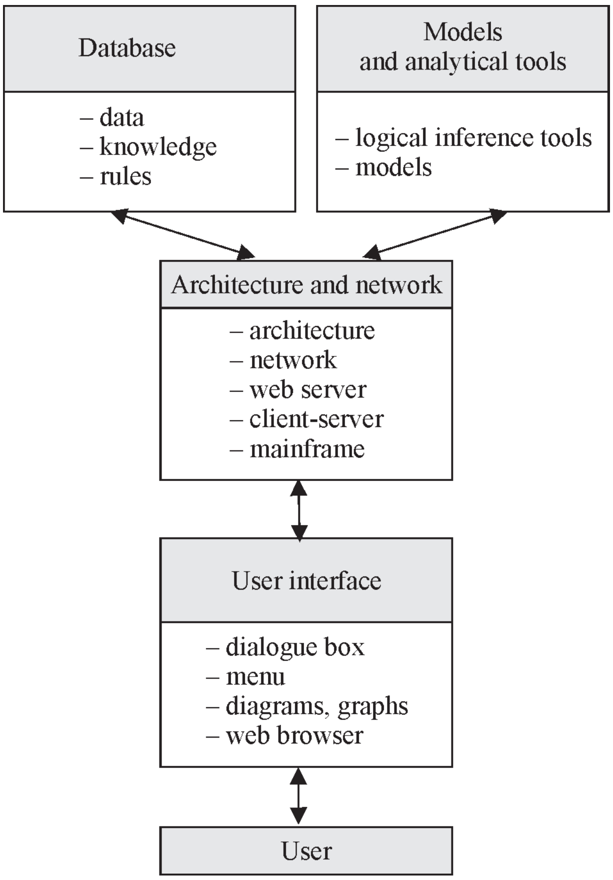

Рис. 2. Общая структура системы поддержки принятия решений

Fig. 2. General structure of the decision support system

The most widely used software is WEKA (Waikato Environment for Knowledge Analysis), which specializes in data mining tasks. ArcGIS, Orion Context Broker (OCB), MATLAB, and Pix4Dmapper are also used. These programs typically include a set of visualization tools and algorithms for data analysis and predictive modeling, as well as graphical user interfaces for easy access to these functions.

The goal of data analysis is to solve problems based on the data collected and the stated objectives. For example, classification indicates whether something will happen, while regression predicts the likelihood of something happening. Multiclass classification is typically the most common data analysis task. Other methods used include binary classification, anomaly detection, clustering, forecasting, and regression.

The following four types of data analysis are used in the Data Science system:

– *descriptive analytics* is applied to historical data to answer the question "what happened". Used to create reports, summaries and data visualizations, it allows you to identify key performance indicators of any activity, identify key trends and anomalies, and also provides the opportunity to get a clear understanding of previous events and trends;

– *diagnostic analytics* is performed by analyzing historical data and data structures to answer the question "why something happened." For example, data analysis may reveal that crop yield losses are related to weather conditions during the growing season, disease development, or violations of agricultural regulations. Additionally, cause-and-effect analysis can be used to understand which specific factors influence yield;

– *predictive analytics* is used to transform raw data into valuable information to make predictions about the future or gather information about unknown events and answer "what will happen" questions. An example would be creating a predictive model for weed growth in agricultural crops based on spring weather, precursor crops, and the use of agrochemicals in agricultural technology;

– *prescriptive analytics* is used during system development to provide end users with forecasts and then suggest behavioral recommendations. This type of analytics helps answer the question "what to do." An example of this is a decision support system (DSS), which enables decision makers to determine, for example, a revenue-maximizing strategy.

The technical and technological support of the platform for creating intelligent systems consists of sensors, an Internet of Things platform, wireless communication technologies, Internet of Things protocols, a cloud platform [30–33], as well as Earth remote sensing (ERS) data.

Sensors play a vital role in monitoring systems, as they act as converters between real-world signals and their digital representations. Various classes of sensors are used, including location and orientation sensors; optical sensors, which measure soil and plant properties in various wavelength ranges; electrochemical sensors, which provide information on soil pH and nutrient content; mechanical sensors, which provide information on soil compaction; dielectric/electromagnetic soil moisture sensors; airflow sensors, which measure soil permeability; photosynthetically active radiation (PAR) sensors, etc. Weather and environmental sensors provide real-time weather data, including temperature, humidity, wind speed, and precipitation. These sensors also measure environmental parameters such as atmospheric pressure and solar radiation. They are essential for forecasting and managing weather-related risks.

Low power consumption, compatibility of data transmission between the microcontroller and the sensor, accuracy, repeatability, sensitivity and reliability are the main factors when choosing a sensor for use in a monitoring system [34].

The Internet of Things is being developed using multi-tier architectures capable of connecting an unlimited number of devices with each other and with existing services. The basic IoT model has a three-tier architecture consisting of the sensing, network, and application layers. IoT sensor platforms consist of a sensor node, including sensors, a power source, energy storage devices, actuators, a main control board or data processing unit, and structural components. These structural components determine the placement of the sensor node in the field. There are two main types of IoT platforms available for environmental monitoring. Stationary platforms can collect continuous telemetry data related to a single plant or an entire crop within a field. The main advantage of stationary IoT is the high temporal resolution of the data. Mobile IoT platforms can collect data over a specific area and with high spatial resolution, but with limited temporal resolution.

Selecting an IoT platform and main control board is a crucial step in system design. The motherboard must support the communication protocols and power requirements (e.g., voltage) of the sensors and actuators. Voltage converters and communication protocol converters are often required to interface the sensors with the main control board. Motherboards support various types of digital memory. Volatile memory stores instructions and data for the currently running program until power is applied and impacts system performance. Larger volatile memory is required for IoT nodes with large volumes of data generated by sensors such as RGB cameras or spectral sensors mounted on UAVs. Common IoT boards have integrated/supported radio modules. Low-power networks are of particular interest.

Wireless data transmission is a key function of the Internet of Things (IoT) system. To design a successful system, it is important to understand the factors that influence signal strength, interference, system design, bandwidth, and transmission range. The received power of a wireless data transmission under line-of-sight conditions in a signal-free zone depends on the transmitter power, the gain of the transmitter and receiver antennas, the distance between the transmitter and receiver, and the wavelength of the radio signal. LPWA technologies such as LoRa and NB-IoT, operating at 900 MHz, are recommended for applications where long-range communication and low power consumption are important. Bluetooth and Wi-Fi, operating at 2.4–5.0 GHz, are recommended for short-range data transmission and are characterized by high power consumption and susceptibility to interference.

IoT protocols are data transmission standards that enable communication between endpoints and services, with the Internet serving as the underlying network. IoT protocols are broadly divided into two main groups: data protocols and network protocols. Data protocols correspond to the application layer, while network protocols correspond to the perception layer of the IoT network. IoT network protocols include LoRaWAN, Wi-Fi, Zigbee, and Bluetooth.

The cloud is an integral part of any IoT system. Data collected by individual sensors becomes more useful when connected to other relevant sensors. Cloud services provided to users are divided into three main classes based on the services offered: infrastructure as a service (IaaS), platform as a service (PaaS), and software as a service (SaaS). A typical cloud architecture has nine layers: network, storage, server, virtualization, operating system, middleware, runtime, data, and applications.

Currently, there are various remote sensing platforms, including satellite and unmanned aerial vehicles, that can be used to collect data with different spatial, temporal, and spectral resolutions [35]. The most appropriate resolutions depend on many factors, including the objectives of analysis and management, crops and their growth stages, field size, etc. For example, for crop emergence detection, it is better to use data with a high spatial resolution (< 0.1 m), while for yield assessment, data with a wider range of resolutions – 1–10 m – can be used. Multispectral imagery allows for assessing crop conditions that visible (RGB) images cannot detect, while thermal imagery is useful for detecting pest infestations, soil moisture, and water stress in plants. Unlike visible and infrared (IR)-based remote sensing, microwaves are less susceptible to atmospheric attenuation and can determine the biophysical properties of crops and soil under any day or night conditions. Remote sensing data is used in specific applications, such as assessing soil properties and moisture, forecasting crop yields, controlling diseases and pests, detecting weeds, etc.

The most important technology in the platform being developed should be the ability to process streaming data, which forms the logic of data operations and helps create computational and predictive models. Software for processing real-time data streams is typically developed in Event Processing Language (EPL). The processing engine provides high-level programming models with built-in functions for event filtering, correlation, and abstraction (e.g., Kafka, Flink, Storm, Samza). Stream processing performs computational operations such as averaging, pattern matching, event prediction, event filtering, correlation, and abstraction based on input data streams or a dataset. The insights gained from the analyzed data are used in user applications.

The Event Processing Language (EPL) is also used to define the templates and logic of forecasting models, specifying parameter thresholds, formulas, including temporal relationships, aggregation, index models, and event correlations. The classification of event templates used in the inference engine is as follows[1]:

[1]*Clemente P.J., Lozano-Tello A.* Model driven development applied to complex event processing for near real-time open data // Sensors. 2018. Vol. 18. N 12. P. 4125. DOI: 10.3390/s18124125.

– the selection pattern is used to detect a simple event;

– window data - to allocate windows in the data stream to limit the scope of action;

– time sequence of events – to indicate the time sequence of events;

– pattern combinations – to combine multiple patterns using logical operators (AND, OR, NOT, etc.) with time connectors (while or until).

For real-time streaming data analysis, it's advisable to use a platform such as Apache Kafka. This open-source, distributed streaming event processing engine (https://kafka.apache.org/) is available as an IaaS (infrastructure as a service) and is used to analyze data streams using filters, aggregations, and combining windowed data sets based on various predefined templates to generate predictive inferences. A stream processing engine processes sensor data streams or other data sets in real time, identifying patterns in incoming data and matching them against a pre-defined threshold for predictive analysis[2] [36, 37].

This platform processes and analyzes streaming data using Kafka-centric data pipelines, which reliably transfer data between disparate systems or applications using the Kafka Connect API. Kafka also uses KSQL, a streaming SQL engine for Kafka, allowing for persistent queries in real time without storing the data stream in a database.

Apache Kafka can run as a cluster on a local server or in a cloud environment, with each user connecting to the cluster via the Kafka Connector API and processing data using stream processors. The cluster stores streams of data records in categories called topics. Each record consists of a key, a value, and a timestamp. The Kafka stream processing engine consumes an input stream from available topics, producing an output stream for one or more output topics, effectively transforming input streams into output streams.

Apache Kafka's application in the context of environmental monitoring and management is as a centralized messaging system, facilitating messaging between disparate devices and systems. Stream processing of heterogeneous data is performed using the Kafka API. This decouples data from system dependencies, enabling seamless integration of existing data analysis systems with new ones and use with the Internet of Things platform.

It should be noted that the digital platform concept described in this paper is a complex of software platforms, i.e., extensible codebases that provide functionality supplemented by modular services. Each modular service is a software subsystem that can extend the functionality of the digital platform. These additions enable the use of standardized interfaces, such as application programming interfaces (APIs), to integrate new modules. The standardized integration process and modular architecture of software platforms minimize interdependencies between modules and facilitate the development of network externalities.

CONCLUSION

To implement the digital farming paradigm based on environmental monitoring using field experiment data obtained at the SFSCA RAS stations, it seems necessary to implement a platform approach currently being developed in Data Science.

The conceptual basis of the architecture of the platform for designing intelligent digital farming systems consists of five blocks: data collection, data processing and quality monitoring, modeling and predictive analytics, recommendations for crop cultivation, and DSS.

The platform approach is based on three core components that perform different functions: an infrastructure system is required to support the entire platform; a sensor and communication

[2]*Hiraman B.R., Viresh C.M., Abhijeet K.C.* A study of apache kafka in big data stream processing // International Conference on Information, Communication, Engineering and Technology (ICICET). IEEE. 2018. P. 1–3. DOI: 10.1109/ICICET.2018.8533771.

system is responsible for collecting and transmitting data; and a modeling component manages the data and facilitates decision making. These components interact with each other to ensure the platform's secure and reliable operation.

The technical and technological support for the platform approach is based on the use of sensors, an Internet of Things platform, wireless communication technologies and data transfer protocols, a cloud platform, and Earth remote sensing data. Platform layers include the data entering the platform, software for collecting and storing the data, and computational algorithms for building models. The technologies that power the platform include big data, machine learning, and cloud-based streaming computing, which enable processing of the data collected on the platform. Machine learning methods are used to generate recommendations and forecasts.

The development of a digital platform and the implementation of a platform-based approach at SFSCA RAS will facilitate the integration, processing, and use of data obtained through environmental monitoring technologies and field experiments. A platform-based approach and maintaining data relevance throughout the processing lifecycle can address various challenges not only in digital agriculture but also in other disciplines of agricultural science.

Given the large volume and complexity of data, computing technologies are increasingly required at all stages—from data collection to application development—to perform the tasks that exceed human capabilities. The integration of modern information technologies on a single platform aligns with the recommendations of world-class data science.

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Математическая модель сорбции паров воды почвами с линейным источником-стоком

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Рассмотрено обобщение математической модели сорбции паров воды почвами агроландшафта в случае нестационарного линейного источника-стока, присутствующего в почвенной системе. Проблема изучения динамики сорбционного процесса – объемной влажности почвы агроландшафта – формализована задачей с начальным условием для неоднородного уравнения Риккати с линейной правой частью, интегрирование которого не является тривиальной задачей. В отличие от классической модели М. Гризмера сорбции водяных паров почвами и рассмотренной ранее авторами сорбционной модели со стационарным источником введение в модель нестационарной функции источника-стока существенно усложнило задачу интегрирования уравнения модели и исследования сорбционной модели, потребовало привлечения методов аналитической теории дифференциальных уравнений, но увеличило многообразие режимов течения моделируемого процесса и расширило возможности управления этим процессом. Методами аналитической теории дифференциальных уравнений найдено решение модельной задачи, с помощью которого была произведена оценка динамики основного показателя сорбционного процесса – объемной влажности почвы. В результате математического анализа динамики процесса сорбции установлено, что все многообразие теоретически возможных режимов течения моделируемого сорбционного процесса формируется в зависимости от значений двух основных регулируемых параметров модели – коэффициента отношения постоянной начальной влажности к постоянной равновесной влажности и углового коэффициента линейной функции источника-стока. С помощью варьирования этих параметров появляется возможность управлять изучаемым процессом: моделировать сорбционный процесс в режиме интенсивного увлажнения почвы, в режиме критического иссушения почвы, в стационарном режиме и др. Результаты исследований могут быть применены для дальнейших исследований динамики влажности в профиле текстурно-дифференцированных мелиорируемых почв.

Ключевые слова: математическая модель, динамика сорбции паров воды почвами

Mathematical model of water vapor sorption by soils with a linear source- drainage

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The generalization of the mathematical model of water vapor sorption by soils of an agricultural landscape in the case of a non-stationary linear source- drainage present in the soil system is considered. The problem of studying the dynamics of the sorption process, the volumetric soil moisture of an agricultural landscape, is formalized by a problem with an initial condition for the inhomogeneous Riccati equation with a linear right-hand side, the integration of which is not a trivial task. In contrast to the classical model of M. Griesemer for the sorption of water vapor by soils and the sorption model with a stationary source previously considered by the authors, the introduction of a non-stationary source- drainage function into the model significantly complicated the task of integrating the model equation and studying the sorption model, required the use of methods from the analytical theory of differential equations, but increased the diversity of flow regimes of the modeled process and expanded the possibilities for controlling this process. Using methods of the analytical theory of differential equations, a solution to a model problem was found, with the help of which an assessment was made of the dynamics of the main indicator of the sorption process – the volumetric soil moisture. As a result of the mathematical analysis of the dynamics of the sorption process, it was established that the entire variety of theoretically possible flow regimes of the simulated sorption process is formed depending on the values of two main adjustable parameters of the model - the coefficient of the ratio of the constant initial humidity to the constant equilibrium humidity and the angular coefficient of the linear source-drainage function. By varying these parameters, it becomes possible to control the process being studied: to simulate the sorption process under conditions of intensive soil moisture, under conditions of critical soil drying, under steady-state conditions, etc. The research results can be applied to further studies of moisture dynamics in the profile of texture-differentiated reclaimed soils.

Keywords: mathematical model, dynamics of water vapor sorption by soils

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INTRODUCTION

The relevance of research into processes in the gas phase of the soil system for agricultural soil science and agroecology, both in connection with the assessment of soil fertility, the preservation of its physical fertility, and in connection with the implementation of the soil system's main ecological functions, including the global regulation of the gas regime of the planet's atmosphere and the environmental safety of agricultural production, has been substantiated by many researchers. This paper examines water vapor sorption processes in agricultural landscape soils and the impact of source-sink processes in the soil system on these processes. It continues a series of studies on modeling water vapor sorption processes in soils, previously conducted by the authors [1, 2].

Among modern works on the study of the sorption of soil gases and water vapor by soils, there are quite a lot of works on the study of factors influencing the water-holding capacity of soils (for example, the temperature factor, climate change) [3–5], on the relationship between the hydrothermal conditions of the soil and the characteristics of energy and mass exchange (including the processes of water vapor sorption) in the soil system [6–9], on the relationship between the adsorption of water vapor by soils and the carbon cycle [10, 11].

The purpose of the study is a mathematical representation of the processes of water vapor absorption by soils of agricultural landscapes and evaporation by the model that takes into account the factors influencing the water-holding capacity of soils by introducing a source-sink function into the model.

The objective of the study is to formalize the problem of studying the dynamics of the water vapor sorption process in the presence of a linear source-sink, solving a non-trivial differential equation of the formulated model and studying the influence of the source-sink function in the sorption model on the dynamics of volumetric moisture in the soil system.

MATERIAL AND METHODS

Previously [1, 2], we examined our own mathematical model of water vapor sorption by soils with a stationary source-sink, and provided the origin of the proposed model. The mathematical model of the sorption process was represented by a problem for an inhomogeneous nonlinear differential equation with a stationary free term. In this paper, we generalize the model of water vapor adsorption by the soil surface to the case of a non-stationary source-sink.

The problem of assessing the dynamics of water vapor sorption is formalized by the task

$$dw(t)/dt = kw(1-w/W) + f(t),\ w(0) = w_0, \quad (1)$$

where $w(t)$ – volumetric soil moisture at a given t time; W – constant equilibrium humidity (a systemic factor limiting the dynamics of volumetric humidity); k – model constant (adsorption rate parameter); w_0 – constant initial humidity; t – time; $f(t)$ – non-stationary source-sink function, free term of the equation (1). In contrast to the sorption model considered in [1, 2], in the proposed model the free term of the equation $f(t)$ is not a constant, but a linear function:

$$f(t) = W/k(at - k^2/4), \quad (2)$$

where coefficient a – source-sink parameter.

Changing the values of the parameter a (along with w_0) allows us to control the sorption process by changing its characteristics. In our opinion, this approach expands the possibilities for modeling water vapor sorption processes by soils.

We have found an analytical solution to problem (1), represented by sums of power series. A distinctive feature of the model under study is that equation (1) is a nonhomogeneous Riccati equation, which in general cannot be reduced to quadratures, and its integration is not a trivial task.

In this article, equation (1) is integrated using the power series method. To do this, we first replace the unknown function w(t) in equation (1)

$$w(t) = [W/kz(t)]dz(t)/dt,\ z(t) = u(t)\exp(k/2t) \quad (3)$$

problem (1) is reduced to the following problem with initial conditions

$$d^2u/dt^2 - atu(t) = 0,\ u(0) = 1,$$
$$du(0)/dt = k(w_0/W) = b. \quad (4)$$

The solution to problem (4) was found using the power series method in the form

$$u(t) = u_1(t) + btu_2(t), \quad (5)$$

where functions $u_1(t)$ and $u_2(t)$ are the sums of power series with common terms

$$a_n(t) = [\Gamma(n + 1/3)/\ \Gamma(1/3)][(3at^3)^n/(3n)!],$$

$$b_n(t) = [\Gamma(n + 2/3)/\ \Gamma(2/3)][(3at^3)^n/(3n + 1)!],$$

respectively $n = 0, 1, 2, \ldots$, $\Gamma(x)$ – gamma function (Euler integral of the second kind).

Substituting the solution u(t) of problem (4) found in (5) into formula (3), we find the solution w(t) of the original problem (1)

$$w(t) = W/2 + (W/ku)du/dt. \quad (6)$$

Formula (6) is the main analytical relationship for analyzing the dynamics of volumetric soil moisture $w(t)$.

RESULTS AND DISCUSSION

In this paper, we propose a generalization of the mathematical model of water vapor sorption by agricultural landscape soils, previously constructed in [1, 2], in the case of a non-stationary (linear) source-sink. The problem of studying the dynamics of the sorption process is formalized by problem (1) with an initial condition for the inhomogeneous Riccati equation with a linear right-hand side (2). Using methods of the analytical theory of differential equations, a solution to problem (1) was found, given by the main relation (6), with the help of which assessment of the dynamics of volumetric moisture content w(t) of the soil was made.

The dynamics of the function $w(t)$ are determined by the properties and behavior of the function $u(t)$, which is included in formula (6) and is the solution to equation (4). Differential equation (4) for $a = 1$ is called the Airy equation; it plays an important role in many applied problems in various sciences. The uniqueness of the Airy equation is that it has an inflection point $t = 0$ on the abscissa axis, at which the type of solution changes from oscillatory at $t < 0$ to exponential at $t > 0$. The graph of the solution $u(t)$ for $a = 1$ and $b = -0.383$ is shown in Fig. 1.

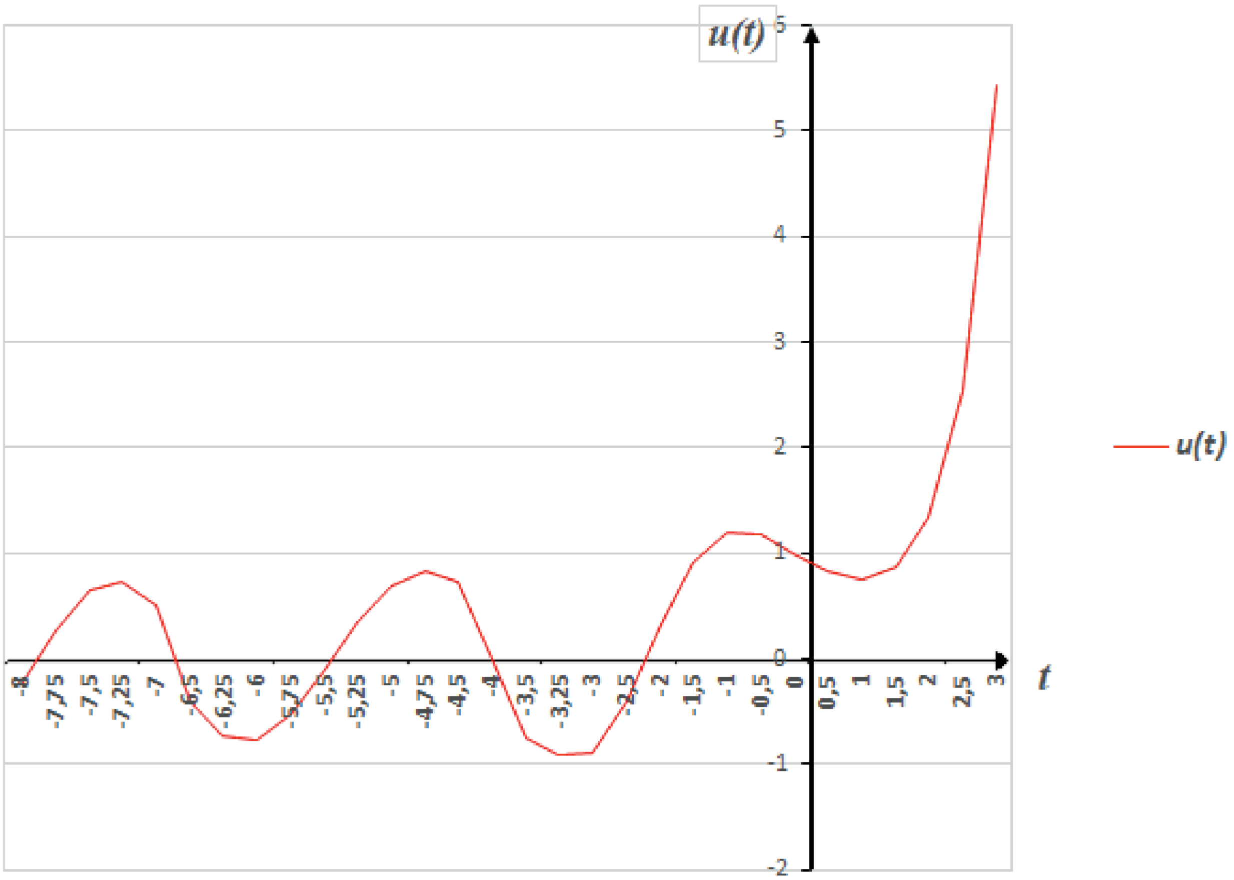

Рис. 1. График функции $u(t)$: $a = 1$; $b = –0,383$

Fig. 1. Function graph $u(t)$: $a = 1$; $b = –0\ 383$

The presence of two parameters a and b of the model in formula (6) significantly increases the diversity of the flow regimes of the simulated sorption process and complicates the study of the dynamics of volumetric soil moisture in the agricultural landscape. The coefficient a characterizes the angular coefficient of the source $f(t)$. The coefficient b in (4) depends on the relationship between w_0 and W, therefore it is convenient to write it in the form $b = k(r–1/2)$, $r = w_0/W$, r can vary in the range [0, 1].

Let us identify the nature of the monotony of the sorption process at the initial stage. Let us denote by $K(0) = dw(0)/dt$ the slope of the tangent to the graph of the function $w(t)$ at the point $t = 0$. As $K(0) = –kW(r–1/2)^2$, then for all r from the segment [0, 1] the values of $K(0)$ are contained in the range $[–kW/4;0]$; $K(0) < 0$ for all r except $r = 1/2$, at which it is equal to zero. In this regard, in the model under study, the onset of the sorption process is accompanied by a drop in the volumetric soil moisture $w(t)$ for any r, except $r = 1/2$.

The conducted analysis revealed from the whole variety of theoretically possible modes of the simulated sorption process several different modes depending on the values of the parameters a and r (i.e. from b).

At $r = 1/2$ (limiting case) the slope coefficient $K(0) = 0$; $b = 0$. The function $w(t)$ increases monotonically from the initial value quite quickly $w_0 = W/2$ to the limit $w(T) = W$, then the process is completed. This process takes place over a limited period of time $[0, T]$ in intensive soil moisture mode, T – its duration, and $f(t)$ acts as a source. Taking the values of the main parameters of water vapor adsorption from the kinetic experiments of M. Griesemer, described in [1], let's depict the sorption curve: $W = 0,2184$; $k = 1,02$. Graph of the function $w(t)$ (7) at $r = 1/2$

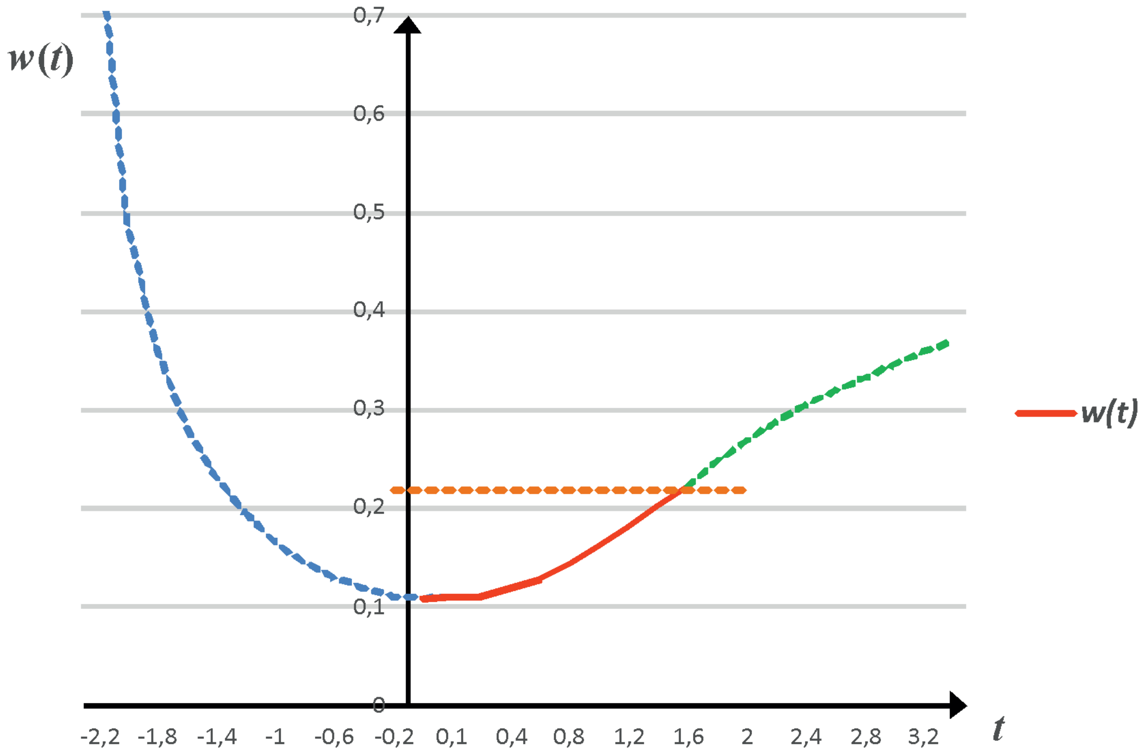

Рис. 2. График функции $w(t)$: $r = 1/2$ ($b = 0$); $a = 0,5$
Fig. 2. Function graph $w(t)$: $r = 1/2$ ($b = 0$); $a = 0,5$

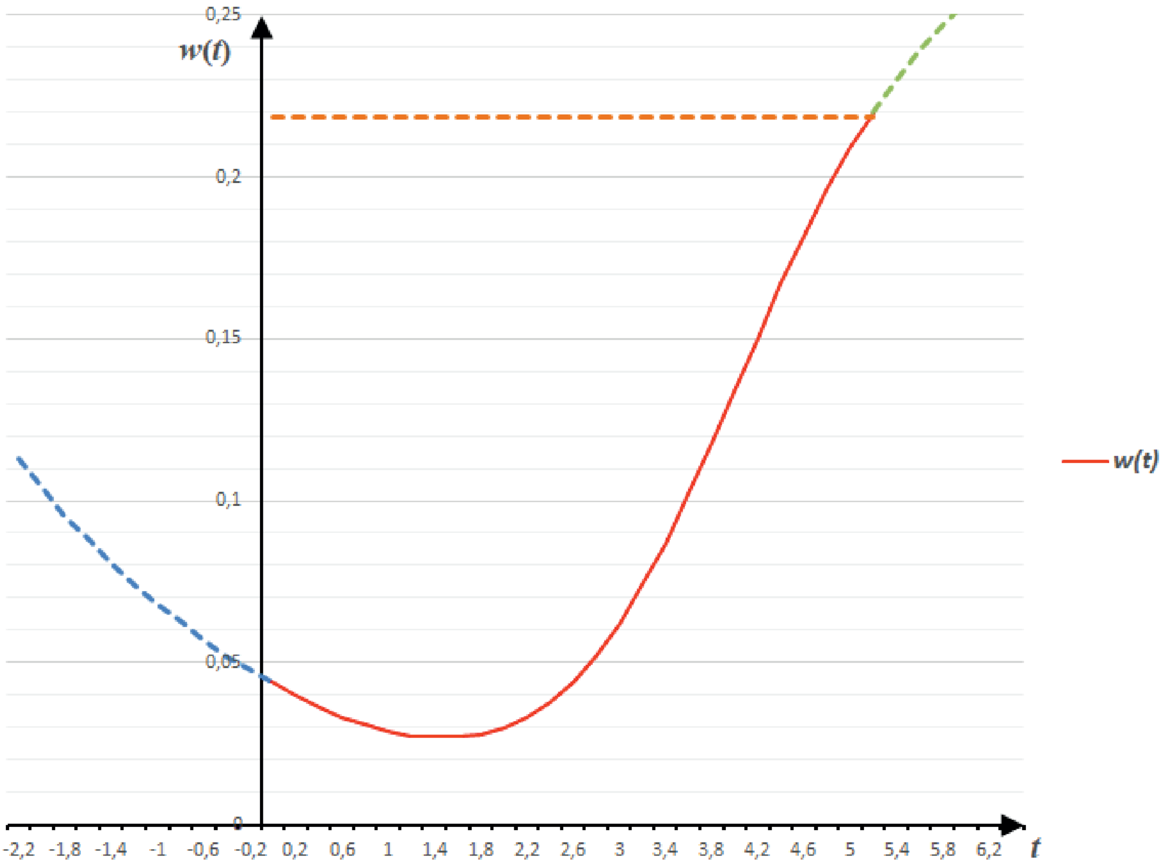

Рис. 3. График функции $w(t)$: $r = 0,2$ ($b = –0,306$); $a = 0,1$
Fig. 3. Function graph $w(t)$: $r = 0,2$ ($b = –0,306$); $a = 0,1$

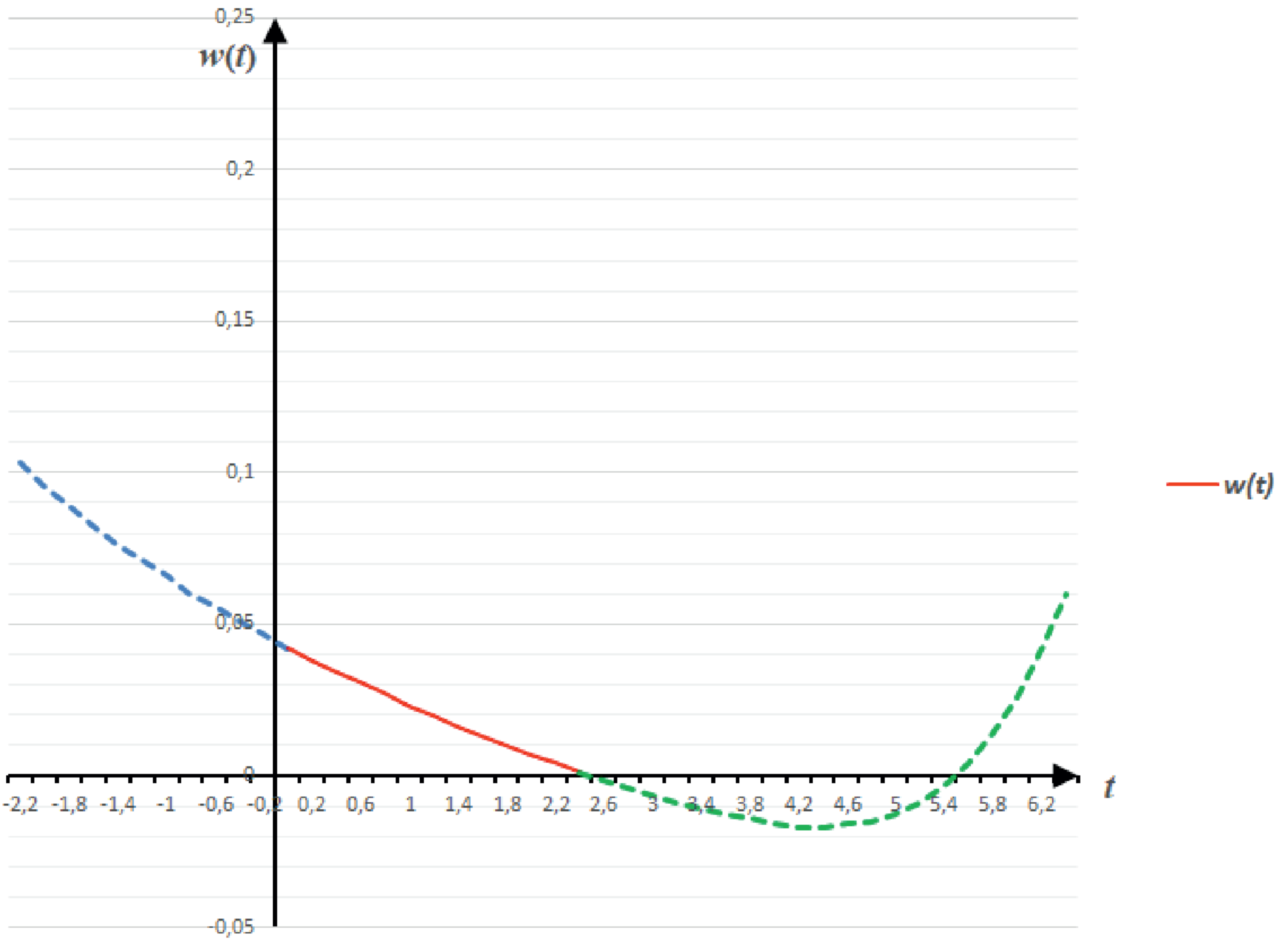

Рис. 4. График функции $w(t)$: $r = 0{,}194$ ($b = –0{,}312$); $a = 0{,}079$
Fig. 4. Function graph $w(t)$: $r = 0{,}194$ ($b = –0{,}312$); $a = 0{,}079$

($w_0 = W/2$, $b = 0$), $a = 0{,}5$ is shown in Fig. 2. The solid line shows part of the graph of the function *w(t)* on the interval [0, *T*], which is interpreted as a sorption curve. The dotted portions of the graph have no physical meaning in this model.

At $r \neq 1/2$ $K(0) < 0$, therefore, at the beginning of the process, the function *w(t)* decreases. There are several possible options for the development of the process:

– $w(t)$ has a positive minimum on the interval under consideration, so its values will initially fall monotonically from w_0 to this minimum, then rise monotonically to the value $w(T) = W$, then the process will be completed (see Fig. 3);

– the smallest value of the function *w(t)* over the time interval under consideration will be non-positive; the volumetric soil moisture *w(t)* will begin to decrease monotonically from the initial value w_0 to zero – $w(T) = 0$, after this, the process will be completed; a time-limited process of critical drying of the soil will occur, and the function *w(t)* plays the role of a sink; the sorption curve in this mode at $r = 0{,}194$ ($w_0 = 0{,}194W$, $b = –0{,}312$), $a = 0{,}079$ is shown in Fig. 4.

CONCLUSION

A generalization of the mathematical model of water vapor sorption by agricultural landscape soils for a non-stationary (linear) source-sink is proposed. Unlike M. Griesemer's classical model of water vapor sorption by soils and the previously considered sorption model with a stationary source, the introduction of a non-stationary source-sink function into the model significantly complicated the study of the sorption model but expanded the possibilities for controlling this process. The conducted analysis of the dynamics of volumetric soil moisture showed that the entire variety of theoretically possible flow regimes of the simulated sorption process is determined by the values of two main adjustable parameters - the coefficient of the ratio of the constant initial moisture content to the constant equilibrium moisture content and the angular coefficient of the linear source-sink function. Varying these parameters allows us to control the process being studied: to simulate the sorption process in the mode of intensive soil moistening, the mode of critical soil drying, the stationary mode, etc. The results of the conducted studies expand knowledge about the processes under consideration and can be applied for further studies of moisture dynamics in the profile of texture-differentiated reclaimed soils.

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Оценка влияния штаммов *Bradyrhizobium elkanii* на семена различных сельскохозяйственных культур

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В статье представлены результаты оценки влияния штаммов *Bradyrhizobium elkanii* (Kuykendall et al., 1992) из коллекции Федерального научного центра «Всероссийский научно-исследовательский институт сои» на семена сои, пшеницы, ячменя, люпина и вигны. Основной целью работы было выявление наиболее перспективных чистых культур ризобий для их дальнейшего применения при производстве биопрепаратов. В процессе исследования использованы штаммы Ву-4, Ву-5, Ву-6, Ву-9, Ву-10, Ву-11, Ву-25, Вр-1, ФЗ-28, выделенные из корневых клубеньков *Vigna unguiculata*, *V. radiate* и *V. angularis*, выращенных на луговой черноземовидной почве (Амурская область, Тамбовский муниципальный округ, с. Садовое). Также использован штамм Мд-0, выделенный из корневых клубеньков *V. unguiculata*, выращенной на дерново-луговой аллювиальной почве, полученной из Магаданской области. В ходе экспериментов установлено, что большинство изучаемых штаммов ризобий способствуют значительному улучшению прорастания семян и снижению уровня эпифитной микрофлоры. Энергия прорастания бактеризованных семян сои в среднем возросла на 15%, длина проростков – на 120% по сравнению с контролем. Похожие результаты получены для пшеницы (32 и 70% соответственно) и люпина (20 и 112%). Штаммы Мд-0 и Ву-25 способствовали увеличению темпов прорастания семян ячменя в 4 и 5 раз соответственно относительно контроля. При посеве семян по «газону» чистых культур *B. elkanii* микрофлора, находящаяся на семенах, либо не прорастала, либо проявлялась в виде единичных колоний. Тогда как в контрольных чашках Петри (без инокуляции) на 7-е сутки роста наблюдали высокую инфицированность нестерильных семян эпифитной микрофлорой. Полученные результаты подтверждают перспективность использования ризобий в агрономии для повышения продуктивности сельскохозяйственных культур и улучшения фитосанитарного состояния посевов.

Ключевые слова: *Bradyrhizobium elkanii*, штамм, сельскохозяйственные культуры, стимуляция прорастания семян, энергия прорастания, всхожесть, длина проростков, сырая масса проростков

Assessment of the effect of *Bradyrhizobium elkanii* strains on the seeds of various crops

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The article presents the results of the studies aimed at assessing the effect of *Bradyrhizobium elkanii* (Kuykendall et al., 1992) strains from the collection of the Federal Research Center "All-Russian Scientific Research Institute of Soybean" on the seeds of soybeans, wheat, barley, lupine and vigna. The main purpose of the work was to identify the most promising pure cultures of rhizobia for their further use in the production of biopreparations. The study used strains Vu-4, Vu-5, Vu-6, Vu-9, Vu-10, Vu-11, Vu-25, Vr-1, FZ-28, isolated from root nodules of *Vigna unguiculata*, *V. radiate* and *V. angularis* grown on the meadow chernozem-like soil (Amur region, Tambov municipal district, Sadovoe village). During the experiments, it was found that the studied rhizobium strains significantly contribute to improving seed germination and reducing the level of epiphytic microflora. The germination energy of bacterized soybean seeds increased by an average of 15%, and the length of the seedlings increased by 120% compared with the control. Similar results were obtained for wheat

(32 and 70%, respectively) and lupine (20 and 112%). Strains Md-0 and Vu-25 contributed to an increase in the rate of germination of barley seeds by 4 and 5 times, respectively, relative to the control. When sowing the seeds on a "lawn" of pure cultures of *B. elkanii*, the microflora on the seeds either did not germinate or appeared as single colonies. Whereas in control Petri dishes (without inoculation) on the 7th day of growth, high infection of non-sterile seeds with epiphytic microflora was observed. The obtained results confirm the potential of using rhizobia in agronomy to increase the productivity of agricultural crops and improve the phytosanitary condition of crops.

Keywords: *Bradyrhizobium elkanii*, strain, agricultural crops, seed germination stimulation, germination energy, germination, length of seedlings, wet weight of seedlings

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INTRODUCTION

The modern world faces growing demand for food, requiring researchers to develop innovative approaches to ensure sustainable food production. Agriculture currently faces significant risks of crop losses due to a number of global challenges, including soil degradation, climate change, and the increasing frequency and intensity of pathogen and pest attacks [1–3]. In these conditions, the methods aimed at increasing crop yields while reducing the negative impact of chemicals on the environment are particularly relevant. These methods include the use of biofertilizers, biopesticides, and the introduction of practices for returning plant residues to the soil, which contributes to improving its structure and maintaining ecosystem biodiversity[1] [4, 5].

Of particular interest in this context are soil microorganisms, which play a key role in maintaining soil fertility and stimulating plant growth. The ability of soil microorganisms to improve plant nutrition and enhance their resistance to stress and pathogens makes them an important research target for the development of environmentally friendly agricultural technologies[2] [6, 7].

One of the most promising areas is the study of rhizobia, which are capable of entering into symbiosis with legumes [8]. Rhizobia not only provide plants with available nitrogen through the process of nitrogen fixation, but also promote the solubilization of phosphates, the synthesis of phytohormones and vitamins, and increase plant resistance to pathogens by inducing systemic resistance [9–11].

However, for maximum effectiveness of rhizobial preparations, it is necessary to take into account the regional characteristics of soil microbial communities [12]. The Far Eastern region of Russia is a unique ecosystem where

[1]*Chestnova Yu.V.* Development of a new preparative form of biofertilizer based on rhizosphere bacteria // Applied biotechnology for the development of agriculture and industry: Proc. I Int. scientific-practical. conf. (Saratov, October 20, 2023), Saratov, 2024, pp. 88–92.

[2]*Krotikova Yu.S., Nikashova L.P.* The role of soil microorganisms in sustainable agriculture: research results // Innovative ideas of young researchers for the agro-industrial complex: collection of materials of the International scientific and practical conference of young scientists (Penza, March 27–28, 2025), Penza, 2025, pp. 320–323.

populations of soybean nodule bacteria are naturally distributed in the soils[3] [13]. Their formation is associated with the growth of wild Ussuri soybeans in this area, as well as with the active cultivation of cultivated soybeans[4]. Far Eastern natural populations of rhizobia are a valuable resource for the search for new competitive strains with high activity, which opens up broad prospects for the creation of effective inoculants.

Thus, the study of rhizobia and their interaction with legumes is an important step in the development of sustainable agriculture capable of responding to the negative challenges of our time.

The purpose of the study is to evaluate the effect of pure cultures of *Bradyrhizobium elkanii* on the seeds of soybeans, wheat, barley, lupine and cowpea, which will help in the future to identify the most promising strains for the development of biopreparations.

MATERIAL AND METHODS

The study was conducted in 2024 in the biological research laboratory of the Federal Scientific Center "All-Russian Research Institute of Soybeans". The objects of the study were collection pure cultures of *B. elkanii*, isolated from Far Eastern natural populations [14], as well as soybean seeds (*Glycine max* (L.) Merr.), wheat (*Triticum* L.), barley (*Hordeum* L.), lupine (*Lupinus* L.), cowpea (*Vigna angularis* (Willd.) Ohwi & H. Ohashi).

Laboratory microbiological experiments were performed four times in accordance with the generally accepted methods[5]. A mineral-plant nutrient medium (MPM) was used. All microbiological work was performed in a cabinet. 96% ethyl alcohol was used to sterilize surfaces and maintain the alcohol lamp. The study of the possibility of stimulating germination and disinfection of soybean seeds and other leguminous crops using pure cultures of soybean rhizobia was carried out according to the methods proposed by the All-Russian Research Institute of Agricultural Microbiology, as modified by S.A. Begoun[6]. The studied variants were replicated four times. Seedling length, germination, and seed germination energy were measured in accordance with GOST 12038–84[7]. The B vitamin content of rhizobia bacteria was determined by chemiluminescent immunoassay using paramagnetic particles and an Access2 automated immunoassay analyzer (Beckman Coulter, USA). Statistical data processing was performed using analysis of variance (ANOVA) in Microsoft Excel (Microsoft Corporation, USA).

RESULTS AND DISCUSSION

Experiments were conducted to examine the possibility of stimulating germination and disinfection of soybean, lupine, cowpea, wheat, and barley seeds using pure cultures of soybean rhizobia. The following *B. elkanii* strains were used: By-4, By-5, By-6, By-9, By-10, By-11, By-25, Bp-1, FZ-28, Md-0. The first nine strains were isolated from the root nodules of different cowpea species grown in the Amur Region (Tambov Municipal District, Sadovoye village): By-4, By-5, By-25 – *V. unguiculata* (L.) Walp., variety к460; By-6, By-9, By-10, By-11 – *V. unguiculata* (L.) Walp., variety к463; Bp-1 – *V. radiate* (L.) R. Wilczek, variety к3096; FZ-28 – *V. angularis* (Willd.) Ohwi & H. Ohashi. Strain Md-0 was isolated from the root nodules of *V. unguiculata* (L.) Walp. (variety K460), grown in the soil obtained from

[3] *He Y., Yu Q.* The influence of mordants and inoculants on the development of soybean diseases in the conditions of the southern zone of the Amur region // Youth Bulletin of the Far Eastern Agrarian Science: collection of student research papers / ed. E.B. Zakharova. Blagoveshchensk, 2023, Issue 8, pp. 66–71.

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[6] *Begoun S.A.* Methods and techniques for studying and selecting effective strains of soybean nodule bacteria. Methods of analytical selection: methodological recommendations. Blagoveshchensk, 2005, 70 p.

[7] GOST 12038–84. Seeds of agricultural crops. Methods for determining germination. Moscow: Standartinform, 2011, 32 p.

the Magadan Region (forecrop – everlasting pea, vegetation experiment, Magadan Research Institute of Agriculture). The seed harvest year for all crops is 2023.

The strains showed good and abundant growth of bacterial mass on MPM and the ability to produce B vitamins. The concentration of vitamin B_9 in the bacterial mass of the strains averaged 31.4 pg/ml, varying widely (8–51 pg/ml) (see Table 1). The highest levels of vitamin B_9 in the biomass (more than 40 pg/ml) were demonstrated by the strains By -6, By -10, Bp-1, and FZ-28. The amount of vitamin B_{12} was several orders of magnitude higher than the concentration of vitamin B_9, with greater variability in this indicator (C_v = 68,5%). The minimum content of vitamin

Табл. 1. Статистические значения концентрации витаминов B_9 и B_{12}, синтезируемых группой штаммов *B. elkanii*, пг/мл

Table 1. Statistical values of the concentration of vitamins B_9 and B_{12} synthesized by a group of *B. elkanii* strains, pg/ml

Indicator	Vitamin B_9	Vitamin B_{12}
$\overline{X}$	31,4	871,5
lim	8–51	310–2008
σ	14,8	566,6
C_v, %	47,2	68,5

Note .$\overline{X}$ – arithmetic mean; lim – limit of variation; σ – standard deviation; C_v – coefficient of variation.

B_{12} in the biomass (310 pg/ml) was noted in the By-4 strain, concentrations of more than 1000 pg/ml were recorded in the strains By-9, By-10, By-25, Md-0.

A consistent stimulating and healing effect was observed in the strain variants. In all control Petri dishes (without inoculation), high levels of epiphytic microflora infection of non-sterile agricultural seeds were observed on the seventh day of growth (see Fig. 1).

When sowing seeds on a “lawn” of pure cultures of *B. elkanii*, the microflora on the seeds did not germinate or appeared in the form of single colonies (see Table 2).

All studied *B. elkanii* strains had a stimulating effect on the seed germination process.

Placing seeds on a "lawn" of pure rhizobia cultures primarily stimulates their germination rate. On average, the germination energy of bacterized soybean seeds increased by 15% compared to the control, seedling length by 120%, wheat by 32% and 70%, and lupine by 20% and 112%, respectively. Significant variability in these parameters was observed (respectively *Cv* = 68,9 and 82,2%).

Strains Md-0 and By-25 allowed increasing the germination energy of barley seeds by 4 and 5 times, respectively. The seedling length in these variants increased by 0.5–0.6 times compared to the control. A positive effect of cowpea

а *б*

Without inoculation | Inoculation with a collective strain | Without inoculation | Inoculation with a collective strain

Рис. 1. Стимуляция прорастания семян сои сорта Алпетра (*а*) и пшеницы сорта Арюна (*б*)

Fig. 1. Stimulation of germination of soybean seeds of the Alpetra variety (*а*), and of wheat of the Aryuna variety (*б*)

Табл. 2. Исследуемые характеристики нестерильных семян при выращивании по «газону» чистых культур *B. elkanii* (7-е сутки)

Table 2. The studied characteristics of non-sterile seeds when grown on a "lawn" of pure cultures of *B. elkanii* (7th day)

Culture	Option	Seed germination		Length of sprouts		Raw mass of sprouts		Presence of microflora
		%	% to the control	cm	% to the control	g/10 plants	% to the control	
Soybeans, Alpetra variety	Control	100	100	3,30	100	4,19	100	+
	Rhizobia	93	93	4,16	126	4,36	104	–
Wheat, Aruna variety	Control	100	100	5,60	100	1,35	100	+
	Rhizobia	98	98	6,68	119	1,72	127	–
Barley, Amur variety	Control	90	100	3,80	100	1,47	100	+
	Rhizobia	100	111	5,22	137	1,80	123	–
Lupine, K408variety	Control	90	100	2,80	100	4,82	100	+
	Rhizobia	97	107	3,39	121	4,12	86	–
Cow pea	Control	60	100	1,20	100	2,26	100	+
	Rhizobia	61	102	1,78	148	2,48	110	–
C_v, %		68,9		82,2		17,3		
LSD_{05}		1,80		1,03		0,88		

Note. The LSD_{05} value was calculated separately for each culture based on the analysis of variance; the values are shown for the key comparisons (strain and control).

Табл. 3. Статистические значения всхожести и длины проростков нестерильных семян при выращивании по «газону» чистых культур *B. elkanii* (3-е сутки)

Table 3. Statistical values of germination and length of seedlings of non-sterile seeds when grown on a "lawn" of pure cultures of *B. elkanii* (3rd day)

Indicator	Seed germination, pcs.	Length of sprouts, cm
$\overline{X}$	4,45	0,60
lim	0–10,0	0–2,3
σ	3,07	0,49
C_v, %	68,9	82,2

Note. Here and in Table 4: the values are calculated based on the data for all crops to illustrate the general trend; LSD_{05} for each crop see Table 2.

seed bacterization was observed in the variants with strains By-5, By-9, By-10, By-11, By-25, FZ-28, Md-0 (see Table 3).

Seed germination of the studied crops in the control was high (100%). In the variants with bacterization, slight variability in this indicator was noted (C_v = 17,5%). Seed germination of barley, lupine, and cowpea exceeded the control by 11–33% in almost all experimental variants. The best seed germination rate for cowpea was recorded in the variant containing the Md-0 strain. In this variant, seed inoculation resulted in a 1.3-fold increase in germination relative to the control (see Table 4). In experiments with seeds of the Alpetra soybean variety and the Aruna wheat variety, the use of strains By-4, By-6, By-9, By-10, Bp-1 caused a 10% decrease in germination. This may be due to the species of rhizobia. On average, the germination rate of bacterized barley, lupine, and cowpea seeds increased by 14% compared to the control.

The rhizobia strains used in the study significantly stimulated an increase in the length of agricultural crop seedlings with an average variability in this indicator (C_v = 56,8%). Thus, inoculation of barley seeds with the By-4 strain

Табл. 4. Статистические значения всхожести, длины и сырой массы проростков нестерильных семян при выращивании по «газону» чистых культур *B. elkanii* (7-е сутки)

Table 4. Statistical values of germination, length and wet weight of seedlings of non-sterile seeds when grown on a "lawn" of pure cultures of *B. elkanii* (7th day)

Indicator	Seed germination, pcs.	Length of sprouts, cm	Raw mass of sprouts, g/10 plants
$\overline{X}$	9,0	4,2	2,9
lim	5,0–10,0	1,2–11,1	1,3–5,8
σ	1,60	2,40	1,24
C_v, %	17,5	56,8	43,2

contributed to an increase in the length of seedlings by 5% compared to the control. Strains By-10, By-25, Bp-1, Md-0 increased this indicator in all studied crops. The greatest length of seedlings was observed in the variants with inoculation of soybean (9.2 cm), wheat (11.1 cm), barley (9.2 cm) and cowpea (3.5 cm) seeds with the By-25 strain. When seeds were bacterized with the By-25 strain, the minimal increase in seedling length was observed in wheat (98%), while the maximal increase was observed in cowpea (192%). The greatest lupine seedling length (4.9 cm) was recorded in the variant bacterized with the Md-0 strain. Overall, in the variants using rhizobia, the seedling length of soybeans, wheat,

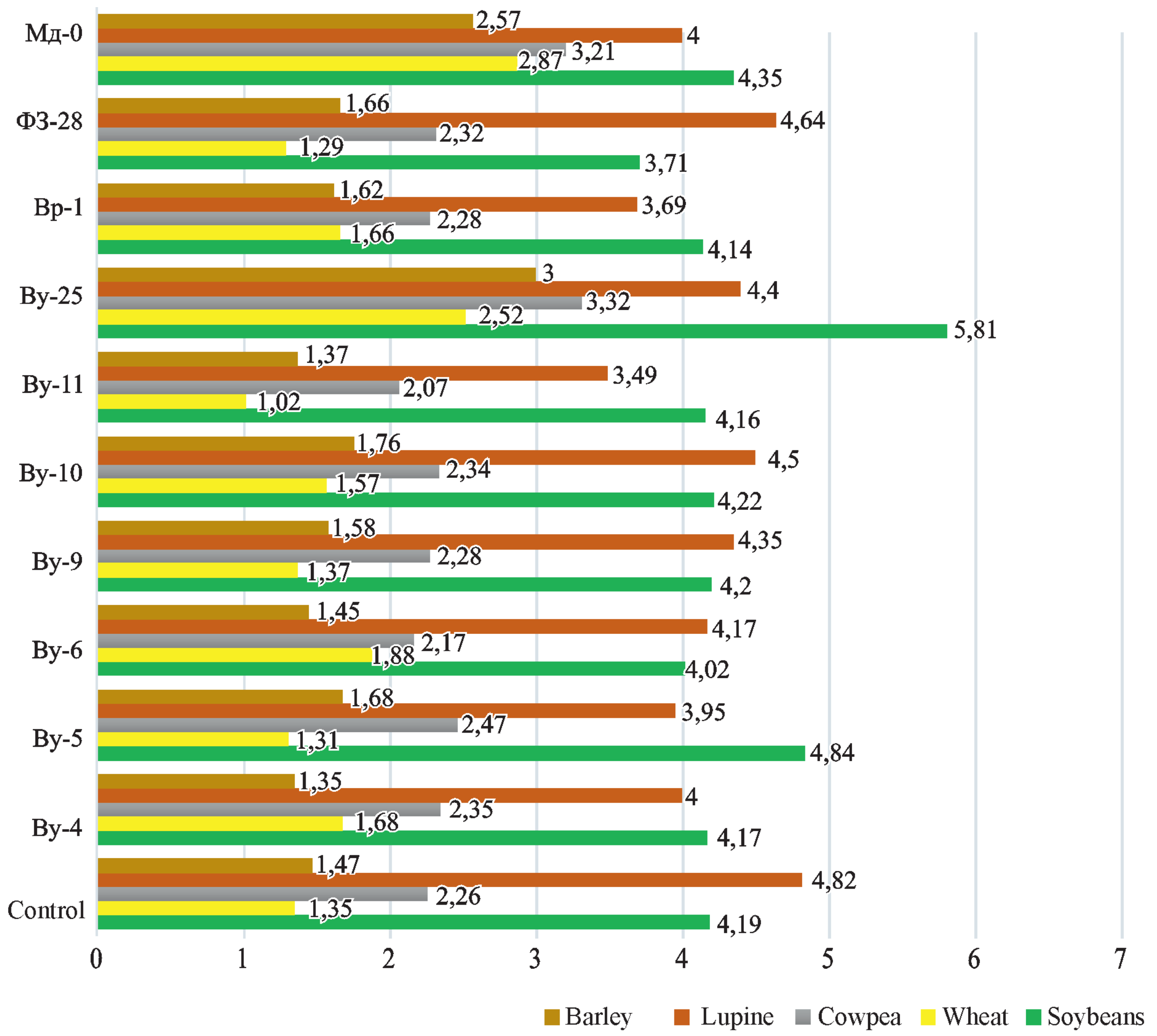

Рис. 2. Сырая масса проростков, г/10 раст.

Fig. 2. Wet weight of sprouts, g/10 plants

barley, lupines, and cowpeas increased by an average of 50%.

When non-sterile seeds of agricultural crops were placed on a "lawn" of pure *B. elkanii* cultures, the wet weight of the seedlings increased (see Fig. 2). The best results were observed in variants with bacterization of Alpetra soybean seeds with strains By-5 and By-25, wheat variety Aruna with strains By-4, By-6, By-25, Md-0, barley variety Amur with strains By-10, By-25, Md-0, cowpea with strains By-25 and Md-0.

In the above-mentioned variants, the fresh weight of soybean seedlings exceeded the control by 16–39%, wheat by 24–113%, barley by 20–104%, and cowpea by 42–47%. *B. elkanii* strains did not affect the fresh weight of lupine seedlings, which remained at the control level. On average, in the treatments with seed bacterization, the fresh weight of soybean, wheat, barley, and cowpea seedlings increased by 29% compared to the control.

CONCLUSION

Thus, the study established the stimulating effect of rhizobia on agricultural crop seeds. The highest rates of seed germination were observed in the variants bacterizated with the following *B. elkanii* strains: By-5, By-10, By-11, By-25 for soybean, By-5, By-25, Md-0 for wheat, By-5, By-11, By-25, FZ-28, Md-0 for barley and lupine, By-25, Мд-0 for cowpea. High rates of cowpea seed germination were recorded using strains By-5, By-10, By-25 and Md-0. The length of soybean and wheat seedlings was maximum when using strains By-4, By-6, By-10, By-25, Md-0, barley and lupine – By-10, By-25, FZ-28, Md-0, cowpea – By-6, By-10, By-11, By-25, Bp-1, Md-0. The maximum fresh weight of cowpea sprouts was 3.32 g/10 plants (strain By-25), wheat – 2.87 (strain Md-0), soybeans – 5.81, and barley – 3.0 g/10 plants. The data obtained are statistically significant. Promising strains are recommended for use in the production of biopreparations.

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Продуктивность одновидовых многолетних трав под влиянием разных покровных культур и сроков посева в лесостепи Приобья

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В условиях лесостепи Приобья изучена продуктивность одновидовых многолетних трав под разными покровными культурами. В качестве покровных культур использованы ячмень и зерносмесь из пяти компонентов: овса, ячменя, пшеницы, гороха, вики. Норма высева ячменя 180 кг/га, зерносмеси – 250 кг/га. Перед посевом семена смешивали в следующей пропорции: овес – 100 кг, ячмень – 70, пшеница – 50, горох – 15, вика – 15 кг. После уборки зерносмесь, как и ячмень, применяли для заготовки зерносенажа. Густота стеблестоя зерносмеси, а также высота растений и продуктивность были выше по сравнению с ячменем. Следовательно, зерносмесь оказывала более угнетающее действие на многолетние травы в последующие 2 года. В дальнейшем разница по урожайности между многолетними травами под разными покровными культурами почти нивелировалась. Урожайность многолетних трав под ячменем в целом была выше, чем под зерносмесью. В среднем по опыту № 1 наибольшей урожайностью под ячменем отличалась люцерна (4,91 т/га абс. сух. в-ва), наименьшей – клевер (2,66 т/га). Под зерносмесью урожайность люцерны и клевера составила соответственно 4,19 и 2,16 т/га абс. сух. в-ва. Таким образом, злако-бобовая зерносмесь оказала угнетающее влияние на рост и развитие многолетних трав, но не решающее. Разница по урожайности многолетних трав в последующие годы под разными покровными культурами была несущественной. Поэтому посев зерносмеси как покровной культуры для многолетних трав предпочтительнее, так как ее урожайность в первый год посева оказалась значительно выше по сравнению с урожайностью ячменя. На основании изучения влияния весеннего и летнего сроков посева на продуктивность покровной культуры (ячменя) и многолетних трав в последующие годы (опыт № 2) можно утверждать, что урожайность покровной культуры весеннего срока посева выше по сравнению с посевом летом. Это объясняется более коротким периодом развития покровной культуры до сроков уборки по сравнению с посевом весной. Средняя продуктивность многолетних трав в течение последующих лет была незначительно выше при летнем сроке посева.

Ключевые слова: покровные культуры, многолетние травы, продуктивность, сроки посева

Productivity of single-species perennial grasses under the influence of different cover crops and sowing dates in the forest-steppe of the Ob region

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The productivity of single-species perennial grasses under different cover crops has been studied in the conditions of the forest-steppe of the Ob region. Barley and a grain mixture of five components were used as cover crops: oats, barley, wheat, peas, vetch. The rate of sowing of barley is 180 kg/ha, grain mixtures – 250 kg/ha. Before sowing, the seeds were mixed in the following proportions: oats –100 kg, barley – 70, wheat – 50, peas – 15, vetch – 15 kg. After harvesting, the grain mixture, like barley, was used for harvesting grain silage. The density of the grain mixture stem, as well as plant height and productivity were higher compared to barley. Consequently, the grain mixture had a more depressing effect on perennial grasses in the next 2 years. Later on, the difference in yield between perennial grasses under different cover crops was almost leveled. The yield of perennial grasses under barley was generally higher than under the grain mixture. On average, according to experiment No. 1, alfalfa had the highest yield under barley (4.91 t/ha abs. dry matter), the smallest was shown by clover (2.66 t/ha). Under the grain mix, the yields of alfalfa and clover were 4.19 and 2.16 t/ha abs. dry matter, respectively. Thus, the cereal-bean grain mixture had a depressing effect on the growth and development of perennial grasses, but not decisive. The difference in yields of perennial grasses in subsequent years under different cover crops was insignificant. Therefore, sowing a grain mixture as a cover crop for perennial grasses is preferable, since its yield in the first year of sowing turned out to be significantly higher than the yield of barley. Based on the study of the influence of spring and summer sowing periods on the productivity of the cover crop (barley) and perennial grasses in subsequent years (experiment No. 2), it should be argued that the yield of the cover crop of the spring sowing period is higher compared to summer sowing. This is due to the shorter period of development of the cover crop before harvesting compared to sowing in spring. The average productivity of perennial grasses over the following years was slightly higher during the summer sowing period.

Keywords: cover crops, perennial grasses, productivity, sowing dates

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INTRODUCTION

Perennial herbaceous plants are the most important forage crops. Perennial grasses can be used not only for hay, haylage, and silage, but also to form cultivated pasture communities. Perennial grasses play a significant role in combating wind and water erosion by forming a thick turf. They also help enrich the soil with organic matter. Forage grasses from the legume family enrich the soil with nitrogen.

Compared to annual forage crops, perennial grasses are much more economical to cultivate. It should be noted that perennial grasses are equally as good as annual forage crops in terms of feed quality. Perennial grasses are indispensable in creating green conveyors. Perennial grasses are also widely used to increase the forage productivity of arable land and to create cultivated pastures [1–3]. Currently, hayfields and pastures occupy almost 50% of the total agricultural land area[1]. Forages made from perennial grasses constitute the main share of forages in foreign countries[2].

Compared to annual forage crops, perennial grasses use photosynthetically active radiation (PAR) more efficiently: the former use PAR only from germination to harvest, the latter – throughout the entire warm period of the year[3].

Despite the extensive study of the issues of improving cultivation technology and the ongoing breeding work [1–12], the issues of comparative productivity of single-species perennial grasses, as well as the influence of different

[1]*Goncharov P.L., Goncharova A.V.* Breeding and seed production of grasses in Siberia // Siberian Herald of Agricultural Science, 2003, vol. 33, N 3, pp. 23–24.

[2]*Humpkreys M., Amstead J., Thorogood D., Turner L.* Mapping out the future for grasses // IGER Junov, 2002, N 6, pp. 12–15.

[3]*Kolomeichenko V.V.* More attention to hayfields and pastures // Kormoproizvodstvo, 2012, N 4, pp. 3–6.

cover crops on their productivity in subsequent years, remain unexplored.

In Siberia, grain mixtures used as cover crops are also widely used for grain silage. The grain mixture is harvested relatively early—in the second half of August. After harvesting, perennial grasses thrive and accumulate nutrients for overwintering[4].

The objectives of the study are to examine the productivity of cover crops and common single-species perennial grasses (galega, clover, alfalfa, timothy, brome) during subsequent years of development after harvesting cover crops, as well as to determine the productivity of perennial grasses (alfalfa, clover, brome) under the cover of barley during spring and summer sowing periods.

MATERIAL AND METHODS

The first set-up of Experiment No. 1 was conducted in early June 2007, and a repeat set-up was conducted in late May 2008 at the Novosibirsk State Agrarian University's training farm. The experiment examined the structural parameters of the grass stand and the productivity of single-species perennial grasses (factor A) and cover crops (factor B).

The training farm's agricultural lands are located in the forest-steppe of Western Siberia. The soils are leached chernozem. The humus content of the topsoil of the experimental plot is 3.5%, and the exchangeable potassium and phosphorus levels are high and very high. Mineral fertilizers were applied to the experimental plot annually during spring harrowing. The fertilizer rate is calculated for a hay yield of 6 tons/ha ($N_{30}P_{30}K_{50}$)[5]. The area of the experimental plot is 20 m^2. The placement of experimental and control plots was randomized. The row spacing for perennial grasses is 30 cm.

Before sowing, the seeds were mixed in the following proportions: oats – 100 kg, barley – 70, wheat – 50, peas – 15, vetch – 15 kg. When sowing, the seeding rates for barley and grain mixture (180 and 250 kg/ha, respectively) were reduced by 20%[6]. All varieties are released for the region. The methods for setting up the experiment and statistically processing the obtained data are generally accepted[7].

In 2017 and again in 2018, Experiment #2 was conducted to study the effect of sowing timing (factor B) on the structural parameters of the grass stand and the productivity of the cover crop and perennial grasses (factor A). Spring sowing was carried out on May 28, and summer sowing was carried out on July 28. Barley (the cover crop) and the following perennial grasses were used in the experiment: alfalfa, clover, and brome. These perennial grasses and the cover crop were identified as the most promising for further research. The experimental methodology, plot area, fertilizers, and grass varieties were the same as in the previous experiment.

RESULTS AND DISCUSSION

Weather conditions varied during the study years. The 2007 growing season was rainy and warm, allowing for a relatively high cover crop yield and laying the foundation for perennial grass production in subsequent growing seasons. In 2008, June was warm and wet, although the rest of the season was dry. The 2009–2012 growing seasons could be characterized as dry. The next experiment was established in 2017.

[4]*Pershilin K.G.* Adaptive intensification of forage production in the forest-steppe of Western Siberia: Doctor's thesis in Agriculture, Novosibirsk, 2000, 54 p.

[5]*Benz V.A., Volkova L.D., Khromov A.Ya. et al.* Parameters and methods for calculating the levels of planned yields of forage crops. Novosibirsk, 1985, 70 p.

[6]Agricultural technologies for feed production in Siberia: practical manual, Novosibirsk, 2013. 246 p.

[7]*Dospekhov B.A.* Methodology of field experiment (with the basics of statistical processing of the research results). Moscow: Alliance, 2014, 386 p.

The work continued until 2020. Throughout the study period, the weather was favorable for grass growth and development.

In the year of the establishment of Experiment No. 1, only plants of barley cultivated as a cover crop and a grain mixture of five components were observed.

It is known that the structural parameters of the grass stand to some extent determine its yield.

Thus, the barley stand density as a cover crop for the different perennial grasses varied only slightly (see Table 1). This is understandable, as the sowing was carried out at the same seeding rate as a continuous background. The lowest barley stand density (205 pcs/m^2) was observed in the plot where galega was the cover crop, and the highest was in the plot where brome was the cover crop (228 pcs/m^2). The height of the barley plants varied from 63 to 69 cm, which is not a significant difference.

In the grain mixture, the density of cereal grasses was 276–293 pcs/m^2, height – 70–75 cm. The density of leguminous grasses reached 29–48 pcs/m^2, height – 37–46 cm (see Table 1).

Thus, together with the cereal grasses, the shoot density in the grain mixture was over 300 shoots/m², which is significantly higher than the barley stem density. This explains the higher yield of the grain mixture. The aboveground barley yield was 1.86 t/ha of absolute dry matter, and the grain mixture yield was 3.74 t/ha (see Table 2). Compared to the grain mixture, barley's dry matter yield is 2.0 times lower, its feed yield is 1.5 times lower, and its metabolizable energy yield is more than 2.0 times lower. This may explain the preference of the grain legume mixture as a cover crop over barley.

In Experiment No. 1, among perennial grasses, alfalfa had the highest stem density: under the barley cover, it reached 225 stems/m^2 (see Table 3). This high stem density created a fairly competitive environment for weed growth. As a

Табл. 1. Структурные показатели травостоя покровных культур в вариантах с разными многолетними травами (среднее по опыту, 2007 и 2008 гг.)

Table 1. Structural indicators of cover crop grass stand in the variants with different perennial grasses (average for the experiment, 2007 and 2008)

Perennial herbs	Barley		Grain mixture			
			Cereal crops		Legumes	
	Stem density, pcs./m^2	Plant height, cm	Stem density, pcs./m^2	Plant height, cm	Stem density, pcs./m^2	Plant height, cm
Galega	205 ± 9,0	67 ± 9,0	284 ± 6,5	75 ± 3,0	29 ± 9,0	44 ± 4,0
Clover	212 ± 9,0	69 ± 3,0	290 ± 4,5	70 ± 2,0	33 ± 8,6	37 ± 2,0
Alfalfa	213 ± 5,0	67 ± 1,5	293 ± 52,5	73 ± 1,0	30 ± 5,0	46 ± 3,5
Timothy grass	218 ± 3,0	63 ± 2,5	282 ± 18,5	70 ± 2,5	34 ± 3,0	38 ± 1,2
Brome	228 ± 4,0	66 ± 2,5	276 ± 4,0	70 ± 4,0	48 ± 2,5	39 ± 2,5

Табл. 2. Продуктивность покровных культур (среднее по опыту, 2007 и 2008 гг.)

Table 2. Productivity of cover crops (average for the experiment, 2007 and 2008)

Cover crops	Yield		
	t/ha abs. dry matter	thousand feed units/ha	GJ/ha
Barley	1,86	0,93	12,36
Grain mixture	3,74	1,72	26,60
LSD_{05}	0,69	0,47	5,72

result, the weed density was very low. The least dense stand of brome grass was 110 weeds/m^2 before mowing. The number of weeds in the brome grass stand was also insignificant, at 61 weeds/m^2.

Under the legume-cereal grain mixture, the stem density of perennial grasses was slightly lower compared to their density under barley. No significant differences were observed. The density of galega under barley was 143 pcs /m^2, under the grain mixture – 140 pcs /m^2, alfalfa – 225 and 236 pcs /m^2, respectively, timothy – 106 and 80 pcs /m^2, brome – 110 and 126 pcs /m^2.

Consequently, a reduction in perennial grass density under the grain mixture was not reliably confirmed in most cases. Weed abundance under barley and the grain legume mixture did not differ significantly.

The average height of single-species perennial grasses varied little across the experiment (see Table 3). The tallest plants were galega and brome grass: under barley, they reached 83 cm, and under the grain mixture, 78 and 75 cm, respectively. The heights of the remaining grass species were much smaller. The effect of the grain mixture as a cover crop has been almost completely ignored. This suggests that perennial grasses sown under different cover crops reach a uniform height by the age of 4–5 years.

Based on the analysis of perennial grass yields in 2007 and 2008, it was found that alfalfa was the most productive: under barley, its yield was 4.91 t/ha of absolute dry matter, and under a grain mixture, 4.19 t/ha (see Table 4). Its biological properties may serve as an explanation in this case. Alfalfa is considered a cold-hardy crop with a long growing season. With proper care, it can remain in the grass stand for over 10 years, although its yield declines starting in the 4th or 5th year[8].

The relatively low yield of galega (2,400 kJ/ha) is explained by the age of the grass stand. For galega, 4–5 years of age is insignificant; the crop has a productive longevity. Higher yields are achieved much later in life [13, 14]. Clover provides forage for only three years, so its average yield is the lowest over the entire study period. Timothy grass and brome grass generally yield less than single-species perennial legumes.

Based on the results of Experiment No. 2, it should be noted that the cover crop (barley) had a slightly higher stand density when sown in summer. This can be explained by the lower soil contamination at the time of cover crop sowing, as the soil had been cultivated prior to sowing. Thus, the barley stem density when sown in spring in a plot where alfalfa was the cover crop was 224 pcs/m^2, clover – 205 pcs/m^2, brome – 236 pcs/m^2 (see Table 5). When sown in summer, the stem density reaches 295, 301 and

Табл. 3. Структурные показатели травостоя многолетних трав первого укоса под разными покровными культурами (среднее по опыту, 2007 и 2008 гг.)

Table 3. Structural indicators of perennial grass stand of the first cut under different cover crops (average for the experiment, 2007 and 2008)

Perennial herbs	Stem density, pcs./m^2			Plant height, cm		
	Barley	Grain mixture	Weeds	Barley	Grain mixture	Weeds
Galega (control)	143	140	51	83	78	92
Clover	140	118	42	53	73	51
Alfalfa	225	236	51	53	47	55
Timothy grass	106	80	44	56	64	9
Brome	110	126	61	83	75	58
LSD_{05} A = 14,25, LSD_{05} B = 14,06, LSD_{05} AB = 20,16 (stem density) LSD_{05} A = 11,9, LSD_{05} B = 11,8, LSD_{05} AB = 20,16 plant height)						

[8] *Goncharov P.L., Lubenets P.A.* Biological aspects of alfalfa cultivation. Novosibirsk: Nauka, 1985. 256 p.

Табл. 4. Продуктивность многолетних трав под разными покровными культурами (среднее по опыту, 2007 и 2008 гг.)

Table 4. Productivity of perennial grasses under different cover crops (average for the experiment, 2007 and 2008)

Perennial herbs	Barley			Grain mixture		
	t/ha abs. dry matter	thousand feed units/ha	GJ/ha	t/ha abs. dry matter	thousand feed units/ha	GJ/ha
Galega (control)	3,69	2,40	38,48	3,29	2,13	27,45
Clover	2,66	1,81	21,37	2,16	1,46	17,30
Alfalfa	4,91	3,54	43,62	4,19	3,01	37,18
Timothy grass	3,47	2,64	28,85	2,92	2,06	24,22
Brome	3,52	2,54	30,61	3,13	2,25	27,15
LSD_{05} A = 0,25, LSD_{05} B = 0,16, LSD_{05} AB = 0,35 (abs. dry matter) LSD_{05} A = 0,18, LSD_{05} B = 0,10, LSD_{05} AB = 0,24 (feed units) LSD_{05} A = 2,11, LSD_{05} B = 1,33, LSD_{05} AB = 2,97 (GJ)						

286 pcs/m^2, respectively. Note that barley, as a cover crop, was sown at the same seeding rate as all undercrop grasses. The low stand density was due to a 20% reduction in the cover crop seeding rate, as required by the technology. Therefore, the seeding rate was 180 kg/ha (5 million seeds/ha).

Moreover, spring-sown barley yielded 1.5–2.0 times more than summer-sown barley. This can be explained by the fact that, despite favorable summer conditions for growth and development, barley, as a cover crop, had significantly less time to harvest compared to spring-sown barley.

As a result, the yield of spring-sown cover crops was significantly higher. For example, spring-sown barley yielded 3.9–4.6 t/ha of absolute dry matter, while summer-sown barley yielded 2.9–3.1 t/ha, which is significantly lower (see Table 6).

The stand density of perennial grasses in subsequent years after cover crop harvesting depended on the time of sowing. The stand density of summer-sown clover and brome grass was higher than that of spring-sown grasses. The denser stand of summer-sown grasses is explained by favorable conditions for the development of perennial grasses compared to spring-sown grasses. For the same reason, summer-sown grasses of the studied crops were slightly taller than spring-sown grasses.

Alfalfa and clover differed only slightly in terms of stem density and plant height (see Table 7). The stem density of spring- and sum-

Табл. 5. Структурные показатели травостоя покровной культуры при разных сроках посева (среднее по опыту, 2017 и 2018 гг.)

Table 5. Structural indicators of cover crop grass stand at different sowing dates (average for the experiment, 2017 and 2018)

Perennial herbs	Spring sowing		Summer sowing	
	Stem density, pcs./m^2	Plant height, cm	Stem density, pcs./m^2	Plant height, cm
Alfalfa	224	86	295	45
Clover	205	84	301	43
Brome	236	80	286	35

mer-sown alfalfa was 121 and 104 pcs/m^2, respectively, while that of clover was 102 and 120 pcs/m^2. The height of spring-sown alfalfa plants was 64 cm, while that of summer-sown clover was 68 cm, while that of clover was 64 and 71 cm.

A significant difference in stem density and plant height was observed in brome grass compared to legumes: these indicators were 1.5–2.0 times lower. The stem density of spring-sown brome grass was 58 plants/m^2, while that of summer-sown brome grass was 86 plants/m^2. The low stem density of perennial grasses is also explained by the sowing method. Perennial grasses were sown with a row spacing of 30 cm. Brome plants are significantly taller than alfalfa and clover, which is due to the morphological characteristics of the grasses studied. A significant difference between the structural parameters of spring- and summer-sown brome should also be noted. For example, the height of spring- and summer-sown brome plants was 77 and 86 cm, respectively. This difference is significant.

The productivity of perennial grasses at different sowing dates varied (see Table 8). The yield of summer legume crops was higher than that of spring crops. The yield of alfalfa from spring and summer sowings was 2.51 and 2.99 t/ha of absolute dry matter, clover – 2.58 and 2.88 t/ha, and brome grass – 2.20 and 2.36 t/ha. Consequently, differences were noted between the different sowing dates for legumes, although not always significant. For brome grass, the yield from summer sowing was also higher than from spring sowing.

With summer sowing, when the soil is prepared as a semi-fallow, cover crops and perennial grasses themselves experience more favorable conditions. Their development is accelerated. For example, in the Moscow region, the studies

Табл. 6. Продуктивность покровной культуры при разных сроках посева (среднее по опыту, 2017 и 2018 гг.)

Table 6. Productivity of cover crops at different sowing times (average for the experiment, 2017 and 2018)

Perennial herbs	Spring sowing			Summer sowing		
	t/ha abs. dry matter	thousand feed units/ha	GJ/ha	t/ha abs. dry matter	thousand feed units/ha	GJ/ha
Alfalfa	3,9	1,5	23,8	2,9	1,1	17,7
Clover	4,6	1,8	28,1	2,9	1,1	17,7
Brome	4,4	1,7	26,9	3,1	1,2	18,9
LSD_{05} A = 0,67, F_{05} B and F_{05} AB > F_{act} (abs. dry matter)						

Табл. 7. Структурные показатели травостоя многолетних трав при разных сроках посева (среднее по опыту, 2017 и 2018 гг.)

Table 7. Structural indicators of perennial grass stand at different sowing dates (average for the experiment, 2017 and 2018)

Perennial herbs	Stem density, pcs./m^2		Plant height, cm	
	Spring sowing	Summer sowing	Spring sowing	Summer sowing
Alfalfa	121	104	64	68
Clover	102	120	64	71
Brome	58	86	77	86
LSD_{05} A = 11,01, LSD_{05} B = 8,98, LSD_{05} AB = 15,56 (stem density) LSD_{05} A = 8,50, LSD_{05} B = 6,90, F_{05} AB > F_{act} (plant height)				

Табл. 8. Продуктивность многолетних трав при разных сроках посева (среднее по опыту, 2017 и 2018 гг.)

Table 8. Productivity of perennial grasses at different sowing times (average for the experiment, 2017 and 2018)

Perennial herbs	Spring sowing			Summer sowing		
	t/ha abs. dry matter	thousand feed units/ha	GJ/ha	t/ha abs. dry matter	thousand feed units/ha	GJ/ha
Alfalfa (control)	2,51	1,80	22,20	2,99	2,15	26,43
Clover	2,58	1,72	20,66	2,88	1,92	23,32
Brome	2,20	1,58	18,70	2,36	1,69	20,10
LSD_{05} A = 0,26, LSD_{05} B = 0,22, F_{05} AB > F_{act} (abs. dry matter)						

were conducted on different timings of overseeding (spring and summer) of Caucasian goat's rue into the sod of a reedgrass bed. According to the results, summer sowings were virtually equal in yield to spring sowings [14].

In conclusion, it can be noted that the studied perennial grasses, sown at different times, differed in terms of their grass stand structural parameters. The stem density and plant height of the summer-sown plants were higher. Consequently, the yield was also higher.

CONCLUSIONS

1. Cover crops had a depressing effect on perennial grasses during the initial growing season. Subsequently, the differences in perennial grass yields under different cover crops leveled out.
2. The productivity of the grain mixture cover crop was almost twice as high as that of barley – 1,720 versus 0,930 feed units/ha. Barley, as a cover crop, has less suppressive effects on perennial grasses. However, growing the grain mixture as a cover crop is also effective, given its undeniable advantages in productivity and suitability for haylage compared to barley.
3. Alfalfa was the most productive of the perennial grasses (3,540 feed units/ha). Red clover showed the lowest yield (1,810 feed units/ha).
4. The productivity of barley used as a cover crop for perennial grasses was higher when sown in spring than when sown in summer. Perennial grass productivity at different sowing times was slightly higher when sown in summer.

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Интенсивность проявления болезней в агроценозе кормовых бобов (*Vicia faba* L.) в условиях Западной Сибири

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В статье приведены результаты многолетних наблюдений в агроценозе кормовых бобов (*Vicia faba* L.) на выщелоченных черноземах в климатических условиях лесостепи Западной Сибири с целью определения частоты и интенсивности заболеваний растений. По данным большого количества исследований как отечественных, так и зарубежных специалистов, эта культура достаточно активно поражается целым комплексом заболеваний, что наносит значительный ущерб урожаю и качеству сельскохозяйственной продукции. В ходе исследования в посевах кормовых бобов выявлен ряд заболеваний (обыкновенная мозаика, фузариоз, пятнистости разной этиологии, ложная мучнистая роса и др.), интенсивность развития которых зависела от погодных условий вегетационного периода и экологических требований возбудителей. Установлено, что в годы с достаточным уровнем увлажнения преобладали фузариоз и ложная мучнистая роса. Коэффициент корреляции распространенности фузариозного увядания с ГТК составил 0,9 при $p < 0,05$. Уровень развития ложной мучнистой росы превышал порог вредоносности (более 40%), что также обусловлено уровнем увлажнения в вегетационный период. Показано, что засушливые условия, благоприятные для роста активности тлей, являющихся переносчиками обыкновенной мозаики, способствовали развитию данного заболевания (до 53%) и увеличению скорости нарастания инфекции. Выяснено, что степень развития различных типов пятнистости, вызываемой комплексом возбудителей (виды родов *Alternaria*, *Stemphylium*, *Cercospora*), была высокой на всех этапах (от появления всходов до созревания бобов) и во все годы исследования (индекс развития – до 61,6%, распространенность – 100,0%). Это привело к заражению до 40% семян нового урожая и снижению их посевных качеств, что свидетельствует о необходимости применения соответствующих защитных мероприятий, особенно на семенных посевах.

Ключевые слова: болезни растений, степень пораженности, фузариоз, мозаика, пятнистость листьев, кормовые бобы

The intensity of disease manifestations in the agrocenosis of broad beans (*Vicia faba* L.) in Western Siberia

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The article presents the results of long-term observations in the agrocenosis of broad beans (*Vicia faba* L.) on leached chernozems in the climatic conditions of the forest-steppe of Western Siberia in order to determine the frequency and intensity of plant diseases. According to a large number of studies by both domestic and foreign experts, this crop is quite actively affected by a whole range of diseases, which causes significant damage to the harvest and quality of agricultural products. During the study, a number of diseases (common mosaic, fusariosis, spotting of various etiologies, downy mildew, etc.) were identified in broad bean crops, the intensity of development of which depended on the weather conditions of the growing season and the environmental requirements of the pathogens. It was found that in years with sufficient moisture levels, fusariosis and downy mildew predominated. The correlation coefficient between the prevalence of fusariosis wilt and HTC was 0.9 at $p < 0.05$. The level of development of downy mildew exceeded the harmfulness threshold (more than 40%), which was also due to the level of moisture during the growing season. It was shown that dry conditions, favorable for the growth of activity of aphids, which are carriers of common mosaic, contributed to the development of this disease (up to 53%) and an increase in the rate of infection growth. It was found that the degree of development of various types of spotting caused by a complex of pathogens (species of the genera *Alternaria*, *Stemphylium*, *Cercospora*) was high at all stages (from emergence to bean ripening) and in all years of the study. (development index – up to 61.6%, prevalence – 100.0%). This led to infection of seeds of the new crop up to 40% and to a decrease in their sowing qualities, which indicates the need for protective measures against these pathogens, especially in seed crops.

Keywords: plant diseases, degree of infestation, fusariosis, mosaic, leaf spot, broad beans

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INTRODUCTION

Broad beans are a valuable protein crop that is widely grown throughout the world[1]. Providing the livestock industry with vegetable protein is one of the most important and pressing issues, which is driving the expansion of the area under cultivation of this crop.

Employees of the Siberian Research Institute of Fodder Crops of the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences (SFSCA RAS) have created a productive variety of fodder beans called Sibirskie[2]. However, its widespread introduction into production is hampered by a number of factors, one of which is the high incidence of diseases in plants of this variety[3].

Numerous studies conducted in various countries around the world indicate that fodder beans are significantly affected by a whole range of diseases, which causes significant damage to the harvest and quality of agricultural products [1, 2]. Thus, in various regions of China, India and Libya, the most common fungal diseases of the crop in question are chocolate leaf spot, root rot, anthracnose, alternaria leaf spot, ascochyta leaf spot and stem rot, sclerotiniose, caused by *Botrytis fabae*, *Fusarium solani*, *F. oxysporum*, *Colletotrichum* spp., *Alternaria alternata*, *Ascochyta fabae* and *Sclerotinia* sp. respectively [3–5]. There are known cases where diseases caused complete crop losses [6]. In Ethiopia, yield losses of 50–62% have been recorded for commercially released faba bean varieties and up to 54% for local varieties [7]. In addition, studies have shown that in China, which accounts for 30% of the world's production of this crop, diseases cause losses of about 20% of the crop[4].

The severity of disease development in legumes depends on a number of factors, including meteorological conditions, which are one of the main limiting factors. For example, temperatures around 20°C, the presence of free moisture on the leaves, and high (less than 90%) relative humidity create optimal conditions for the development of most types of bean leaf spot[5] [8–10].

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[3] *Ashmarina L.F., Konyaeva N.M., Gorobey I.M.* Fungal diseases of fodder beans in Western Siberia // Vestnik of the Russian Agricultural Science, 2008, N 5, pp. 25–27.

[4] *Lang L.J., Yu Z.H., Zheng Z.J., Xu M.S., Ying H.Q.* Faba bean in China: a state-of-the-art review / International Center for Agricultural Research in the Dry Areas, Aleppo, 1993, 144 p.

[5] *Badina G.V.* Cultivation of legume crops and weather. L.: Gidrometeoizdat, 1974, 242 p.

The significant prevalence of legume diseases in Siberia is due to several factors, including climate conditions, soil characteristics, and agricultural practices used in the region. Siberia is characterized by a harsh climate with sharp temperature fluctuations, which can favor the development of certain diseases adapted to such conditions.

As a result of climate warming, dominant diseases are shifting. While rust was the dominant disease in the region's fodder bean crops several decades ago, other diseases are now gaining prominence[6]. Due to changes in weather conditions, there is a risk of an increase in the incidence of certain diseases.

Identifying the pathogens that can reduce yield and seed quality is a key area of protecting this crop from diseases. Therefore, it is essential to conduct continuous phytosanitary monitoring of crops to identify priority diseases and then develop scientifically sound recommendations for their control.

In this regard, the purpose of our research was to study the development and intensity of various diseases in the agrocenosis of fodder beans in the forest-steppe conditions of Western Siberia, which will improve the effectiveness of the strategies for protecting this crop to ensure a stable harvest.

MATERIAL AND METHODS

Field studies were conducted in a field community of the Sibirskie variety of fodder beans at the Siberian Federal Scientific Centre of Agro-BioTechnologies of the Russian Academy of Sciences field station from 2020 to 2024. Disease development was monitored regularly throughout the growing season. To analyze the phytosanitary situation, methods for determining the prevalence and development of diseases in the field using standard scales were used[7, 8].

Pathogen detection and identification were performed in laboratory conditions. Samples of affected plants were placed in Petri dishes on Czapek agar medium supplemented with sterile streptomycin at a dose of 100 mg/l to inhibit bacteria and limit the development of rapidly growing soil fungi. Incubation was carried out in a thermostat at a temperature of 23–24°C. The grown fungal colonies were examined on days 7, 10, and 14 using appropriate identification kits. The rate of infection growth was calculated according to Odum[9].

In terms of weather, the study years were diverse, covering the full spectrum of climatic conditions typical of the forest-steppe zone of Western Siberia. For example, 2020 and 2023 were slightly dry (HTC = 1.3–1.0), 2021 and 2022 were dry (HTC = 0.9 and 0.6, respectively), and 2024 was excessively wet (HTC = 2.0). This diversity of weather conditions determined the manifestation patterns and dynamics of disease development, as well as the phytosanitary situation in forage bean agrocenoses.

RESULTS AND DISCUSSION

Long-term observations in the fodder bean agrocenosis revealed the presence of a whole range of diseases of various etiologies. Among them, the most common in the forest-steppe conditions of the Ob region were various types of spotting (including chocolate spot), fusariosis, mosaic, downy mildew, and others. Each disease has its own ecological optimum[10], so the dominance of a particular disease was observed depending on the weather conditions of the year.

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[6] *Ashmarina L.F., Gorobey I.M., Konyaeva N.M., Agarkova Z.V.* Atlas of forage crop diseases in Western Siberia. Novosibirsk, 2010, 174 p.

[7] Guidelines for the recognition and recording of pests and diseases of peas and fodder beans and the assessment of the effectiveness of their control. Moscow: Selkhozizdat, 1962, 32 p.

[8] Methodology for identifying, recording, and predicting pests and diseases of grain legumes and forage legumes, and signaling the timing of their control. Moscow: Kolos, 1970, 46 p.

[9] *Odum Yu.* Fundamentals of Ecology: trans. from English. Moscow: Mir, 1975, 740 p.

[10] *Stoddard F.L., Nicholas A.H., Rubiales D., Thomas J., Villegas-Fernández A.M.* Integrated pest management in faba bean // Field Crops Research, 2010, N 115, pp. 308–318.

Every year, the development of fusarium wilt caused by a complex of species of the genus Fusarium (*F. oxysporum* Schl., *F. solani* (Mart.) Sacc., etc.) was noted in bean crops[11]. The disease manifested itself throughout the entire growing season (see Fig. 1, 2).

During the germination period, basal stem rot was observed. Brown spots were observed on the cotyledons. On the stem, the disease manifests as a constriction, while dark brown, almost black, round spots form on the leaves. Plants affected by fusarium turn yellow, dry out, and are easily pulled from the soil. During the flowering and fruiting period, fusariosis manifests as lesions and drooping of the plant tips, as well as wilting of the leaves. The pathogens are transmitted through seeds, soil, and airborne droplets.

It was found that the prevalence of fusariosis varied by year (from 66.7 to 31.0%) and was clearly correlated with the moisture level (see Fig. 1). The correlation coefficient with the HTC was 0.9 and was reliable ($p < 0,05$).

The seasonal dynamics of disease development shown in Figure 2 show that in the dry year of 2022, the rate of infection increased sharply in late July, when precipitation was significantly below normal. Plants experienced stress during the drought, which contributed to the intensification of disease development. A similar situation was observed in 2024. Meanwhile, in 2021, which was characterized by a uniform distribution of precipitation, the disease was sporadic.

Every year, cases of leaf spot caused by a whole group of pathogens were recorded in bean crops.

The most common were Alternaria blights (caused by the imperfect fungus *Alternaria tenuis* Nees et Fr.). Alternaria blight affects cotyledons and leaves, primarily in the early stages of crop development. The disease manifests as spots of varying size and shape, brown or dark brown in color, with or without a yellow border.

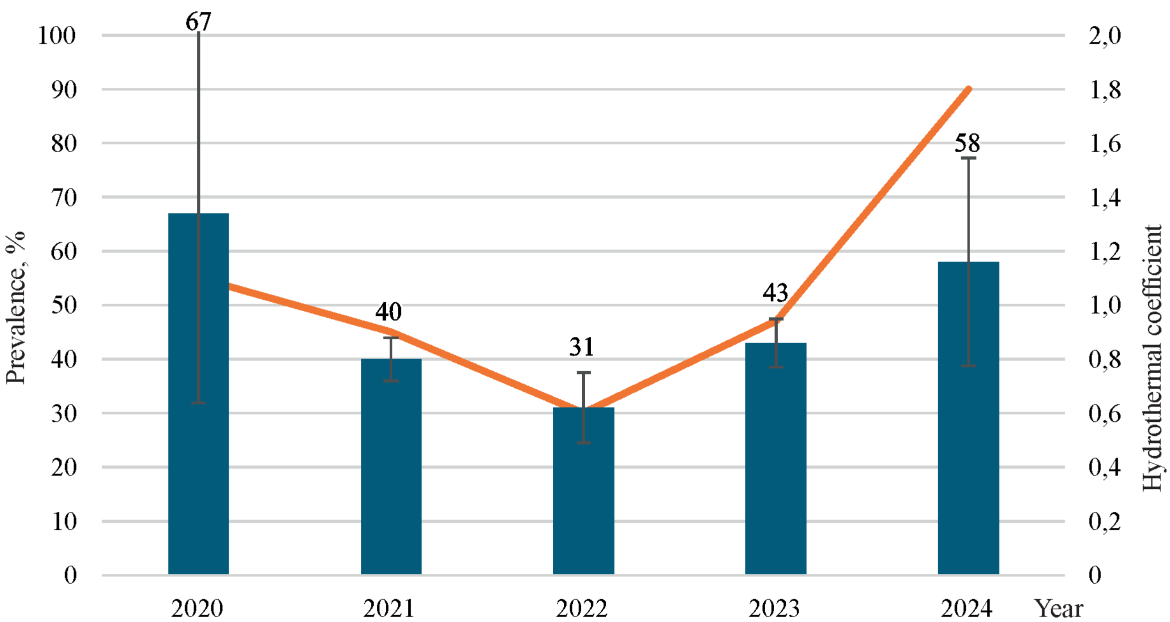

Рис. 1. Распространенность фузариозного увядания в зависимости от величины ГТК
На рис. 1, 3, 5, 6: планки погрешностей – стандартное отклонение
Fig. 1. Prevalence of fusarium wilt depending on the HTC value
Figs. 1, 3, 5, 6: error bars – standard deviation

[11] *Ashmarina L.F., Gorobey I.M., Davydova N.V.* Fusariosis of fodder beans in the forest-steppe of Western Siberia // Siberian Herald of Agricultural Science, 2008, vol. 187, N 7, pp. 42–46.

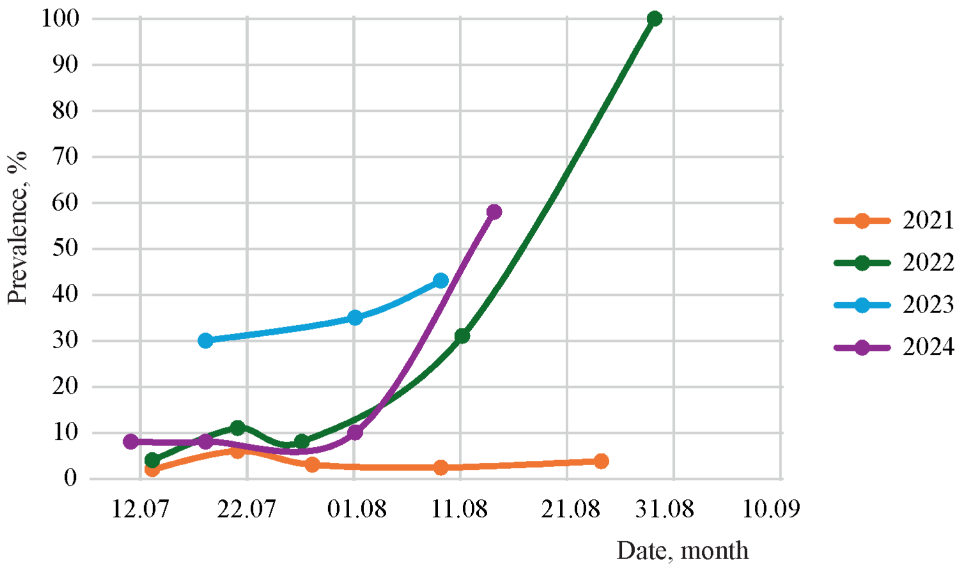

Рис. 2. Сезонная динамика развития фузариозного увядания
Fig. 2. Seasonal dynamics of fusarium wilt development

The spots can enlarge, destroying large areas of the leaves. This dramatically reduces seed yield and their sowing quality.

Additionally, cases of spotting caused by *Cercospora fabae* Fautr. have been observed. This appears as large, round, brownish-purple spots with a light center. The spots gradually merge, and their surface becomes concentrically wrinkled. On the stems, the spots are elongated, dark, and have rims; on the beans, they are the same as on the leaves.

Black spot (caused by the imperfect fungus *Stemphylium sarciniforme* Wiltsh.) has also been observed, affecting the lower leaves first, then the upper leaves, as well as the stems and pods. A typical symptom of the disease is the formation of dark brown spots, which enlarge over time and often cover a significant area of the plant.

Figure 3 shows the results of long-term observations, according to which the prevalence of spotting was high in all years of the study. The disease was observed from seedling emergence to plant maturity. Mycological analysis of the new bean crop revealed a fairly high level of infestation (Alternaria species – up to 40%), leading to a decrease in the sowing quality of the seeds. This indicates the need for protective measures, especially in seed crops.

For spotting, the highest Disease Progression Index (DPI) was observed in the years with sufficient moisture (2020 and 2024), as confirmed by a significantly significant correlation coefficient (r = 0.7) and long-term seasonal disease dynamics (see Fig. 4). The plants were infected with pathogens to varying degrees from seedling stage. The highest rate of infection growth was observed in August (during the fruit formation and ripening phase).

During monitoring of bean crops, isolated cases of chocolate spot were observed in some years with adequate moisture. Chocolate spot, like powdery mildew, is an airborne disease transmitted by airborne droplets. Therefore, the epiphytotic process of these diseases was similar. A survey conducted in early August 2022 revealed a low prevalence of the disease, which after two weeks reached 50%, and the disease progression rate was 25.5%. The results obtained are consistent with the data of B. Bankina et al. [1], who conducted research in Latvia.

During the study period, cases of plant damage by downy mildew were observed annually (see Fig. 5).

The causative agent of the disease is *Peronospora fabae* Jacz. et Serg. The disease affects leaves, stems, and beans. On the upper surface of affected leaves, light green spots first appear,

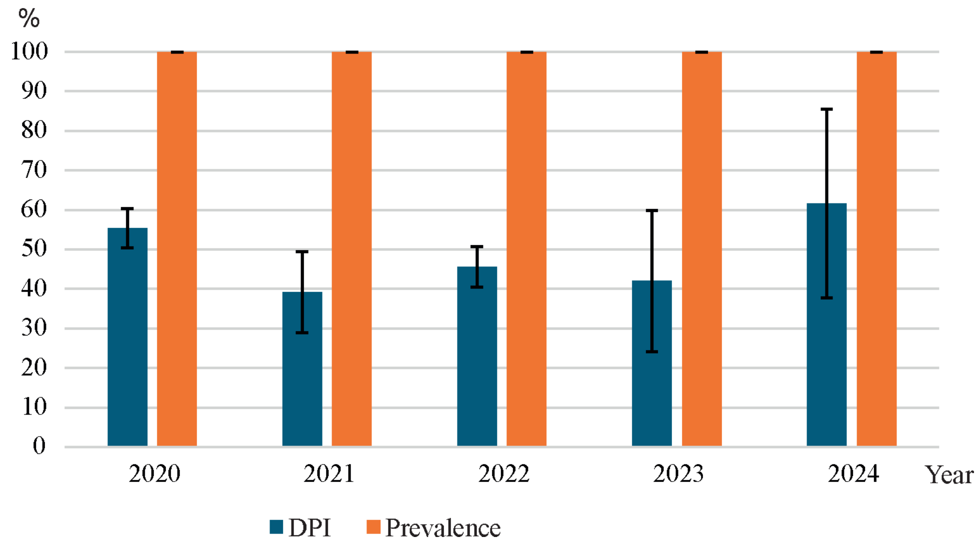

Рис. 3. Индекс развития и распространенность пятнистости
Fig. 3. Development index and prevalence of spot disease

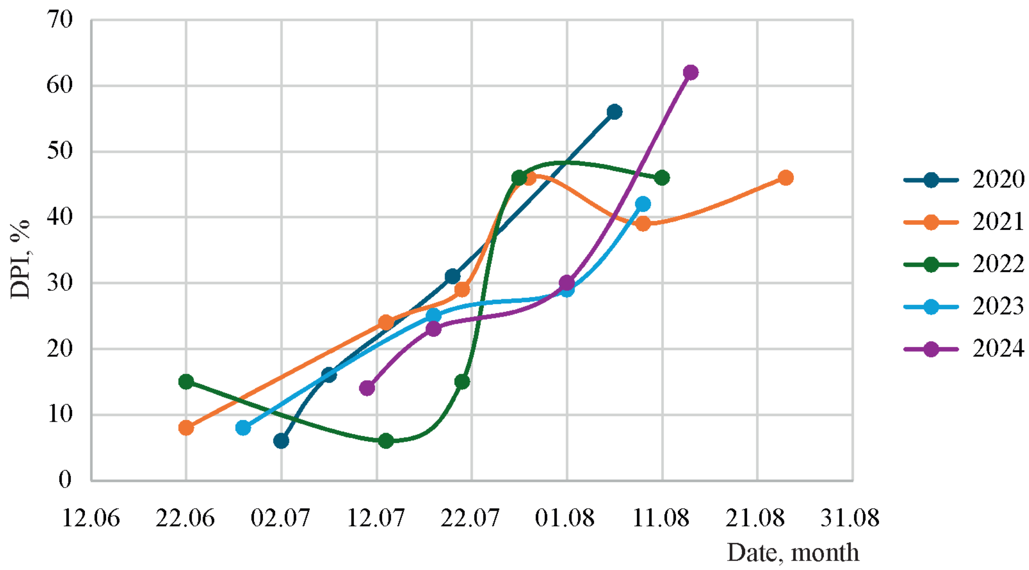

Рис. 4. Сезонная динамика развития пятнистости
Fig. 4. Seasonal dynamics of spot disease development

followed by large chlorotic spots that later turn dark brown and gradually dry out. All affected plant organs become covered with a continuous coating of fungal sporulation, significantly reducing crop productivity.

Disease severity depended on moisture levels during the growing season. In 2021, when the HTC for May–June was 1.1, the disease development index exceeded the ETH and reached 47.9%, with prevalence reaching 100%. In 2022, when the HTC for May–August was 0.6, disease development did not reach the harmfulness threshold and reached 11.6%.

Among the transmissible diseases in crops, the common mosaic of fodder beans has been noted (see Fig. 6, 7). The causative agents are *Pisum virus 2* Smith, *Phaseolus virus 1* Smith and *Phaseolus virus 2* Smith.

The disease is characterized by general chlorosis and yellow-green leaf spotting, often accompanied by wavy and slight leaf curling. The disease slows plant growth, especially at the

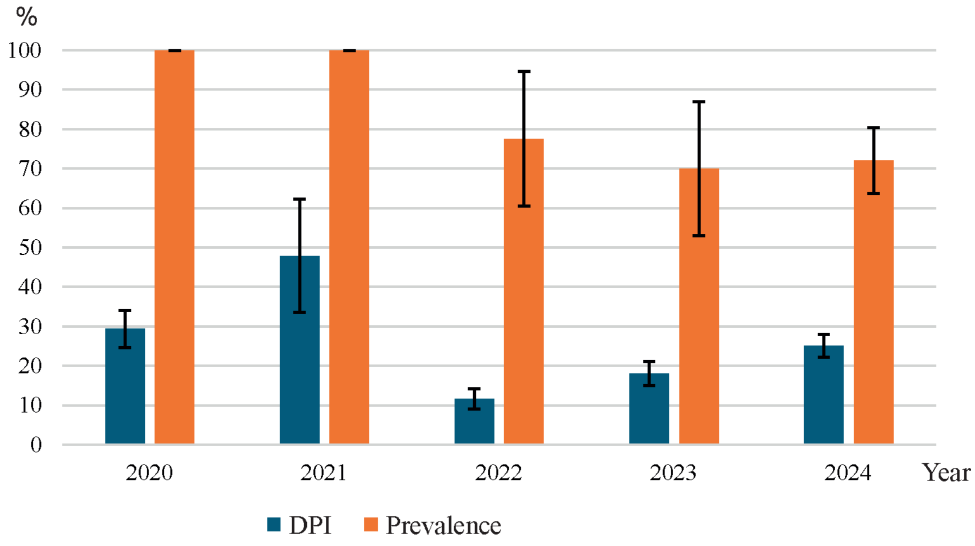

Рис. 5. Индекс развития и распространенность ложной мучнистой росы
Fig. 5. Development index and prevalence of powdery mildew

apical internodes, impairs fruiting, and reduces yield. It is transmitted by aphids.

In hot, dry weather, insect activity increases, contributing to increased infection transmission in crops. An inverse correlation has been found with the humidity of the growing season. Thus, in the dry year of 2021, characterized by uneven precipitation, the disease prevalence was the highest (53%). The rate of infection growth in the second ten-day period of July, when precipitation was only 22% of the long-term average, was very high, reaching 4.8 units, due to increased vector activity. A similar pattern was observed in 2022 from late July to the first ten-day period of August.

Thus, regular disease monitoring in the fodder bean agrocenosis revealed the specific development patterns of a complex of diseases. The importance of phytosanitary monitoring lies in collecting sufficiently comprehensive disease information and proposing the most rational approaches to preventive and protective measures. Identifying the most common bean diseases in a region provides the basis for short- and long-term forecasts and determines control measures for the most harmful diseases.

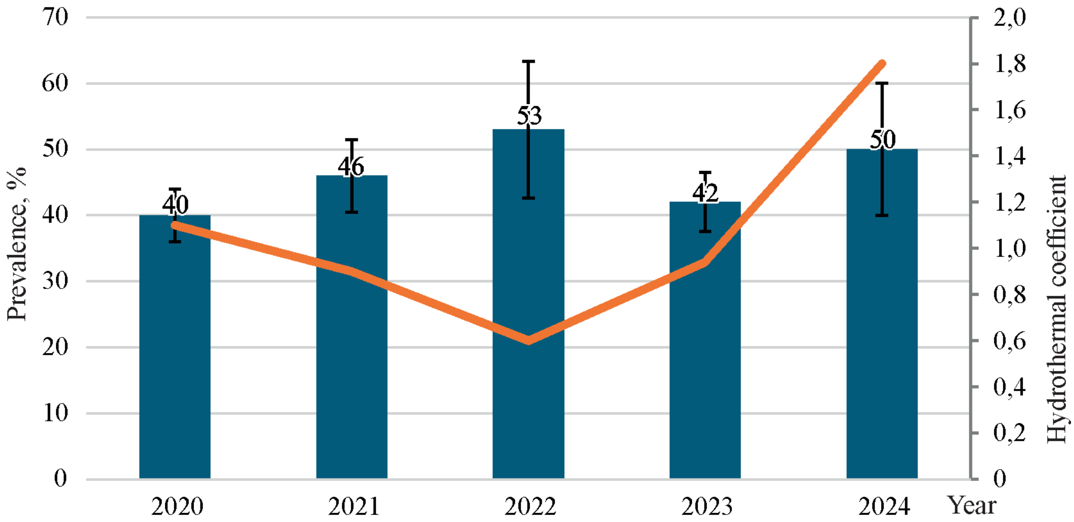

Рис. 6. Распространенность обыкновенной мозаики в зависимости от величины ГТК
Fig. 6. Prevalence of common mosaic depending on the HTC value

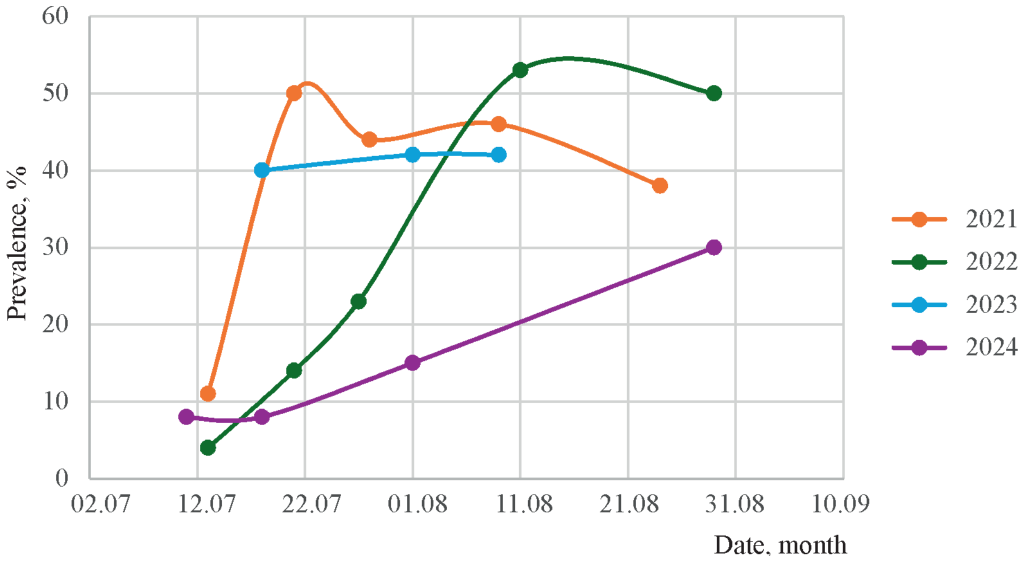

Рис. 7. Сезонная динамика развития обыкновенной мозаики
Fig. 7. Seasonal dynamics of common mosaic development

CONCLUSIONS

1. In the course of long-term research in the agrocenosis of fodder beans in the forest-steppe of Western Siberia, a whole complex of diseases (common mosaic, fusariosis, spotting of various etiologies, downy mildew, etc.) was identified, the intensity of development of which depended on the weather conditions of the growing season and the environmental requirements of the pathogens.

2. It was found that fusariosis and downy mildew were prevalent under conditions of sufficient moisture. The correlation coefficient between fusariosis prevalence and the HTC was 0.9 at $p < 0.05$. Downy mildew development, exceeding the harmfulness threshold (more than 40%), was also determined by moisture conditions during the growing season.

3. It has been shown that dry conditions, by increasing the activity of insects that carry the disease in bean crops, contributed to the development of common mosaic (up to 53%) and increased the rate of growth of this infection.

4. It has been found that the degree of development of the spots caused by a complex of pathogens (types of genera *Alternaria*, *Stemphylium*, *Cercospora*), was high in all years of the study from germination to bean ripening (DPI – up to 61,6%, prevalence – 100%). This resulted in the infection of up to 40% of the new crop's seeds (*Alternaria* species) and a reduction in their sowing quality. This fact demonstrates the need for protective measures against these pathogens, especially in seed crops.

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Изучение чувствительности сорных растений к гербициду Кельвин Плюс и его эффективность в посеве кукурузы на зерно в условиях Приморья

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Исследования проводили в Приморском крае на экспериментальной базе Дальневосточного научно-исследовательского института защиты растений в 2022–2024 гг. В условиях вегетационного домика изучена чувствительность 15 видов сорных растений к гербициду Кельвин Плюс. Проведены визуальные наблюдения за их развитием после проведенных обработок. Отмечены симптомы гербицидного действия и время их проявления. Установлено, что высокочувствительными к гербициду являются щетинник сизый, просо куриное, шерстняк мохнатый, щирица запрокинутая, эльсгольция гребенчатая, коммелина обыкновенная, гибискус тройчатый, сигезбекия пушистая и осот полевой. К чувствительным относятся горец почечуйный, марь белая, акалифа южная, бодяк щетинистый и амброзия полыннолистная. Устойчивым к действию препарата был канатник Теофраста. Дана оценка биологической и хозяйственной эффективности гербицида Кельвин Плюс в норме расхода 0,4 кг/га при внесении в фазы 5–6-го и 7–8-го листа кукурузы. Гербицид с момента внесения и до уборки урожая независимо от сроков обработки практически полностью уничтожал многолетние двудольные, однолетние – злаки и двудольные, в том числе доминировавшую в посевах по наращиваемой надземной массе амброзию полыннолистную. Высокая эффективность внесения гербицида Кельвин Плюс в фазу 5–6-го листа культуры позволила повысить урожайность в среднем на 43,9 ц/га, при урожайности в контроле 9,0 ц/га. Существенно меньшее количество урожая сохранено при позднем использовании гербицида – 24,5 ц/га. Интервал между обработками достигал 20 сут. За этот промежуток времени сорные растения оказывали серьезную конкуренцию культуре, что повлияло на полученную урожайность зерна.

Ключевые слова: сорные растения, гербицид, кукуруза, препарат, фаза, надземная масса, эффективность, урожайность

Study of weed sensitivity to the herbicide Kelvin Plus and its effectiveness in sowing corn for grain in the conditions of Primorye

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The research was conducted in the Primorsky Territory at the experimental base of the Far Eastern Research Institute of Plant Protection in 2022–2024. The sensitivity of 15 weed species to the Kelvin Plus herbicide was studied in a vegetation house. Visual observations of their development after the treatments were carried out. Symptoms of herbicide action and the time of their manifestation were noted. It was found that the following are highly sensitive to the herbicide: *Setaria glauca*, *Echinochloa crusgalli*, *Eriochloa vilosa*, *Amaranthus retroflexus*, *Elsholtzia cristata*, *Commelina communis*, *Hibiscus trionum*, *Siegesbeckia pubescens,* and *Sonchus arvensis*. Sensitive plants include *Polygonum persicaria*, *Chenopodium album*, *Acalypha australis*, *Cirsium setosum* and *Ambrosia artemisiifolia*. *Abutilon theophrasti* was resistant to the drug's action. An assessment was made of the biological and economic efficiency of the herbicide Kelvin Plus at a consumption rate of 0.4 kg/ha when applied in the 5–6 and 7–8 leaf phases of corn. From the moment of application until harvest, regardless of the timing of treatment, the herbicide almost completely destroyed perennial dicotyledons, annual cereals and dicotyledons, including *Ambrosia artemisiifolia*, which dominated the crops in terms of growing aboveground mass. The high efficiency of applying the Kelvin Plus herbicide in the 5–6th leaf phase of the crop allowed increasing the yield by an average of 43.9 c/ha, with the yield in the control being 9.0 c/ha. A significantly smaller yield was preserved with late herbicide application – 24.5 c/ha. The interval between treatments was up to 20 days. During this period, weeds seriously competed with the crop, which impacted the resulting grain yield.

Keywords: weeds, herbicide, corn, preparation, phase, aboveground mass, efficiency, yield

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INTRODUCTION

Corn is one of the most widely cultivated crops in global plant production. It ranks first in gross grain yield and second in sown area [1]. Currently, corn cultivation areas in the Russian Federation are vast and span a variety of natural, climatic, and agroclimatic zones [2]. In 2022, 71,900 ha of grain corn were sown in the Primorsky Territory. In recent years, the region has seen an upward trend in gross corn grain harvest, driven by the increased interest from agricultural producers and demand in the Asia-Pacific region. Gross corn harvest in 2022 nearly tripled compared to 2015, with a yield of 7.6 t/ha [3, 4]. In Primorye, the share of agricultural land is 10.07% of the total land in the Far Eastern Federal District: this is approximately 80% of the region's agricultural land, of which 703.8 thousand ha are arable land [5].

Severe weed infestation hinders high and stable corn grain yields. High seed productivity and the long viability of weed seeds entering the soil are key biological traits that have historically contributed to the species' survival, but they have also contributed to significant weed infestation and have been a major obstacle to improving agricultural practices [6]. Corn reacts to a deficiency of any of these vital factors primarily by delayed development, followed by suppression of the production process. Under competition with weeds, it loses more grain than silage productivity; weeds also reduce the quality of grain and green mass [7, 8]. In corn crops in the south of the Far East, the main weeds are: cereals (barnyard grass (*Echinochloa crusgalli* (L.) *Beauv*.), yellow-foxtail grass (*Setaria glauca* (L.) *Beauv*.) and green foxtail grass (*Setaria viridis* (L.) *Beauv*.), hairy cupgrass (*Eriochloa vilosa* (Thump.) Kuth), dicotyledons (common ragweed (*Ambrosia artemisiifolia* L.)), China jute (*Abutilon theophrasti* Medik.), redroot amaranth (*Amaranthus retroflexus*), lamb's-quarters (*Chenopodium album* L.), St.-Paul's-wort (*Sigesbeckia pubescens*), southern copper leaf (*Acalypha australis* L.), field milk thistle (*Son-*

chus arvensis L.), yellow thistle (*Cirsium setosum*). Barnyard grass grows in quantities of 50 pcs. / m^2 or more in most areas. Research conducted at the Far Eastern Research Institute of Plant Protection (FERIPP) found that corn grain yields significantly decrease by an average of 29% with barnyard grass infestation at levels of 12 pcs. /m^2, and at a contamination density of 10 pcs. /m^2 of common ragweed – by 34–41%[1, 2]. According to S.V. Kuznetsova and V.N. Bagrintseva, with the same amount of common ragweed in the crop, the grain yield shortfall can be 6–7 c/ha or more[3].

Assessing the harmfulness of pests is one of the key tasks of agrobiocenological diagnostics of agricultural crops, since it is aimed at determining their economic significance and the need for protective measures [9]. Crop infestation remains one of the key problems in agriculture. The most effective method is considered to be the use of herbicides. Without herbicides, two pre-sowing cultivations do not ensure that corn crops are free of weeds [10]. The list of pesticides and agrochemicals approved for use in corn crops in the Russian Federation in 2021 includes more than 200 names[4]. With the increasing use of plant protection products, the diversity of pesticides has increased depending on the chemical structure of their active ingredients. Recently, combination pesticides have been used, capable of destroying a range of pests in a single application, and considerable attention has been paid to studying the potential for extending the application period [11–13]. Such herbicides include Kelvin Plus, a WSG containing sodium salts, dicamba, and diphenbenzopyr, as well as nicosulfuron.

The purpose of the study is to investigate the sensitivity of weeds to herbicide Kelvin Plus in a greenhouse, as well as its effectiveness in sowing corn for grain.

MATERIAL AND METHODS

The studies were conducted in the experimental fields of the Far Eastern Research Institute of Plant Protection in 2022–2024, as well as in a vegetation house. The soil was meadow-brown podzolized, containing 3–4% humus in the arable horizon. Corn cultivation was carried out using the no-till technology. The mid-early Canyons hybrid was sown at a seeding rate of 80,000 seeds/ha. Mineral fertilizer (nitroammophoska) was applied before sowing at a rate of 100–150 kg/ha of physical mass. The forecrop was soybeans in 2022 and 2023, and autumn fallow in 2024.

The 2022–2024 growing seasons were characterized by alternating dry and rainy periods. In 2022, precipitation in the first and second ten-day periods of May was only 12 mm (the norm is 57 mm); in the third ten-day period of May and the first ten-day period of June, it was 104 mm (the norm is 66 mm); in the third ten-day period of June and July, it was 214 mm (the norm is 147 mm); and in the first two ten-day periods of August, it was 18 mm (the norm is 84 mm). Temperatures from the third ten-day period of May to mid-August reached 29.3–33.7 ºC. In 2023, during the initial stages of corn development, soil moisture was insufficient. In May, only 31 mm of rain fell, which was three times less than the monthly average (94 mm). In the first ten days of June, by contrast, rainfall was three times (116 mm) above the long-term average (38 mm), then in the second and third ten days of June, it was again half (25 mm) below the average (54 mm), and in the first ten days of July, conversely, it was 1.5 times above the average. Rainfall in the second and third ten days of July (95 mm) was four times less (24 mm) than the long-term average. Precipitation was close to the norm only in August, while in September it

[1] *Altukhova T.V., Kostyuk A.V.* Harmfulness of barnyard grass in grain corn crops // Corn and sorghum, 2006, N 3, pp. 16–19.

[2] *Altukhova T.V., Kostyuk A.V., Spiridonov Yu.Ya., Shestakov V.G., Ginevsky N.K.* How to protect corn from common ragweed // Plant protection and quarantine, 2005, N 7, pp. 38–39.

[3] *Kuznetsova S.V., Bagrintseva V.N.* Herbicides for ragweed control in corn crops // Plant protection and quarantine, 2019, N 6, pp. 41–43.

[4] List of pesticides and agrochemicals permitted for use in the Russian Federation in 2021: reference ed., Moscow, 2021, 816 p.

was 2.3 times lower. Temperatures in the second ten-day period of July and August, the third ten-day period of July, and the first and second ten-day periods of September exceeded the long-term average by 1.8–3.1°C. 2024 turned out to be extremely unfavorable for the growth and development of corn plants. In the third ten-day period of May (when the first shoots were just beginning to emerge), 139 mm of moisture fell (the norm is 39 mm), in the second and third ten-day periods of June – about 205 mm (the norm is 53 mm), and in the third ten-day period of July – 79 mm (the norm is 25 mm). Air temperatures in August exceeded the long-term average by 1.1–2.5°C, while in the remaining months they were within the norm.

Kelvin Plus herbicide was applied at a rate of 0.4 kg/ha in two stages: during the 5th-6th and 7th-8th leaf stages of corn. A DASH adhesive (surfactant) was added to the working solution (1.2 l/ha). A manual boom sprayer (ORSh-2.5) with a working solution application rate of 200 l/ha was used for application. The experimental plot area was 22.5 m^2, with four replicates and randomized placement.

Three surveys were conducted during the growing season: before applying the working solutions and 30 and 60 days after. The first was conducted using a quantitative species-based method, while the subsequent ones also used a gravimetric method.

In a vegetation house, plastic cups were filled with meadow-brown soil. Then, 10 seeds of one of 15 weed species were sown in each of them. Solutions of the Kelvin Plus herbicide were applied to the vegetative weed plants in the early stages of their development using an OL-5 laboratory sprayer designed by the All-Russian Research Institute of Phytopathology at the doses of 0.1; 0.2; 0.3; 0.4 and 0.5 kg/ha with the addition of DASH surfactant in a ratio of 1:3.

The studies were carried out in accordance with the “Methodological guide for the study of herbicides used in plant growing”[5], the digital material was processed using mathematical methods according to B.A. Dospekhov[6] and V.A. Koronevsky[7].

RESULTS AND DISCUSSION

The study results indicate that weeds responded differently to the herbicide applied. For example, plant twisting was observed just two hours after the treatment on redroot amaranth, China jute, lamb's-quarters and St.-Paul's-wort, and the next day on trailing hollyhock (*Hibiscus trionum* L.), common persicaria (*Polygonum persicaria* L.) and common ragweed. A slowdown in the growth and development of elsholtzia cristata (*Elsholtzia cristata* Willd.), hairy cupgrass, barnyard grass and yellow-foxtail grass was also detected. Similar signs of herbicide action were noted on the other weeds studied. On the 4th day, the growth points of the elsholtzia cristatus turned yellow, the copper leaf leaves drooped, necrosis appeared on the yellow-foxtail grass, the plants of the yellow thistle and the field milk thistle slightly wilted, the common persicaria and the common ragweed twisted strongly. On the 7th day, the death of individual plants of elsholtzia cristata, redroot amaranth, and yellow-foxtail grass was detected at a consumption rate of 0.1 kg/ha, hairy cupgrass – at a rate of 0.2 kg/ha, lamb's-quarters and barnyard grass – at a rate of 0.3 kg/ha. Necrosis appeared on the leaves of St.-Paul's-wort at all application rates. Restoration of growth was observed on the China jute plants at an application rate of 0.1 kg/ha. On the 10th day, complete death of redroot amaranth, yellow-foxtail grass, elsholtzia cristata plants was observed at all application rates, as well as on hairy cupgrass starting with a rate of 0.2 kg/ha and common dayflower starting with a rate of 0.4 kg/ha. Necrosis appeared on the leaves of trailing hollyhock, field milk thistle and yellow thistle.

[5] *Spiridonov Yu.Ya., Larina G.E., Shestakov V.G.* Methodological guide for the study of herbicides used in plant growing. Moscow: Pechatny Gorod, 2009, 252 p.

[6] *Dospekhov B.A.* Methodology of field experiment. Moscow: Kolos, 1979, 416 p.

[7] *Koronevsky V.I.* On the methodology of statistical processing of data from long-term field experiments // Zemledelie, 1985, N 11, pp. 56–57.

The conducted inventory of the green mass of weeds showed that for the complete destruction of yellow-foxtail grass, redroot amaranth and elsholtzia cristata, 0.1 kg/ha of the herbicide Kelvin Plus is sufficient, for hairy cupgrass – 0.2, barnyard grass – 0.3, common dayflower – 0.4 kg/ha (recommended consumption rate) (see Table 1).

When using the recommended application rate, the aboveground mass of the trailing hollyhock and St. Paul's-wort plants was 95% less than in the control, field milk thistle - 92% less, common persicaria, lamb's-quarters, southern copper leaf and yellow thistle - 70-75% less, common ragweed - 61% less, China jute - only 27%. To destroy the latter by 47%, it was necessary to apply the studied herbicide at a dose of 0.5 kg/ha.

The plots where the field trials were conducted before the application of the Kelvin Plus herbicide in the 5-6 leaf stage were infested with 480-535 weeds/m^2. Before the treatment in the 7-8 leaf stage, the crops in the sown area contained 546-585 weeds/m^2 (see Table 2).

Within 20 days of application, the herbicide Kelvin Plus reduced the total number of weeds to 65 pcs./m^2 (or by 89%). Annual grasses (barnyard grass, foxtails and hairy cupgrass) were destroyed most effectively – by 86% (33 pcs./m^2), as well as annual dicotyledonous plants – by 95% (16 pcs./m^2), and perennials – by 91% (1 pcs./m^2). In addition, the number of common dayflower plants decreased to 7 pcs./m^2 (by 50%), and common horsetail (*Equisetum arvens* L.) – to 8 pcs./m^2 (by 53%).

By mid-growing season, weed populations under the herbicide-free control had increased to an average of 739 pcs/m^2, and they had accumulated 2874 g/m^2 of aboveground mass (see Table 3). Annual dicotyledons accounted for the largest amount of aboveground mass at 1558 g/m^2 (54%), of which common ragweed accounted for 88%. Annual cereals increased the aboveground mass by 823 g/m^2 (29%), perennial dicotyledons, represented by species of wormwood, yellow thistle and field milk thistle, by 329 g/m^2 (11%), common dayflower by 110 g/m^2 (4%) and common horsetail by 54 g/m^2 (2%).

Regardless of the application timing, the herbicide Kelvin Plus reduced the total number of weeds to 185–199 pcs/m^2 (by 73–75%) and the growth of aboveground mass to 296–343 g/m^2. The product effectively inhibited the growth and development of perennial dicotyledons to 2–53 g/m^2, annual grasses to 68–129 g/m^2,

Табл. 1. Чувствительность сорных растений к гербициду Кельвин Плюс
Table 1. Susceptibility of weeds to the Kelvin Plus herbicide

Plant	Drug dose, kg/ha						
	Control*	0,1	0,2	0,3	0,4	0,5	HCP^{**}_{05}
Barnyard millet	5,28	80	93	100	100	100	14
Hairy cupgrass	4,18	91	100	100	100	100	10
Common dayflower	3,16	5	39	39	100	100	24
Common ragweed	1,28	12	29	56	70	82	17
Southern copper leaf	2,96	27	26	56	71	73	14
China jute	3,92	17	21	26	27	47	12
Lamb's-quarters	3,83	34	52	76	72	81	10
Common persicaria	1,96	23	62	60	75	87	12
Trailing hollyhock	3,07	69	87	88	95	94	7
St.-Paul's-wort	3,34	75	80	91	95	100	6
Field milk thistle (from seeds)	3,06	74	90	91	92	94	9
Yellow thistle (from seeds)	2,68	60	68	71	70	80	10

*Aboveground mass of plants, g.
**Least significant difference at 5% significance level.

Табл. 2. Засоренность посева кукурузы (шт./м²) перед внесением гербицида Кельвин Плюс в фазу 7–8-го листа (через 20 сут после обработки в фазу 5–6-го листа) (среднее за 2022–2024 гг.)

Table 2. Weed infestation of corn crops (pcs./m²) before application of the Kelvin Plus herbicide in the 7–8th leaf phase (20 days after treatment in the 5–6th leaf phase) (average for 2022–2024)

Experiment option	Total number	Annuals			Perennials	
		cereal crops	common dayflower	dicotyledons	dicotyledons	common horsetail
Control (no herbicides)	585	233	14	312	11	15
Kelvin Plus:						
5–6th leaf phase	65	33	7	16	1	8
7th–8th leaf phase	546	221	14	284	13	14

and annual dicotyledons to 28–81 g/m². In the last group, common persicaria, St. Paul's-wort, trailing hollyhock, lamb's-quarters, elsholtzia cristata, as well as common ragweed, which dominates the above-ground mass, were almost completely destroyed. The vegetative mass of southern copper leaf and individual China jute plants was several times greater than in the control due to the lack of competition.

When the herbicide was applied at the 5-6 leaf stage, it exhibited a more active effect on common dayflower, while when applied at the 7-8 leaf stage, it was more effective on annual grasses and common horsetail. The product demonstrated high efficacy in trials in Belarus [14], Moscow, Voronezh, and Astrakhan regions [15].

Despite the fact that the overall effectiveness of the Kelvin Plus herbicide was equal at both application times, significantly more (the smallest significant difference at a significance level of 5% = 3.8 c/ha) (52.9 c/ha) corn grain was harvested when the herbicide was applied at the early stages of weed and corn development, with a yield in the control of 9.0 c/ha. With late treatment with the Kelvin Plus herbicide, the weeds seriously competed with the crops and thereby significantly reduced the grain yield, which averaged 33.5 c/ha over the 3 years of research.

CONCLUSIONS

1. In a greenhouse, the weeds found to be

Табл. 3. Эффективность гербицида Кельвин Плюс (0,4 кг/га) в посеве кукурузы на зерно (среднее за 2022–2024 гг.)

Table 3. Efficiency of the Kelvin Plus herbicide (0.4 kg/ha) in sowing corn for grain (average for 2022–2024)

Experiment option	Weediness												Grain yield c/ha	Yield increase, c/ha
	quantity, pcs/m²						above ground mass, g/m²							
	total	annuals			perennials		total	annuals			perennials			
		cereals	common dayflower	dicotyledons	dicotyledons	common horsetail		cereals	common dayflower	dicotyledons	dicotyledons	common horsetail		
Control (no herbicides)	739	378	22	294	13	32	2874	823	110	1558	329	54	9,0	–
Kelvin Plus:														
5–6th leaf phase	185	86	14	44	7	34	343	129	49	28	53	84	52,9	43,9
7th–8th leaf phase	199	94	16	69	1	19	296	68	101	81	2	44	33,5	24,5
LSD^*_{05}													3,8	

*Least significant difference at 5% significance level.

highly sensitive to the herbicide Kelvin Plus were: yellow-foxtail grass, redroot amaranth, elsholtzia cristata, hairy cupgrass, barnyard grass, common dayflower, trailing hollyhock, St. Paul's wort, and field milk thistle. Sensitive weeds included common persicaria, lamb's quarters, southern copper leaf, yellow thistle, and common ragweed. China jute was found to be resistant.

2. In corn crops, Kelvin Plus herbicide has been found to be highly effective when applied during the 5-6 leaf stage and in the early stages of weed development. It virtually completely eradicates broadleaf weeds and annual grasses. This increases the yields by 43.9 c/ha. When applied during the 7-8 leaf stage, the herbicide can have a significant impact on corn grain yield.

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Урожайность гибридов подсолнечника в зависимости от технологии и условий возделывания на юге Западной Сибири

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Представлены результаты исследований по апробации трех технологий возделывания подсолнечника (*Express, Clearfield* и классическая), проведенной на полях хозяйства ОАО «Надежда» в Баганском районе Новосибирской области в 2021–2022 гг. Приведены показатели биологических особенностей и урожайности трех гибридов подсолнечника с учетом технологии выращивания, предшественника и предпосевного фона. Установлено, что длительность периода вегетации подсолнечника существенно различалась у разных гибридов и зависела от погодных условий. Наибольшая продолжительность вегетационного периода наблюдалась у гибрида Санмарин 444, возделываемого по классической технологии – 180 ± 2 дня в 2021 г. и 151 ± 2 дня в засушливом 2022 г. Самый короткий период вегетации (162 ± 2 и 140 ± 2 дня соответственно) отмечен у гибрида Светлана КЛП, выращиваемого по технологии *Clearfield*. Показано, что в условиях юга Западной Сибири основным ограничивающим фактором для получения высоких урожаев подсолнечника является дефицит осадков. В 2021 г., отличающемся более благоприятными условиями для роста подсолнечника (ГТК = 0,8), урожайность семян гибридов составляла от 1,92 до 2,28 т/га без существенных различий в зависимости от технологии и предпосевного фона. В условиях засушливого 2022 г. (ГТК = 0,3) урожайность подсолнечника была значительно меньше и составляла от 0,42 до 1,3 т/га у разных гибридов в соответствии с технологиями их возделывания. Масличность семян изучаемых гибридов подсолнечника составляла 50–53%. Наибольшая эффективность гербицидных обработок была достигнута на посевах подсолнечника, выращиваемого по технологии *Clearfield*. Протравливание семян фунгицидами предотвращало развитие болезней культуры в полевых условиях, а использование инсектицида во время массового размножения лугового мотылька в 2021 г. привело к полному уничтожению вредителя на подсолнечнике.

Ключевые слова: гибриды подсолнечника, технологии и условия возделывания, предшественник, урожайность, масличность семян, средства защиты растений

Sunflower hybrid yields depending on the cultivation technology and conditions in the south of Western Siberia

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The article presents the results of research on testing three sunflower cultivation technologies (*Express, Clearfield* and classical), carried out in the fields of the OAO "Nadezhda" in the Bagansky district of the Novosibirsk region in 2021–2022. The indicators of biological characteristics and yield of three sunflower hybrids are given, taking into account the cultivation technology, forecrop and the pre-sowing background. It was found that the duration of the sunflower growing season varied significantly among different hybrids and depended on the weather conditions. The longest growing season was observed in the Sanmarin 444 hybrid, cultivated using the classical technology, which amounted to 180 ± 2 days in 2021 and 151 ± 2 days in the dry 2022. The shortest growing season (162 ± 2 and 140 ± 2 days, respectively) was noted in the Svetlana KLP hybrid, grown using the *Clearfield* technology. It was shown that in the conditions of the south of Western Siberia, the main limiting factor for obtaining high sunflower yields is the lack of precipitation. In 2021, characterized by more favorable conditions for sunflower growth (hydrothermal coefficient (HTC) = 0.8), the yield of hybrids ranged from 1.92 to 2.28 t/ha without significant differences depending on the technology and pre-sowing background. In the dry conditions of 2022 (HTC = 0.3), the sunflower yield was significantly lower and ranged from 0.42 to 1.3 t/ha for different hybrids in accordance with their cultivation technologies. The oil content of seeds of the studied sunflower hybrids was 50–53%. The highest efficiency of herbicide treatments was achieved on sunflower crops grown using the *Clearfield* technology. Seed treatment with fungicides prevented the development of crop diseases in the field, and the use of an insecticide during the mass reproduction of the meadow moth in 2021 led to a complete destruction of the pest on sunflower.

Keyword: sunflower hybrids, cultivation technologies and conditions, forecrop, yield, seed oil content, plant protection products

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INTRODUCTION

Sunflower is the main oilseed crop grown in various regions of the Russian Federation, due to its high yield and profitability [1–3]. The ever-growing demand for sunflower processed products is leading to an increase in the area devoted to this crop. Currently, Russia accounts for up to 40% of global oilseed production [4]. However, expanding the area under cultivation alone does not solve the problem of increasing sunflower production volumes. Therefore, current research areas include improving cultivation technology, optimizing production costs, and increasing yield per unit area [5–8].

Sunflower yield depends on a range of factors, of which the most important are cultivation technology and the selection of hybrids with high genetic resources[1] [1, 9–14]. Modern sunflower hybrids have a yield potential of over 40 centners of seeds per hectare [4]. However, achieving such a yield in production conditions is quite difficult due to crop rotation problems, increased weed damage, diseases, and pests[2] [6, 15–18]. Unfavorable agroclimatic conditions, especially moisture deficiency during the growing season, can also significantly reduce the yield [11, 19].

Weeds are a major problem in crop production, significantly reducing the quality and quantity of the harvest. To combat weeds, sunflower hybrid growers have found a solution by using herbicide-resistant varieties and specialized cultivation technologies. Several technologies have been developed for sunflower cultivation. *Classical (traditional) technology* involves the use of agronomic tillage techniques, particularly mechanized tillage, and primarily soil-applied herbicides to reduce weed damage. However, this technology is generally not very effective in controlling broadleaf weeds. New sunflower cultivation technologies focus on the interaction between the hybrid and herbicide, enabling effective weed control at all stages of the plant's growing season. Thus, the *Express Sun technology* can only be used on sunflower hybrids that are resistant to tribenuron-methyl: the use of preparations based on it allows inhibiting the growth of dicotyledonous weeds, including in some cases perennial species. However, when

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growing *Express* hybrids, it is not possible to suppress the development of such a malicious weed as broomrape. In this regard, a third stage was developed – the *Clearfield technology*, which allows for the cultivation of sunflower hybrids that are genetically resistant to preparations based on imazapyr and imazamox[3, 4] [7, 8, 13]. The *Clearfield* herbicide treatment method is based on the use of innovative preparations with a broad spectrum of action and adapted to specific agro-climatic conditions. *Clearfield* can be used for any tillage scheme – from classic to No-till, Strip-till, Mini-till. Sunflower hybrids grown using this technology are resistant to drought, lodging, white and gray mold, phoma disease and phomopsis leaf and stem blight. A significant advantage of this technology is its ability to successfully combat broomrape[5–8] [20].

In the conditions of Western Siberia, the effectiveness of new technologies for sunflower cultivation has been practically not studied, and therefore the aim of the study was a comparative study of *Express* and *Clearfield* hybrids and technologies in comparison with the classical technology for growing the crop in the south of Western Siberia.

MATERIAL AND METHODS

The object of the research were hybrid (F1) sunflower plants Safari, Svetlana KLP and Sanmarin 444, grown using different cultivation technologies.

Safari F1 is a two-line hybrid, included in the State Register for the Central Black Earth, Ural, and West Siberian regions. Its growing season lasts 120 days and it is resistant to downy mildew and white rot. Svetlana KLP F1 is a first-generation hybrid with a growing season of 122 days. It belongs to the "northern" type and is used as a standard in trials for early-maturing hybrids. It has genetic resistance to downy mildew. Sanmarin 444 F1 is a simple hybrid with high oil content and early maturing. It is susceptible to broomrape and phomopsis leaf and stem blight[9].

The research was conducted in 2021–2022 on the fields of the OAO “Nadezhda” in the Bagansky District of the Novosibirsk Region (53.844747 N, 77.741662 E). The soil of the experimental plot is southern alkaline sandy loam chernozem. The light mechanical composition of the parent rocks contributes to wind and water erosion on the ridges. According to the agroclimatic zoning, the area belongs to the Kulunda zone with a continental climate. It is characterized by a lack of moisture and a short growing season for plants, as well as early and deep soil freezing, which impedes the mobilization of mobile forms of nutrients and the accumulation of humus in the soil.

Agrometeorological conditions during the 2021–2022 growing seasons differed from long-term averages, primarily in terms of precipitation (see Table 1). During the study years, higher average monthly temperatures were observed in the spring (April and May) compared to long-term averages. However, 2022 is characterized as dry due to low precipitation (hydrothermal coefficient (HTC) = 0.3), while in 2021 the lack of precipitation in May and April was compensated by abundant precipitation in the summer (HTC = 0.8), which, in combination with high temperatures, had a beneficial effect on the growth and development of sunflower.

In 2021, sowing was carried out using TSM-8000 seeders from May 4 to 11, and in 2022, us-

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ing a Tempo L precision seeding drill from April 29 to May 8. The Safari hybrid was grown using the *Express* technology (field area: 86 hectares), Svetlana KLP – using the *Clearfield* technology (74 hectares), and Sanmarin 444 – using the conventional technology (64 hectares). The seeding rate was 1 seeding unit/2.5 ha (60,000 seeds/ha).

The seeds were treated with a pesticide complex containing Mefenoxam, Fludioxonil, Thiamethoxam, and Fulvital Plus. Azofoska N16-P16-K16 mineral fertilizer was applied at a rate of 100 kg/ha during sowing.

Phenological observations and determination of the growing season of sunflower hybrids were carried out according to the methodology of state variety testing of agricultural crops[10].

A TUMAN-2 self-propelled sprayer was used for herbicide treatments. Treatments were carried out from June 7 to June 15, at the stage of 2-4 to 6-8 true leaves of the crop using the *Express* technology and at 4-5 true leaves of the crop using the *Clearfield* technology, using August herbicides mixed with fertilizers and adhesives. The formulations were not varied from year to year; they were applied at the same rate and amount of working solution (see Table 2).

In addition to herbicide treatments in sunflower fields grown using conventional technology, inter-row cultivation was carried out using the KRN-5.6 cultivator to control weeds.

In 2021, to suppress the development of the meadow moth, crops were sprayed with the insecticide Break, OE at a rate of 0.15 l/ha and a working solution of 200 l/ha using an Amazon trailed sprayer.

Sunflower fields were surveyed for weed infestations before and after weed control efforts. A quantitative method for recording crop weed infestations was used[11], with 10 replicates. To monitor sunflower pests and diseases throughout the growing season, visual field surveys were conducted diagonally across the field every 7–10 days. The number of meadow moth larvae was calculated per one square meter.

The harvesting was carried out using the Vector, Polesie 1218 and New Holland combines equipped with specialized headers: rowless combing with a cutting width of 9.8 m and 6-meter row cutting.

The oil content was determined by the NIR spectroscopy in accordance with GOST 22391–2015[12] using an InfraLUM FT-10 infrared analyzer.

Statistical processing of the obtained data was carried out with the calculation of the standard error (SE) using the Excel computer program.

Табл. 1. Температура воздуха и осадки вегетационного периода в годы исследований, локальная метеостанция Agrokeep (Bayer 2833641312), с. Мироновка

Table 1. Air temperature and precipitation during the growing season during the years of research, local weather station Agrokeep (Bayer 2833641312), Mironovka village

Period	Average daily air temperature, ºC					Total precipitation, mm				
	norm	2021	2022	deviations from the norm		norm	2021	2022	deviations from the norm	
				2021	2022				2021	2022
April	4,7	9,7	7,0	5,0	2,3	18	0	3,2	–18,0	–14,8
May	13,0	18,6	16,0	5,6	3,0	23	0	26,7	–23,0	3,7
June	18,0	18,7	17,8	0,7	–0,2	50	52,7	14,5	2,7	–35,5
July	20,0	21,5	20,2	1,5	0,2	65	56,2	8,8	–8,8	–56,2
August	17,6	19,3	17,1	1,7	–0,5	42	53,9	5,6	11,9	–36,4

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Табл. 2. Даты гербицидных обработок посевов подсолнечника в 2021–2022 гг.
Table 2. Dates of herbicide treatments of sunflower crops in 2021–2022

Technology	Date of treatment	Hybrid (F1)	Preparation and the application rate
Express	07.06–11.06	Safari	Quickstep 0.5 l/ha + Mortar 40 g/ha + Humate (fertilizer) 1 l/ha
Clearfield	13.06–15.06	Svetlana KLP	Paradox 0.33 l/ha + Grader 0.07 l/ha + Adju (adhesive) 0.33 l/ha + Humate 1 l/ha
Classical	12.06	Sanmarin 444	Quickstep 0.5 l/ha + Humate 1 l/ha

RESULTS AND DISCUSSION

The onset dates of the phenological phases of sunflower growth and development varied among hybrids and were largely dependent on meteorological conditions during the growing season. Seedlings of the Sanmarin 444 hybrid, grown using conventional technology, emerged 12–13 days after sowing; seedlings were uneven, spread over 8–10 days in 2021 and 10–12 days in 2022. The emergence time for the Svetlana KLP (*Clearfield*) hybrid ranged from 9 to 12 days. The Safari (*Express*) hybrid had very uniform emergence, emerging 10 to 12 days after sowing. The emergence time for the same hybrid varied slightly depending on the preceding crop and pre-sowing soil treatment. Thus, the emergence of hybrid seedlings Svetlana KLP and Safari, sown on wheat and barley stubble, was delayed by 1–2 days compared to plants in fields with autumn tillage with a forecrop – spring wheat.

During the study years, sunflower flowering began in the third ten-day period of July and lasted for 10–12 days for the Svetlana KLP and Safari hybrids, grown using new technologies. For the Sanmarin 444 hybrid, flowering was delayed by an additional 7–8 days.

The length of the sunflower growing season depended on the genetic characteristics of the hybrid and weather conditions, which varied significantly across the years of the study. Thus, the growing season of sunflower hybrids in 2022 was significantly shorter, likely due to insufficient precipitation, compared to 2021 (see Table 3). While the forecrop had some influence on the progression of individual phases of crop development, it ultimately had no effect on the overall maturity of the hybrids.

Although all tested hybrids belong to the early-ripening group, differences in the length of their growing seasons were noted, including across the years of study. The longest growing season was observed for the Sanmarin 444 hybrid, which in 2021 amounted to 180 ± 2 days; in the dry 2022 year, it ended a month earlier (151 ± 2 days). The shortest growing season was observed for the Svetlana KLP hybrid – 162 ± 2 and 140 ± 2 days, respectively, in 2021 and 2022.

Sunflower hybrid yields varied across years of study, as well as depending on the technology and the forecrop (see Table 3). A comparative analysis of sunflower hybrid yields over two years of testing revealed that the main limiting factor for achieving high yields of this crop is insufficient precipitation, regardless of cultivation technology. Thus, the yield of the Svetlana KLP hybrid, grown in fallow land using the *Clearfield* technology, was 1.7 times lower during the dry growing season of 2022 than in 2021. An even greater difference was observed for the Safari (*Express*) hybrid, for example, when grown in fallow land – its yield was reduced by 4.2 times, and for Sanmarin 444 (classic technology) – by 5 times. Pre-planting tillage and pre-sowing soil cultivation also influenced the crop yield. This influence was particularly pronounced during the critical weather season (2022), when precipitation was deficient. Specifically, the yield of the Safari hybrid, grown using the *Express* technology, ranged from 1.19 t/ha when grown on wheat stubble to 0.54 t/ha when grown on fallow. At the same time, this hybrid, sown after fallow, demonstrated the highest yield in 2021 – 2.28 t/ha. Overall, during the dry 2022, the yield of hybrids grown using the latest technologies

Табл. 3. Биологические и продуктивные показатели гибридов подсолнечника в зависимости от предпосевного фона и технологий их возделывания, ОАО «Надежда», 2021–2022 гг.

Table 3. Biological and productive indicators of sunflower hybrids depending on the pre-sowing background and cultivation technologies, OAO "Nadezhda", 2021–2022

Technology	Hybrid	Pre-sowing background (forecrop)	Vegetation period, days	Seed yield, t/ha	Oil content of seeds, %
2021					
Classical	Sanmarin 444	Autumn ploughing (wheat)	180 ± 2	2,1	50,0
ClearField	Svetlana KLP	Autumn ploughing (wheat)	162 ± 2	1,92	52,0
		Complete fallow	162 ± 2	1,99	52,0
Express	Safari	Complete fallow	175 ± 2	2,28	53,0
2022					
Classical	Sanmarin 444	Stubble field (wheat, barley)	151 ± 2	0,42	52,0
Clearfield	Svetlana KLP	Autumn ploughing (wheat)	140 ± 2	1,1	52,4
		Stubble field (wheat)	140 ± 2	1,3	51,8
Express	Safari	Autumn ploughing (wheat)	150 ± 2	0,99	52,0
		Stubble field (wheat)	150 ± 2	1,19	52,8
		Complete fallow	150 ± 2	0,54	52,6

significantly exceeded that of conventional technology.

Weather conditions and the preceding crop did not significantly affect the oil content of sunflower seeds, which varied from 50 to 53%. The highest oil content was observed in the seeds of the Safari hybrid, grown using the *Express* technology.

Observations revealed that weeds predominated in sunflower crops grown using various technologies: barnyard grass, field bindweed, and leafy euphorbia, with lesser amounts of wild buckwheat, wild oats, common wormwood, and Canadian fleabane. In addition to the above-mentioned species, saltwort grew in significant quantities in sunflower fields grown using conventional technology (see Table 4).

Herbicide treatment of sunflower crops grown using the *Clearfield* technology completely suppressed the growth of all growing weeds until harvest. Herbicide treatment of sunflowers grown using the *Express* technology also resulted in the death of virtually all weed species, with the exception of the Canadian fleabane weed, which subsequently regenerated in isolated numbers but did not compete with the crops. The number of weeds decreased by 3 times in sunflower crops grown using conventional technology despite the use of herbicidal and mechanical treatments, but the species such as common wormwood, saltwort, Canadian fleabane, sow thistle, and leafy euphorbia continued to develop competing with sunflower.

It should be noted that, despite their high effectiveness, *Clearfield* herbicides negatively impact the next crop in the rotation, so fallowing the following year is essential. With conventional technology, fallowing the following year is also substantial due to the large number of weeds accumulated during the sunflower year.

No signs of sunflower diseases have been recorded on the OOO “Nadezhda” premises over two years of cultivation, indicating adequate fungicide treatment of the seed. No specialized pests have been observed. However, in 2021, a massive outbreak of the meadow moth was observed, including in some sunflower fields. The average number of pest caterpillars on July 31, 2021, was 133 ± 22 per square meter. As of August 2, 2021, larvae of various instars were found not only on leaves but also on the heads of the crop, necessitating the use of insecticides. The biological efficacy of treatment with Break, OE insecticide was 100%.

CONCLUSIONS

1. The length of the sunflower growing season varied depending on the hybrid's genetic characteristics and weather conditions. The late hybrid Sanmarin 444 had a growing season of 180 ± 2 days in 2021, while in the dry 2022 season, it ended a month earlier (151 ± 2 days). The Svetlana KLP hybrid proved to be the earliest maturing, completing its development in 162 ± 2 and 140 ± 2 days in 2021 and 2022, respectively.

2. In the southern conditions of Western Siberia, the main limiting factor for high sunflower yields is insufficient precipitation. In 2021, a year with favorable moisture conditions, hybrid seed yields varied slightly depending on the technology and the preceding crop, ranging from 1.92 to 2.28 t/ha. In the dry 2022-year, seed yields were significantly lower and varied widely from 0.42 to 1.30 t/ha. However, the yield of the hybrids grown using the latest technologies was higher than that of the hybrids grown using conventional technologies. Weather conditions and the previous crop did not significantly affect the oil content of sunflower seeds, which ranged from 50 to 53%.

3. The effectiveness of herbicide treatments for sunflower crops grown using new technologies was high, reaching 100% (*Clearfield*). In sunflower crops grown using conventional technology, weed numbers were reduced by a factor of three after herbicide and mechanical treatments. The timely use of fungicides and insecticides to prevent disease and pest damage enabled complete control of pest growth in sunflowers.

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Табл. 4. Эффективность гербицидов в посевах подсолнечника, 2022 г.
Table 4. Efficiency of herbicides in sunflower crops, 2022

Technology	Hybrid	Number of weeds, pcs../ m^2 ± SE		Types of vegetative weeds	
		before treatment	on the 10th day after treatment	before treatment	after treatment
Express	Safari	15 ± 5	1 ± 0,5	Barnyard millet, corn bindweed, leafy euphorbia, wild buckwheat, oatgrass, common wormwood, Canada fleabane	Canada fleabane
Clearfield	Svetlana KLP	19 ± 2	0		–
Classical	Sanmarin 444	24 ± 2	8 ± 2	Barnyard millet, corn bindweed, leafy euphorbia, wild buckwheat, oatgrass, common wormwood, Canada fleabane, Russian thistle	Leafy euphorbia, Canada fleabane, common wormwood, Russian thistle

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Морфофункциональные параметры молочной железы коров разных генотипов по гену *PGR*

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Прогестерон регулирует репродуктивную функцию, стимулирует развитие железистой ткани молочной железы и секрецию молока. Большинство его эффектов опосредовано ядерными рецепторами, являющимися транскрипционными факторами. Данных о частоте распределения генотипов и аллелей гена рецептора прогестерона (*PGR*) и ассоциации их с морфофункциональными параметрами молочной железы у крупного рогатого скота ограниченное количество, и все они касаются трансграничных пород. Цель исследования – изучение морфофункциональных параметров молочной железы коров костромской и голштинской пород разных генотипов по гену *PGR* в условиях племенных хозяйств Костромской области. Исследование выполнено в 2024 и 2025 гг. на племенных первотелках костромской (n = 81) и голштинской пород (n = 26). Определена взаимосвязь генотипа по гену *PGR* и морфофункциональных параметров молочной железы. Выявлено, что в исследуемых выборках коров костромской и голштинской пород наиболее распространен генотип *AA* гена *PGR* (частота распределения 0,568 и 0,462 соответственно). Однако оптимальными морфологическими параметрами для машинного и роботизированного доения и ваннообразной формой молочной железы обладают носители редкого генотипа PGR^{GG}. Также по результатам первой лактации установлено, что в выборке костромской породы у носителей генотипа PGR^{GG} удой был выше на 9,26 и 14,29%, чем у носителей генотипов PGR^{AA} и PGR^{AG} соответственно ($p \leq 0{,}5$). На основе полученных данных определено, что носители генотипа PGR^{GG} обладают предпочтительными для машинного и роботизированного доения морфофункциональными параметрами молочной железы, поэтому необходимо продолжить исследования в данном направлении на большем поголовье животных и в рамках других популяций крупного рогатого скота.

Ключевые слова: ген рецептора прогестерона, генотип, морфофункциональные параметры, коровы, костромская и голштинская породы, молочная железа

Morphofunctional parameters of the mammary gland of cows of different genotypes for the *PGR* gene

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Progesterone is a regulator of the reproductive function and stimulates the development of glandular tissue of the mammary gland and milk secretion. Most of its effects are mediated by nuclear receptors, which are transcription factors. There is a limited amount of data on the frequency of distribution of genotypes and alleles of the progesterone receptor gene (*PGR*) and their association with morphofunctional parameters of the mammary gland in cattle, and all of them concern transboundary breeds.

The purpose of the scientific work is to study the morphofunctional parameters of the mammary gland of the Kostroma and Holstein cows of different genotypes for the *PGR* gene in the conditions of breeding farms of the Kostroma region. The studies were carried out in 2024–2025 on breeding first-calf cows of the Kostroma (n = 81) and Holstein (n = 26) breeds. The relationship between the genotype of the *PGR* gene and the morphofunctional parameters of the mammary gland was determined. It was revealed that in the studied samples of cows of the Kostroma and Holstein breeds, the most common genotype is *AA* of the *PGR* gene (distribution frequency 0.568 and 0.462, respectively). However, carriers of the rare PGR^{GG} genotype had optimal morphological parameters for machine and robotic milking and a bath-shaped mammary gland. Also, based on results of the first lactation, it was found that in the sample of the Kostroma breed, the milk yield of carriers of the PGR^{GG} genotype was 9.26% and 14.29% higher than that of the carriers of the PGR^{AA} and PGR^{AG} genotypes ($p \leq 0.5$), respectively. Based on the data of the study, it was determined that carriers of the PGR^{GG} genotype have morphofunctional parameters of the mammary gland that are preferable for machine and robotic milking, therefore it is necessary to continue research in this area on a larger number of animals and within other cattle populations.

Keywords: progesterone receptor gene, genotype, morphofunctional parameters, cows, the Kostroma and Holstein breeds, mammary gland

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INTRODUCTION

Progesterone is an important regulator of the reproductive function, ensuring a normal menstrual cycle and maintaining pregnancy, stimulating the development of mammary gland tissue, and milk secretion. Progesterone's effects are mediated by its nuclear receptors, which are transcription factors. The progesterone receptor interacts with progesterone in the cell nucleus, thereby activating the expression of a number of specific genes [1, 2].

Among open scientific sources, the majority of the studies are devoted to the association of this hormone and the gene encoding its receptor with superovulation and embryogenesis[1,2] [3–5]. However, there is also information about the relationship between the level of this hormone and the incidence of mastitis in cows [6].

Data are available on the single nucleotide polymorphisms *G59752C* and *T81637C*, located in introns 3 and 4 of the progesterone receptor gene (*PGR*). Association analysis showed that these *SNP*s have a significant effect on the total number of eggs ($p < 0.01$), and the *T81637C* polymorphism is also associated with the number of embryos. Furthermore, these polymor-

[1]*Driver A.M., Huang W., Gajic S., Monson R.L., Rosa G.J., Khatib H.* Short communication: Effects of the progesterone receptor variants on fertility traits in cattle // Journal of Dairy Science, 2009, vol. 92 (8), pp. 4082–4085.

[2]*Morris D., Diskin M.* Effect of progesterone on embryo survival // Animal, 2008, vol. 2 (8), pp. 1112–1119.

phisms are associated with superovulation traits in cows [3, 7].

Yu.Yu. Shakhnazarova et al. [4] found that among the Holstein cows, carriers of the *AA* genotype of the *PGR* gene were significantly superior to carriers of the *AG* genotype in lifetime productivity.

Data on the genotype and allele frequencies of the progesterone receptor gene in cattle is limited, and all available data pertain to transboundary breeds. Overall, the PGR^{AG} genotype has the highest frequency, but the predominant allele in different populations can be either *A* or *G* (see footnote 1) [4, 8].

Thus, taking into account the results of the studies of the previous authors and information about the biological role of progesterone and its receptor, it is necessary to continue studying the frequency of distribution of the *PGR* gene genotypes and their association with economically valuable traits in domestic cattle breeds.

The purpose of the study is to investigate the morphofunctional parameters of the mammary gland of the Kostroma and Holstein cows of different genotypes for the *PGR* gene in the conditions of breeding farms in the Kostroma region.

MATERIAL AND METHODS

The study was conducted in 2024 and 2025 on the farms in the Kostroma region on 107 breeding first-calf cows of the Holstein (n = 26, OOO "Sushchevo") and Kostroma breeds (n = 81; AO "Karavaevo Breeding Farm" – 33 heads, OOO ""Planeta" Agrofirm" – 17 heads, OOO "Minskoe" – 31 heads).

The zootechnical records data were obtained from the IAS "SELEKS" (Russia), the veterinary records from "M-complex" (Russia) [9]. Linear assessment of cows was carried out from the 30th to the 120th day of lactation[3, 4]. Morphological assessment of the udder was performed according to the VASKHNIL methodology[5]. The udder shape was assessed visually 1–1.5 hours before milking. The udder function was assessed in the second and fourth months of lactation using an MM-04V milk monitoring device (Russia). Milking time was measured using a stopwatch.

Blood samples were collected from the cows' tail veins using vacuum systems with the anticoagulant K2 EDTA (Germany). The DNA was isolated using the PROBA-GS-GENETIKA reagent kit (Russia). During the study, a test system for genotyping cattle for the progesterone receptor gene using real-time polymerase chain reaction (RT-PCR) was developed. Nucleotide sequences were selected using the NCBI (National Center for Biotechnology Information) databases[6] and Ensembl[7] (see Table 1). Primer and probe analysis

Табл. 1. Нуклеотидные последовательности для генотипирования коров по гену *PGR*

Table 1. Nucleotide sequences for genotyping cows for the *PGR* gene

Name	Sequence
Progesterone receptor gene – *rs136764006* (*1:g.7861416G>A*)	
PGR_for	*5′-gCA gTg AAA AgA CAC ATT CAg gAg C-3′*
PGR_rev	*5′-AAA ggC ATT AAg gCA ATT TCT gAC C-3′*
PGR_A	*5′-gAg ACC ATA ATg TgT ATg-3′*-(*FAM*)
PGR_G	*5′-gAg ACC gTA ATg TgT ATg-3′*-(*HEX*)
PGR_BHQ	(*BHQ1*)-*5′-gAg AAg TTA CTC Agg AAA ACT g-3′*-(*P*)

[3]Order of the Ministry of Agriculture of the Russian Federation dated February 1, 2011 No. 25 "On approval of the Rules for maintaining records in pedigree cattle breeding of dairy and dairy-meat productivity directions" // GARANT.RU: information and legal portal. URL: https://www.garant.ru/products/ipo/prime/doc/2074157/.

[4]SNPlem R 10-96. Rules for evaluation the body conformation of the daughters from sires of dairy and dairy-meat breeds (approved by the Department of Animal Husbandry and Breeding of the Ministry of Agriculture of Russia on June 14, 1996). Moscow: Agropromizdat, 1996, 18 p.

[5]Evaluation of cow udders, milk flow process and mammary gland diseases in connection with machine milking: index. lit. for 1982–1988. Moscow: Central Scientific Agricultural Library, 1990, 101 p.

[6]https://www.ncbi.nlm.nih.gov/

[7]https://www.ensembl.org/index.html

was performed using the Oligo 6.0 software.

To perform real-time PCR, 30 µl of PCR mixture and 5 µl of DNA sample were added to each tube of the strip using variable volume dispensers. The PCR mixture contained fluorescently labeled FAM and HEX probes (0.1 µl each), fluorescence quencher – BHQ probe (0.3 µl), reverse (0.6 µl) and forward primers (0.1 µl), 25 mM dNTP (0.24 µl), 10 µl of enzyme solution (0.5 µl of Taq polymerase and 9.5 µl of PCR buffer).

Genotyping of cow DNA samples was performed using a DT Prime thermocycler (Russia) at an annealing temperature of 57°C. Genotype was determined by melting curve analysis.

The frequency of *PGR* genotypes was determined using the formula

$$P = m/N,$$

where P – genotype frequency in a group; m – number of genotype carriers; N – total number of individuals.

The frequency of alleles *A* and *G* of the *PGR* gene was calculated as follows:

$$p = \frac{2n_{AA} + n_{AG}}{2N} \text{ и } q = \frac{2n_{GG} + n_{AG}}{2N},$$

where p – allele frequency *A*; q – allele frequency *G*; n_{AA}, n_{AG}, n_{GG} – number of genotype carriers *AA*, *AG* and *GG* respectively; N – total number of ianimals in a group.

The standard error of the genotype frequency was determined using the formula

$$SE_{AA} = \sqrt{\frac{P_{AA} \cdot (1 - P_{AA})}{N}},$$

where SE_{AA} – standard error of the genotype frequency *AA*; P_{AA} – *AA* allele frequency.

The standard error of the allele frequency was calculated as

$$SE_p = \sqrt{\frac{p \cdot q}{2 \cdot N}},$$

where SE_p – standard error of the allele frequency *A*.

Gene equilibrium was estimated using the Hardy–Weinberg equation:

$$p^2 + 2pq + q^2 = 1.$$

Statistical processing of the results was performed in Microsoft Office Excel (2019). Statistical hypotheses were tested in the RStudio development environment version 2024.12.0 (Build 467) using the R language version 4.4.2. Testing the statistical significance of differences between animal groups was performed by calculating the Student's *t*-test.

Табл. 2. Частота распределения генотипов гена *PGR* у коров разных пород
Table 2. Distribution frequency of *PGR* gene genotypes in cows of different breeds

Breeding farm	*N*, heads	*AA*			*AG*			*GG*		
		n, heads	lobes, $P \pm SE_{AA}$	%	*n*, heads	lobes, $P \pm SE_{AG}$	%	*n*, heads	lobes, $P \pm SE_{GG}$	%
Kostroma breed										
AO “Karavaevo Breeding Farm”	33	16	0,485 ± 0,087	48,48	11	0,333 ± 0,082	33,33	6	0,182 ± 0,157	18,18
OOO “Minskoe”	31	23	0,742 ± 0,091	74,19	7	0,226 ± 0,158	22,58	1	0,032 ± 0,177	3,23
OOO ““Planeta” Agrofirm”	17	7	0,412 ± 0,186	41,18	10	0,588 ± 0,156	58,82	0	0,000	0,00
For the sample as a whole	81	46	0,568 ± 0,073	56,79	28	0,346 ± 0,090	34,57	7	0,086 ± 0,106	8,64
Holstein breed										
OOO “Sushche-vo”	26	12	0,462 ± 0,144	46,15	7	0,269 ± 0,168	26,92	7	0,269 ± 0,168	26,92

RESULTS AND DISCUSSION

As a result of genotyping DNA samples of breeding cows, the following results were obtained (see Table 2).

It was found that the PGR^{AA} genotype was most frequent in the Kostroma cow sample. However, in the herd of the OOO "“Planeta” Agrofirm", the heterozygous genotype for the progesterone receptor gene was predominantly recorded (58.8%). In a sample of Holstein cows, the PGR^{AA} genotype also showed a tendency toward the highest prevalence, while PGR^{AG} and PGR^{GG} had similar frequencies in the herd. These findings differ from those reported by other researchers (see footnote 1) [4, 8].

The analysis showed that the highest frequency in the samples of the cows of both the Kostroma and Holstein breeds in the breeding farms of the region was recorded for allele *A* (see Table 3).

Testing the hypothesis of free distribution of the *PGR* gene alleles among the cows of the

Табл. 3. Частота распределения аллелей гена *PGR* у коров разных пород
Table 3. Distribution frequency of *PGR* gene alleles in cows of different breeds

Breeding farm	*N*, heads	*A*		*G*	
		lobes, $P \pm SE_p$	%	lobes, $P \pm SE_p$	%
Kostroma breed					
AO "Karavaevo Breeding Farm"	33	0,652 ± 0,059	65,15	0,348 ± 0,059	34,85
OOO "Minskoe"	31	0,855 ± 0,045	85,48	0,145 ± 0,045	14,52
OOO "“Planeta” Agrofirm"	17	0,706 ± 0,078	70,59	0,294 ± 0,078	29,41
For the sample as a whole	81	0,741 ± 0,034	74,07	0,259 ± 0,034	25,93
Holstein breed					
OOO "Sushchevo"	26	0,596 ± 0,068	59,61	0,404 ± 0,068	40,38

Табл. 4. Линейная оценка вымени коров костромской породы в разрезе генотипов гена *PGR*, балл
Table 4. Linear assessment of the Kostroma cows udder in terms of the *PGR* gene genotypes, score

Indicator	Optimal value (see footnote 4)	Genotype		
		AA	*AG*	*GG*
n, heads	–	46	28	7
Attachment of the anterior lobes	8	5,11 ± 0,15	5,21 ± 0,24	5,00 ± 0,22
Length of the anterior lobes	9	5,33 ± 0,14*	5,39 ± 0,25	5,86 ± 0,14
Height of attachment of the posterior lobes	9	5,39 ± 0,14	5,54 ± 0,21	5,71 ± 0,47
Width of the posterior lobes	9	5,91 ± 0,20	5,82 ± 0,28	6,29 ± 0,47
Fissura	9	6,93 ± 0,26	6,71 ± 0,39	7,29 ± 0,52
Position of the bottom	6	5,04 ± 0,12	5,46 ± 0,25	5,00 ± 0,00
Nipple positioning: front	5	4,98 ± 0,06	5,11 ± 0,08	5,00 ± 0,00
rear	5	5,15 ± 0,10	5,21 ± 0,17	4,86 ± 0,14
Nipple length: front	5	5,41 ± 0,15*	5,36 ± 0,23	4,86 ± 0,42
rear	5	3,92 ± 0,19*	4,00 ± 0,22*	3,14 ± 0,28
General appearance	100	80,72 ± 0,47	79,86 ± 0,66	81,14 ± 1,45

Note. In Tables 4, 5, 7: the reliability of differences is indicated in comparison with the *GG* genotype of the *PGR* gene (*$p \le 0{,}5$; **$p \le 0{,}01$; ***$p \le 0{,}001$).

studied populations made it impossible in none of the cases to accept the alternative hypothesis of a significant difference between the observed genotype frequencies and the theoretically expected ones (p > 0,05). The difference closest to the significance threshold was observed in Holstein cows from the OOO "Sushchevo" (χ^2 = 5,053, p = 0,08). Consequently, in all the studied populations, the alleles of the *PGR* gene spread freely and do not experience selection pressure.

When analyzing the morphological parameters of the mammary gland in a sample of cows of the Kostroma breed, the best scores were noted for six of the eleven assessed parameters in individuals of the rare genotype PGR^{GG} (see Table 4).

In carriers of the PGR^{GG} genotype, the length of the anterior udder lobes was estimated to be 9.04% significantly higher than in the individuals with the alternative homozygous genotype ($p \leq 0.5$), which may indicate greater milk productivity of these cows[8]. Also, cows with the *GG* genotype of the progesterone receptor gene had optimal anterior nipple length compared to the individuals with the PGR^{AA} ($p \leq 0.5$) and PGR^{AG} genotypes. Meanwhile, the posterior nipple length in first-calf heifers with the PGR^{GG} genotype was 24.84% and 27.39% shorter ($p \leq 0.5$) than in the cows with the alternative homo- and heterozygous genotypes, respectively. In our opinion, the mammary gland of the individuals with a heterozygous genotype developed more harmoniously, since the same length of the nipples is a necessary condition for machine and robotic milking.

Among the Holstein cows, the mammary gland parameters of the *GG* genotype carriers were closest to optimal – they corresponded to nine out of eleven points (see Table 5).

However, a significant difference in the assessment was only observed for the height of the posterior udder attachment. In the cows with the PGR^{GG} genotype, this indicator was 20.03% and 21.67% higher than in the cows with the PGR^{AA} and PGR^{AG} genotypes, respectively ($p \leq 0.5$). A higher posterior udder attachment in a cow indi-

Табл. 5. Линейная оценка вымени коров голштинской породы в разрезе генотипов гена *PGR*, балл
Table 5. Linear assessment of the Holstein cows udder in terms of the *PGR* gene genotypes, score

Indicator	Optimal value (see footnote 4)	Genotype		
		AA	*AG*	*GG*
n, heads	–	12	7	7
Attachment of the anterior lobes	8	5,00 ± 0,48	4,57 ± 0,37	5,29 ± 0,42
Length of the anterior lobes	9	5,33 ± 0,40	5,29 ± 0,42	4,71 ± 0,29
Height of attachment of the posterior lobes	9	5,83 ± 0,39*	5,71 ± 0,36*	7,29 ± 0,36
Width of the posterior lobes	9	6,17 ± 0,46	6,14 ± 0,34	7,14 ± 0,74
Fissura	9	5,58 ± 0,34	6,00 ± 0,49	6,50 ± 0,89
Position of the bottom	6	4,42 ± 0,34	4,71 ± 0,52	4,71 ± 0,42
Nipple positioning: front	5	4,92 ± 0,15	5,29 ± 0,18	5,29 ± 0,18
rear	5	5,42 ± 0,23	5,43 ± 0,37	5,71 ± 0,29
Nipple length: front	5	4,88 ± 0,09	4,86 ± 0,32	4,93 ± 0,28
rear	5	3,63 ± 0,21	3,57 ± 0,30	3,86 ± 0,32
General appearance	100	78,92 ± 1,13	78,29 ± 1,48	78,86 ± 1,28

[8]*Kuzmina N.V., Listratenkova V.I., Koltsov D.N.* The relationship between linear assessment indicators and exterior indices with the productivity of Brown Swiss cows in the Smolensk region // "Transactions of the educational establishment "Vitebsk the Order of "the Badge of Honor" State Academy of Veterinary Medicine": scientific and practical journal, 2009, vol. 45, Issue 2, Ch. 2, pp. 93–94.

Распределение коров костромской и голштинской пород с разными генотипами по форме вымени
Distribution of cows of the Kostroma and Holstein breeds with different genotypes by the udder shape

cates a smaller distance between the lower edge of the vulva and the upper edge of the glandular tissue of the mammary gland, meaning the udder of such an animal has the ability to fill better and the cow is predisposed to high milk yield. Also, the height of the attachment of the posterior lobes of the udder characterizes the supporting function of the ligamentous apparatus of the mammary gland (prevents it from sagging with age), which facilitates convenient fixation of the apparatus for machine milking and reduces the risk of infection of the nipple canals with pathogenic microflora [10].

In the Kostroma breed sample, a predominantly cup-shaped mammary gland was observed (see the figure). It is known that cows

Табл. 6. Функциональные свойства вымени коров разных генотипов гена *PGR*
Table 6. Functional properties of the udder of cows with different genotypes of the *PGR* gene

Indicator	Genotype		
	AA	*AG*	*GG*
Kostroma breed			
n, heads.	46	28	7
Daily milk yield, kg	25,41 ± 0,85	24,66 ± 0,77	25,69 ± 1,88
Milking time, min	11,86 ± 0,38	11,35 ± 0,46	12,44 ± 0,92
Milk flow rate, kg/min	2,15 ± 0,05	2,22 ± 0,08	2,07 ± 0,06
Holstein breed			
n, heads.	10	7	5
Daily milk yield, kg	28,39 ± 1,12	31,06 ± 2,23	28,02 ± 1,66
Milking time, min	11,47 ± 0,70	10,93 ± 0,59	10,60 ± 0,99
Milk flow rate, kg/min	2,53 ± 0,15	2,88 ± 0,22	2,75 ± 0,33

Табл. 7. Показатели молочной продуктивности коров разных генотипов гена *PGR* за первую лактацию

Table 7. Milk productivity indicators of cows with different genotypes of the *PGR* gene during the first lactation

Indicator	Genotype		
	AA	*AG*	*GG*
Kostroma breed			
n, heads	45	28	5
Milk yield, kg	7380,10 ± 233,37	6970,64 ± 234,82*	8133,10 ± 443,40
Fat, %	4,21 ± 0,05	4,04 ± 0,04	4,33 ± 0,16
Protein, %	3,58 ± 0,04	3,51 ± 0,04	3,71 ± 0,09
Holstein breed			
n, heads	10	7	5
Milk yield, kg	9308,10 ± 367,58	9753,29 ± 775,84	9559,80 ± 403,69
Fat, %	3,85 ± 0,03	3,79 ± 0,04	3,83 ± 0,05
Protein, %	3,38 ± 0,03	3,35 ± 0,02	3,36 ± 0,02

with cup- and tub-shaped udders are most prone to high milk production[9]. Thus, the carriers of the *GG* genotype are preferable, as no individuals with an undesirable rounded udder shape were found among them. In the sample of Holstein cows, the highest frequency (80%) of tub-shaped mammary glands was also found in the cows with the PGR^{GG} genotype.

When assessing the functional properties of the mammary gland during control milkings in the samples of the Kostroma and Holstein breeds of cows, no reliable differences were found in terms of *PGR* gene genotypes (see Table 6).

Carriers of the heterozygous genotype tended to have the highest milk flow rate (2.22 ± 0.08 and 2.88 ± 0.22 kg/min in the Kostroma and Holstein breeds, respectively), which is preferable for machine and robotic milking in order to reduce production costs and reduce the impact of vacuum on the mammary gland. Milk flow rate and milking duration are inversely related: the shorter the time spent on milking cows, the lower the likelihood of udder injury associated with prolonged exposure to vacuum on its parenchyma [11].

Moreover, analysis of milk productivity indicators during the first lactation showed that the Kostroma cows with the PGR^{GG} genotype had a 9.26% and 14.29% higher milk yield than the cows with the PGR^{AA} and PGR^{AG} genotypes, respectively ($p \leq 0.5$). No significant differences in fat and protein mass percentages were found between the different genotypes (see Table 7).

In the sample of Holstein breed, no significant differences in the qualitative and quantitative indicators of milk productivity in the cows with different genotypes of the *PGR* gene during the first lactation were found (see Table 7).

CONCLUSIONS

1. It was found that the *AA* genotype of the progesterone receptor gene was the most common genotype in the studied samples of the Kostroma breeding cows (frequency of 0.568). A tendency toward the prevalence of this genotype was also observed in the Holstein cattle population (frequency of 0.462). The predominant allele was PGR^{A} in both samples.

2. Carriers of the rare PGR^{GG} genotype have optimal morphological parameters for machine and robotic milking and a tub-shaped mammary gland, which is also characteristic of the first-calf cows of both the Kostroma and Holstein breeds in the studied samples.

3. Analysis of the first-lactation data revealed that in a sample of the Kostroma cows carrying

[9] *Samusenko L.D., Mamaev A.V.* Cattle breeding: practical training. St. Petersburg, 2020, 240 p.

the PGR^{GG} genotype, the milk yield was 9.26% and 14.29% higher than in the cows carrying the PGR^{AA} and PGR^{AG} genotypes, respectively ($p \leq 0.5$). In a sample of the Holstein cows with different *PGR* gene genotypes, no significant differences were found in either quantitative or qualitative milk production characteristics during the first lactation.

4. In connection with the above, it can be assumed that carriers of the PGR^{GG} genotype have preferable morphofunctional parameters of the mammary gland for machine and robotic milking, therefore it is recommended to continue research in this direction on a larger number of animals and within other populations of cattle.

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Разработка нового способа утилизации свежих побочных продуктов животноводства

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Способ утилизации свежеполученных побочных продуктов животноводства заключается в том, что свежий навоз и/или помет разделяется на жидкую и твердую фракции путем предварительного разведения водой с последующим гомогенизированием и сепарированием. Жидкая фракция использовалась в качестве жидкого биоорганического удобрения. Твердая фракция использовалась в качестве субстрата для разведения дождевых червей семейства Lumbricidae, с последующим получением органического удобрения вермикомпоста и биомассы дождевых червей. Первоначально способ направлен на снижение токсичности свежеполученных побочных продуктов животноводства путем их разбавления водой в соотношении от 1:1,5 до 1:2,5 м^3 и гомогенизации до однородного состояния. В результате класс опасности снижается до V (практически не наносит вреда окружающей среде). При этом происходит очищение от балластных инородных механических включений с высокой (камни, щебень, металл и т.д.) и низкой (шпагат, веревки, щепа, палки и т. д.) удельной массой, первые из которых оседают на дно емкости, вторые всплывают на поверхность, после чего удаляются механическим путем. Затем гомогенизированная субстанция подается в пресс, где происходит выдавливание и отделение жидкой фракции от твердой, которые собираются в отдельную тару. Твердая фракция использована в качестве субстрата для выработки вермикомпоста дождевыми червями семейства Lumbricidae. Агрохимический состав жидкой и твердой фракций соответствовал требованиям ГОСТ, предъявляемым к органическим и минеральным удобрениям. Токсикологическая характеристика жидкой фракции свидетельствовала о безвредности для биологических объектов окружающей среды.

Ключевые слова: побочные продукты животноводства, вермикомпостирование, агрохимический состав вермикомпоста, дождевые черви (Lumbricidae*)*

Development of a new disposal method of fresh animal by-products

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The method for disposal of freshly obtained by-products of animal husbandry consists of separating fresh manure and/or droppings into liquid and solid fractions by preliminary dilution with water, followed by homogenization and separation. The liquid fraction was used as a liquid bioorganic fertilizer. The solid fraction was used as a substrate for breeding earthworms of the family Lumbricidae with subsequent production of organic fertilizer vermicompost and earthworm biomass. Initially, the method is aimed at reducing the toxicity of freshly obtained animal by-products by diluting them with water in the ratio from 1:1.5 to 1:2.5 m^3 and homogenizing them to a homogeneous state. As a result, the hazard class is reduced to V (virtually no harm to the environment). At the same time, the ballast foreign mechanical inclusions with high (stones, rubble, metal, etc.) and low (twine, ropes, wood chips, sticks, etc.) specific mass are cleared, the former of which settle to the bottom of the tank, and the latter float to the surface, after which they are removed mechanically. The homogenized substance is then fed into a press, where squeezing and separation of the liquid fraction from the solid fraction takes place, which are collected in a separate container. The solid fraction is used as a substrate for vermicompost production by earthworms of the family Lumbricidae. The agrochemical composition of liquid and solid fractions met the GOST requirements for organic and mineral fertilizers. Toxicological characteristics of the liquid fraction indicated that it was harmless to biological objects of the environment.

Keywords: animal by-products, vermicomposting, vermicompost agrochemical composition, earthworms (Lumbricidae)

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INTRODUCTION

Research conducted by scientists in the main agricultural regions of Russia and abroad clearly demonstrates the steady growth of the main negative processes recognized as the main challenges to food and environmental security: the toxic impact on the environment of animal by-products (ABP) and the degradation of agricultural lands [1−3].

The volume of accumulated animal and poultry waste amounts to hundreds of millions of tons, with which tens of millions of tons of organic matter, nitrogen, phosphorus, and potassium compounds, as well as a wide range of other chemical elements included in feed and vitamin-mineral complexes, enter the environment [4−6].

In Russia, livestock farming is one of the leading sectors of agriculture and plays a key role in providing the population with food. In the face of macroeconomic instability, a gradual expansion of production capacity is underway across the country to reduce the cost of livestock products [7, 8]. At the same time, the growth in the number of farm animals and poultry is accompanied by an increase in the volume of the generated ABP, which is accompanied by a deterioration in public health and the withdrawal of millions of hectares of agricultural land from economic circulation [9].

The widespread use of agrochemicals, primarily herbicides and pesticides, contributed to the degradation of natural soil flora and fauna, inhibiting the soil's natural regenerative functions, and, consequently, reducing crop fertility and yields. In an attempt to mitigate the negative impact, farmers began applying increasing amounts of fertilizers and agrochemicals. However, this only accelerated soil degradation due to the death of soil biota and an imbalance of organic components, macro- and micronutrients [10, 11].

The high cost of modern fertilizers makes them unaffordable to medium and small agricultural producers, which only worsens the situation.

At the same time, ABP can act as a valuable raw material for the production of environmentally friendly organic fertilizers, the use of which will serve to restore soil fertility, increase crop yields, and improve the profitability and competitiveness of agricultural enterprises [12, 13].

Federal Law No. 248-FZ of July 14, 2022 "On Animal By-Products and Amendments to Certain Legislative Acts of the Russian Federation"[1] the increase in the efficiency of the ABP use in agricultural production has been consolidated, including to ensure the restoration of the fertility of agricultural lands. The classification of waste as ABP is regulated by Article 5 “Classification of the substances generated during the keeping of farm animals as by-products of animal husbandry and the maintenance of their records”, and according to Article 6 they can again be recognized as waste. At the same time, the Decree of the Government of the Russian Federation of October 31, 2022 No. 1940 “On ap-

[1]On animal by-products and on the amendments to certain legislative acts of the Russian Federation: Federal Law of July 14, 2022 No. 248-FZ. URL: https://www.garant.ru/products/ipo/prime/doc/404891791.

proval of the requirements for the circulation of animal by-products"[2] regulates the application of the recycled ABP to soil as organic fertilizers.

The disposal of ABP with the production of fertilizers based on mechanical, physical, and chemical methods has shown insufficient economic efficiency. The main drawbacks of these methods are high energy costs and the technical complexity of the equipment, which prevent their use for processing fresh manure and litter in small and medium-sized agricultural enterprises. For the most part, they are also not designed for producing environmentally friendly organic fertilizers and substrates for vermicomposting [14, 15].

Methods of disposal of organic-containing waste based on the use of bacteriological and enzymatic preparations have shown good results and demonstrated their potential in experimental conditions, but turned out to be quite expensive and have not yet found wide application in agriculture. Common disadvantages of these methods are the complexity of preparing the compost mixture, the use of expensive microbiological preparations, as well as significant losses of organic matter and nitrogen during aerobic composting [16].

The steady rise in fertilizer prices in Russia, against the backdrop of stabilization, and in some years even a decrease in the purchase prices of final crop production, forces agricultural producers to use manure and litter, which have undergone natural and technological composting, as fertilizer to replenish soil humus.

However, natural composting has a number of significant disadvantages. Firstly, it requires a fairly long period of time to carry out, during which the content of beneficial organic and mineral substances substantially decreases. Secondly, the need to apply compost to the soil can reach tens of tons per hectare, which, considering logistical costs, is economically impractical for many agricultural producers [17].

In some studies, it was noted that ABP, their fractions, and vermicomposts derived from them can be used as organic fertilizers [18]. At the same time, the liquid fraction was directly transported to the fields, while the solid fraction was sent to dumps for disposal through natural composting lasting up to 6–8 months depending on the natural and climatic conditions of the region [19].

We were interested in the works on the disposal of such types of ABP as fresh manure and droppings, which, according to the Federal Waste Classification Catalog, approved by the order of Rosprirodnadzor (The Federal Service for Supervision of Natural Resources) dated 22.05.2017 No. 242[3], are classified as hazard classes III–IV.

The process of animal products production is accompanied by the entry of all kinds of foreign objects into ABP, which contribute to increased wear of technological equipment and can lead to its breakdown [20].

At the same time, it has been repeatedly proven in experimental conditions that the environmentally friendly technology of ABP vermicomposting not only significantly accelerates the composting process but also allows obtaining a more concentrated and balanced organic fertilizer.

At present, vermicomposting is the safest and most environmentally friendly method of processing livestock waste [21, 22]. However, the lack of technologically simple equipment that allows ABP to be transformed into a substrate and raw material for vermicompost production that is maximally adapted for worm activity hinders the widespread implementation of vermicomposting technologies.

The purpose of the study is to develop a simplified method for the rapid environmentally

[2]On the approval of the requirements for handling of animal by-products: Decree of the Government of the Russian Federation dated 31.10.2022 No. 1940. URL: http://government.ru/docs/all/143923/.

[3]On the approval of the Federal Waste Classification Catalogue: the Order of Rosprirodnadzor (Federal Service for Supervision of Natural Resources) dated 22.05.2017 No. 242. URL: https://rpn.gov.ru/upload/iblock/e54/prikaz_rosprirodnadzora_ot_22_05_2017_n_242_ob_utverzhdenii.pdf.

safe disposal of fresh manure and litter, resulting in bioorganic fertilizers and a substrate for breeding earthworms, with subsequent production of vermicompost and worm biomass for use in agriculture.

MATERIAL AND METHODS

Research on the specified topic was conducted in 2023 at the physiological station of the All-Russian Research Institute of Sheep and Goat Breeding – a branch of the FSBSI “North Caucasian Agrarian Center”. The research was carried out in the spring-summer period directly on the territory of the livestock farm. The experiments were repeated three times.

The diagram of the method for processing and disposing of fresh manure and litter by producing liquid bio-organic fertilizers and vermicompost is shown in the figure.

At the initial stage of the experiment, about 500 kg of substrate (fresh manure or droppings) was placed in container 1, which had been previously filled with water at a ratio of fresh manure/water of 1:1 m^3, followed by adjusting the ratio from 1:1.5 to 1:2.5 m^3. The volume of the added liquid depended on the ambient temperature, the amount and structure of the bedding material, the housing and manure removal technology (the initial moisture content of the manure). As a result, the hazard class decreases to V (virtually harmless to the environment).

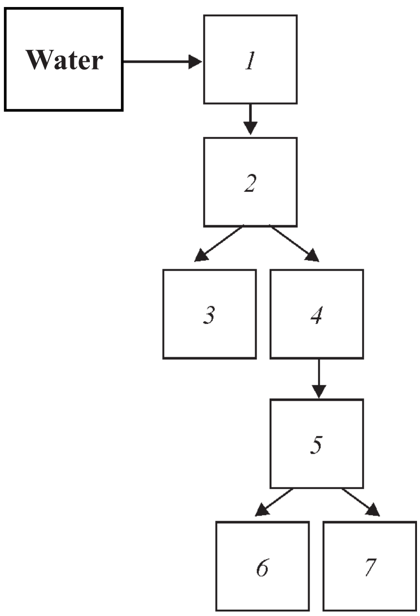

Схема способа переработки и утилизации свежего навоза и помета

Scheme of the method for processing and recycling fresh manure and litter

After 1 hour of natural softening, the manure was additionally homogenized using submersible screws, as a result of which ballast foreign mechanical inclusions with high specific gravity (stones, gravel, metal, etc.) settled to the bottom, and those with low specific gravity (twine, ropes, chips, sticks, etc.) floated to the surface. Then, using submersible pumps, the homogenized substance was fed into press *2*, where the liquid fraction *3* was expelled and separated from the solid *4*.

The solid fraction 4 was used as a substrate for the activity of earthworms of the Lumbricidae family and was sent to a vermicomposter 5 (bin-type vermireactors) or a heap (length − 8.0 m, width − 1.5 m, depth − 0.3 m). The stocking density of the earthworms was 3,000 individuals per 1 m^2 of the compost mass. The composting process lasted 6 weeks at a substrate moisture content of 70 to 75%, during which aeration by means of turning was carried out 1–2 times a week.

Then the earthworms 6 were mechanically separated from the vermicompost 7, after which the latter was dried under natural conditions and used as fertilizer.

Statistical processing of the data was performed using Statistica and Microsoft Excel programs.

Toxicological analysis of manure extracts and samples of the liquid fraction for acute toxic effects was carried out in the certified chemical and environmental laboratory of the OOO "Southern Personnel Training Center Industrial Safety" using daphnia *Daphnia magna* Straus as test organisms (measurement procedure – FR.1.39.2007.03222 "Biological control methods. Methodology for determining the toxicity of water and water extracts from soils, sewage sludge, waste by mortality and changes in the fertility of daphnia"[4]) and algae *Scenedesmus quadricauda* (measurement procedure – FR.1.39.2007.03223 "Biological control methods. Methodology for determining the toxicity of water, water extracts from soils, sewage sludge and waste by changing the level of chlorophyll fluorescence and the number of algae cells"[5]).

Agrochemical studies were conducted under the conditions of the accredited laboratories of the FSBI State Center of Agrochemical Service "Stavropol" in accordance with the requirements reflected in the GOST R 56004–2014[6], GOST 27980–88[7], GOST 26717–85[8], M-MP-80–2008[9], GOST 27979–88[10], Methodical guidelines for the determination of heavy metals in the soils of agricultural lands and crop products[11] and Methodical guidelines for the determination of arsenic in soils by the photometric method[12].

Sanitary-bacteriological and sanitary-parasitological studies were carried out at the Testing Center of the FSBI "North Caucasus Interregional Veterinary Laboratory", guided by the GOST R 54001–2010[13], GOST R 57782–2017[14], MG 2.1.7.2657–10[15], MG 4.2.3695–21[16].

RESULTS AND DISCUSSION

The claimed technical solution makes it possible to significantly accelerate the natural composting of manure/litter and reduce its toxicity.

The agrochemical composition of the liquid and solid fractions meets the GOST requirements for organic and mineral fertilizers, which allows enriching the soil with nutrients necessary to increase its fertility and the yield of agricultural crops (see Table 1).

Based on the results of biotesting of the extracts of fresh manure and liquid fraction on test objects, the harmless reciprocal dilution (HRD) of the sample has been identified, causing the death of no more than 10% of *Daphnia magna* Straus test organisms compared to the control over a 96-hour period (1 < HRD 10-96 < 100) and no more than 20% of *Scenedesmus quadricauda* algae compared to the control over 72 hours (1 < HRD 20-72 < 100) (see Table 2).

The method of processing and disposal of the ABP can be applied in agricultural enterprises of any capacity, resulting in organic fertilizers in both liquid and solid form as the final product. At the same time, the solid fraction can be used as a substrate for vermicomposting. The method reduces the full processing time of freshly obtained manure by at least 4–6 times, depending on the geoclimatic conditions of the region. The proposed technology ensures the intensification of the ABP processing.

In terms of agrochemical composition, liquid and solid fractions and the produced vermicom-

[4]Biological control methods. Methodology for determining the toxicity of water and water extracts from soils, sewage sludge, waste by mortality and changes in the fertility of daphnia: FR (Federal register). 1.39.2007.03222. Moscow: Akvaros, 2007, 51 p.

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Табл. 1. Агрохимический, бактериологический и паразитологический состав навоза крупного рогатого скота (бесподстилочного), жидкой и твердой фракций

Table 1. Agrochemical, bacteriological and parasitological composition of cattle manure (semiliquid), liquid and solid fractions

Indicator	Test results		
	cattle manure	liquid fraction	solid fraction
Quality indicators			
Mass fraction of dry matter, %	14	11	27
Mass fraction of moisture, %	86	89	73
Mass fraction of organic matter, %	20,6	74	80,2
Mass fraction of nutrients, %:			
total nitrogen	0,48	0,77	0,79
total phosphorus, in terms of P_2O_5	0,29	0,16	0,28
total potassium, in terms of K_2O	0,57	1,06	1,12
Hydrogen ion activity index, pH	6,5	7,2	6,9
Mass fraction of microelements			
Iron, mg/kg	199,4	224,98	240,3
Zinc, mg/kg	10,1	8,28	9,0
Manganese, mg/kg	20,3	14,47	14,5
Copper, mg/kg	12,2	2,13	54,1
Cobalt, mg/kg	7,1	0,30	6,8
Borium, %	0,005	0,002	0,01
Molybdenum, %	0,003	0,002	0,001
Magnesium, %	0,12	0,04	0,08
Calcium, %	0,44	0,86	0,92
Content of ballast foreign mechanical inclusions from dry matter, %, no more than:			
with a high specific gravity (rocks, crushed stone, metal, etc.) less than 40 mm in size	0,9	Not found	
with low specific gravity (twine, rope, wood chips, sticks, etc.) less than 150 mm in size	0,5	» »	
Safety indicators			
Mass concentration of impurities of individual toxic elements (total content), mg/kg:			
lead	4,55	2,24	2,18
cadmium	0,28	0,01	0,14
mercury	< 0,005	< 0,005	< 0,005
arsenic	0,64	1,22	0,36
Benz(a)pyrene, mg/kg	< 0,005	< 0,005	< 0,005
Polychlorinated biphenyls, mg/kg	< 0,005	< 0,005	< 0,005
Mass concentration of residual amounts of pesticides, mg/kg: HCCH (sum of isomers)	< 0,005	< 0,005	< 0,005
DDT and its metabolites (total amounts)	< 0,005	< 0,005	< 0,005
Specific effective activity of natural radionuclides, Bq/kg	23,1	23,1	23,1
Specific effective activity of man-made radionuclides (ACs/45 + ASr/30), rel. units	0,01	0,01	0,01
Presence of larvae and pupae of synanthropic flies, specimens/kg	Not found		
CGB index, CFU/g:			
coliforms	8	6	2
enterobacteria	6	4	2
Presence of pathogenic and disease-causing microorganisms CFU/g	Not found		
Presence of viable eggs and larvae of helminths, specimens/kg	» »		
Cysts of intestinal pathogenic protozoa, specimens/100 g	» »		

Note. MU – measurement unit; BC – cattle; HCCH – hexachlorocyclohexane; DDT – dichlordipheniltrichlormethane; CGB – Escherichia coli group bacteria.

Табл. 2. Токсикологическая оценка проб вытяжек свежего навоза и жидкой фракции методом биотестирования

Table 2. Toxicological evaluation of the samples of fresh manure extracts and liquid fraction by the method of biotesting

Test object	Duration of observation, h	Harmless dilution ratio (HDR10-96/ HDR20-72)	Evaluation of the test sample	Methodology for performing measurements
Daphnia magna Straus	96	1,5	It has an acute toxic effect	FR. 1.39.2007.03222
Scenedesmus quadricauda	72	1,6	the same	FR. 1.39.2007.03223

post met the GOST requirements for organic and mineral fertilizers, which allows their use as organic fertilizers for agricultural crops when applied to the soil.

The solid fraction proved suitable for the survival of earthworms and the production of vermicompost.

CONCLUSION

The disposal of fresh manure and litter using the proposed method is achieved by utilizing the freshly obtained manure/litter to produce bio-organic fertilizers and the substrate for breeding earthworms by reducing the toxicity of the primary material through dilution with water, followed by pressing and collection of liquid and solid fractions. In this case, the liquid fraction can be immediately used as a bio-organic fertilizer, while the solid fraction can be used as raw material for breeding earthworms and producing vermicompost.

The levels of total phosphorus, zinc, manganese, cobalt, molybdenum, magnesium, lead, cadmium, and ballast foreign mechanical inclusions in cattle manure exceed those, while total nitrogen, total potassium, iron, and calcium are lower than those in the liquid and solid fractions.

The harmless reciprocal dilution with water of fresh manure extract samples and the liquid fraction were 1.5 and 1.6, respectively, for the test subjects *Daphnia magna* Straus and *Scenedesmus quadricauda*.

The method of obtaining bio-organic fertilizers and substrate for breeding earthworms from fresh manure/litter is simple and does not require the use of special equipment.

The proposed technology allows for the intensive utilization of the ABP, which previously had no practical use, and for producing environmentally friendly fertilizers balanced in macro- and microelements, contributing to increased crop yields and improved product quality.

The maximum effect from using the proposed method of processing the ABP can be achieved in agricultural enterprises that are comprehensively engaged in both livestock and crop production, as well as through close inter-farm cooperation of agricultural enterprises specializing in crop and livestock production separately.

The technical result that can be achieved by the proposed method is the rapid and environmentally safe disposal or processing of the ABP and the production of liquid organic fertilizers and substrate for breeding earthworms, derived from animal and plant agricultural production waste, which allows significantly reducing the negative impact on the environment in areas with livestock complexes, and obtaining liquid fertilizers and substrate for earthworm breeding.

Thus, the ABP disposal is fundamental to the environmental safety of agricultural regions and the food security of the entire Russian Federation.

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Внедрение усовершенствованной технологии содержания в производственный процесс выращивания ягнят молочного периода

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Производство овцеводческой продукции с наименьшими затратами материальных и трудовых ресурсов является актуальной проблемой, требующей решения с использованием разных технологических приемов. Цель исследования – разработка усовершенствованной технологии содержания ягнят при выращивании в молочный период. Выращивание ягнят от рождения до отъема проводилось по двум технологиям: традиционной и усовершенствованной, когда рядом с тепляком была оборудована секция на 100 маток (10 сакманов), отгороженных от общей кошары брусом и целлофановой пленкой. В течение окота в тепляке за счет обогревателей поддерживалась температура в пределах 15–17 ºС, тогда как в оборудованной секции – 7–9 ºС, а в помещении она колебалась в пределах 4–7 ºС. В результате оборудования дополнительной секции в переходный период из индивидуального тепляка в сакманные группы, затем через 10–15 дней в общую кошару удалось снизить падеж практически в 2 раза. К отъему от матерей сохранность ягнят при усовершенствованной технологии составила 91,5%, при традиционной – 87,2%. Рост сохранности ягнят к отъему (практически 5 ягнят на 100 овцематок) является перспективным резервом производства ягнятины (в среднем 45,0–47,5 кг мяса), что при сложившихся в условиях Заволжья ценах на баранину означает получение дополнительной выручки в размере 27–30 тыс. р. Следовательно, улучшение условий содержания маток с ягнятами путем оборудования дополнительной секции для адаптации к групповому содержанию при более низкой, чем в тепляке, и более высокой, чем в общей кошаре, температуре воздуха, а также уменьшение сквозняков способствуют повышению выхода ягнят к отъему на 4,9% и увеличению их живой массы из-за снижения стресса в переходный период на 5,3%, что обеспечивает получение дополнительной продукции и прибыли.

Ключевые слова: ягнята, молочный период, усовершенствованная технология, падеж, сохранность, живая масса

Introduction of an improved management technology into the production process of growing preweaning lambs

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The production of sheep products with minimal expenditure of material and labor resources is a pressing issue that requires a solution using various technological methods. The objective of the study was to develop an improved technology for keeping lambs during the preweaning period. Lambs were reared from birth to weaning using two technologies: traditional and improved, where a section for 100 ewes (10 sakmans) was equipped next to the winter shelter, separated from the common sheepfold shed by a beam and cellophane film. During lambing, the temperature in the winter shelter was maintained at 15–17 ºС using heaters, while in the equipped section it was 7–9 ºС, and indoors it fluctuated within 4–7 ºС. As a result of equipping an additional section during the transition period from an individual winter shelter to sakman groups, and then after 10–15 days to a common sheepfold shed, it was possible to reduce mortality by almost a half. By weaning, the survival rate of lambs using the improved technology was 91.5%, while using the traditional technology it was 87.2%. The increase in the survival rate of lambs to weaning (almost 5 lambs per 100 ewes) is a promising reserve for lamb production (an average of 45.0–47.5 kg of meat), which, given the current prices for mutton in the Trans-Volga region, means additional revenue of 27–30 thousand rubles. Consequently, improving the conditions for keeping ewes with lambs by equipping an additional section for adaptation to group housing, with a lower than in a winter shelter and higher than in a common sheepfold shed air temperature, as well as reducing drafts, contributes to an increase in the yield of lambs to weaning by 4.9% and an increase in their live weight due to a decrease in stress during the transition period by 5.3%, which ensures additional production and profit.

Keywords: lambs, preweaning period, improved technology, mortality, survivability, live weight

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INTRODUCTION

The economic efficiency of managing the sheep breeding industry, along with the influence of genetic factors, is determined by natural-climatic, fodder, and organizational-technological characteristics [1–3]. The main criterion determining the choice of a particular resource-saving technology is the system of sheep keeping [4].

Low-cost technologies for the production of livestock products continue to remain a relevant problem, the solution of which appears to be an important national economic task for Russia, especially in light of the restriction of supplies of equipment and technologies from unfriendly foreign countries [5, 6]. In this regard, the further development of the country's sheep breeding should be accompanied by the application of the Russian resource-saving technologies that ensure its sustainable development, with the maximum use of the biological characteristics of sheep and their genetic productivity potential [7, 8].

Considering that environmental factors have a significant impact on the growth of lambs in the first months of rearing (until weaning from their mothers), increased attention should be paid to care issues, which will ensure the preservation of the young [9]. The overwhelming majority of losses in the sheep industry are associated with lamb mortality, starting from the newborn period and until weaning from the mothers [10–12].

The various reproduction technologies used in sheep farms do not always ensure compliance between the production-technological operations performed and animal welfare, which reduces the efficiency of the industry. In particular, the production and rearing of lambs during the stall period using the sheep shed-based method does not allow for an optimal microclimate in the sheepfold for each age group of animals.

In addition, with this method of keeping the breeding stock and their offspring, there is an overspending of feed, bedding material, energy, and labor costs. During the period of weaning lambs from their mothers, an important criterion is their survival rate [13, 14]. The joint housing of ewes and lambs contributes to an increase in morbidity and a decrease in the quantitative and qualitative indicators of production. The recommended separate housing of ewes from lambs according to the separate-contact method, unlike sheep shed-based housing, has a number of advantages, consisting in the possibility of creating differentiated conditions for feeding, keeping, and care, which ensures comfortable conditions for the animals' bodies and increases the survival of young animals in the first months of rearing [15, 16].

Lambs obtained from ewes that were kept from the second half of gestation during the stall period on an open exercise yard using deep straw bedding, in terms of blood indicators and growth rate, surpassed their peers kept by the sheep shed-based method. At the same time, morbidity and mortality of lambs under the sheep shed-based method of keeping significantly exceeded the values of their peers – by 41.6 and 9.8 absolute percent, respectively[1].

The main reason for the increase in lamb mortality during the milk-feeding period is considered to be colds, which usually occur with a change in the housing technology (accordingly, a sharp change in temperature and humidity conditions) – transfer from the winter shelter to the communal sheepfold shed[2].

It is proposed to avoid a number of diseases in the early periods of life of young farm animals, and along with this, to reduce mortality by creating local zones with the required thermal conditions for them. The introduction of such developments into the technology of the milk period of rearing ensures disease prevention, an increase in the body's defenses, and an increase in growth rate[3].

The purpose of the study is to develop an improved technology for keeping lambs during the milk-feeding period.

MATERIAL AND METHODS

The research was carried out in 2 stages on the Stavropol breed sheep from the peasant (farm) household “Ruslan” in the Dergachyovsky district of the Saratov region from 2023 to 2024.

Lambing was conducted in March according to the traditional scheme. The ewes that had given birth were kept in a winter shelter in individual pens for the first 10 days, then sections of 10 ewes with lambs were formed in a common room, gradually increasing the size. Record-keeping was done according to the lambs born in the first 10 days of lambing.

The growth of laboratory animals was studied according to the indicators of live weight at birth and weaning from mothers at the age of 4 months.

In the first stage, a flock of 3-year-old first-grade ewes was taken. The live weight of the ewes was 47.0 kg, and the yield of clean wool was 2.5 kg, which corresponds to the breed standard. At lambing, all ewes' offspring were marked by assigning a serial number, which was recorded in a journal. Mortality was also tracked on a ten-day basis up to 4 months of age (i.e., until weaning).

In the second stage of the study, an additional section for 100 ewes (10 sacks) was set up next to the winter shelter in the sheepfold shed, separated from the general sheepfold shed by a beam and plastic film.

In a flock of 528 ewes, 242 ewes lambed over

[1]*Akhmadiev G.M., Safin M.A.* Natural and technological foundations for obtaining viable offspring of sheep // Veterinarny Vrach, 2015, N 5, pp. 63–67.

[2]*Aboneev V.V., Konik N.V.* Selection and technological methods for increasing the competitiveness of fine-wool sheep breeding // Sheep, goats, wool business, 2015, N 3, pp. 3–5.

[3]*Trunov S.S., Rastimeshin S.A.* Requirements for the thermal regime of livestock buildings with young animals and the prerequisites for the use of local heating // Bulletin of the All-Russian Scientific-Research Institute for Electrification of Agriculture, 2017, N 2 (27), pp. 76–82.

a period of 10 days, yielding 329 live lambs. Fertility amounted to 136%, including 8 stillborn lambs (3.3%). Subsequently, 234 heads were under observation.

Of the live lambs kept in the winter shelter, only 4 died. Over the following 10 days, 23 drop herds were formed (an average of 2 per day), and further recording of the dead lambs was carried out for 10 days after the formation of the drop herds. After that, the grouping of drop herds was done taking into account the age and development of the lambs.

Using a personal computer and the Staf program, all digital material was processed biometrically according to N.A. Plokhinsky (1969) and E.K. Merkureva (1970) with the calculation of the arithmetic mean (X) and the error of the arithmetic mean (mx). Using the values of X and mx, the criterion of reliability of differences td was determined. Based on td and the number of observations n, the probability level of differences (p) was determined. The differences were considered reliable if p was greater than 0.95, 0.99, and 0.999.

RESULTS AND DISCUSSION

Information on the mortality of lambs from birth to weaning from their mothers is presented in Table 1.

In both rearing technologies, the highest mortality of lambs was observed in the second ten-day period of the first month of ontogenesis, i.e., after the sheep were moved from the winter shelter to the general housing (from the 11th to the 20th day of the lambs' lives). Mortality amounted to 4.27%. In the third ten-day period of the first month, mortality decreased almost threefold and increased in the second month of life, during the period when the sheep were taken to pasture.

The total mortality rate over 4 months of life was 10.25%.

The dynamics of real cases are clearly presented in Fig. 1.

The mortality rate of lambs during the milk period of rearing, depending on the applied management technology, can be judged by the data presented in Table 2.

Based on the results of the first stage of the research, it can be preliminary concluded that the mortality is associated with the changes in the lambs' housing (transfer to group housing and release to pasture) and, accordingly, with the influence of paratypic environmental factors (temperature, wind, drafts, etc.).

During the implementation of the second stage of work, the conditions for the transitional periods were modernized to ensure greater comfort for the animals under the influence of external environmental factors, which consisted of additionally equipping a section for 100 ewes (10 drop herds) next to the winter shelter in the sheepfold shed, separated from the main sheepfold by a beam and plastic film (see Fig. 2).

Табл. 1. Динамика падежа ягнят от рождения до отъема

Table 1. Dynamics of lamb mortality from birth to weaning

Indicator	1st month			2nd month	3rd month	4th month	Total
	I ten-day period	II ten-day period	III ten-day period				
Mortality: heads	4	10	3	5	2	–	24
%	1,70	4,27	1,28	2,13	0,85	–	10,25
Viability, %	98,20	95,72	92,73	90,59	89,20	–	89,75

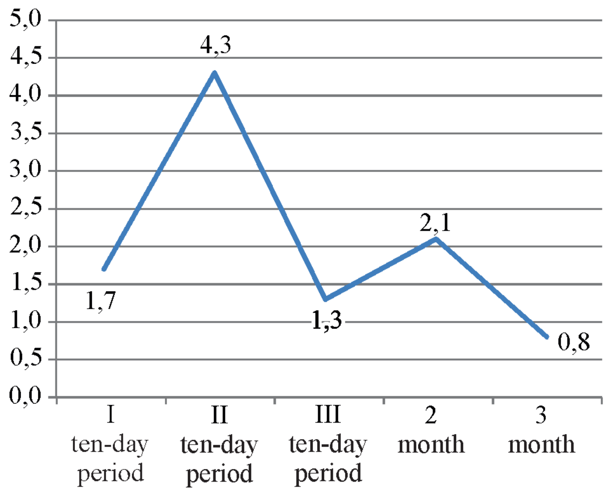

Рис. 1. Динамика падежа ягнят в подсосный период, % (дек. – декада)

Fig. 1. Dynamics of lamb mortality during the suckling period, % (t-d per. – ten-day period)

Табл. 2. Падеж и сохранность ягнят в молочный период выращивания при разных технологиях содержания

Table 2. Mortality and safety of lambs during the preweaning period of rearing under different housing technologies

Indicator	1-й мес				2nd month	3rd month	4th month	Total
	I ten-day period	II ten-day period	III ten-day period	total				
Technology being tested (n = 118)								
Mortality: heads	2	3	1	6	2	1	1	10
%	1,69	2,54	0,84	5,07	1,69	0,84	0,84	8,44
Viability, %	98,30	95,76	94,91	96,32	90,32	92,37	91,52	91,52
Traditional technology (n = 117)								
Mortality: heads	3	4	2	9	3	2	1	15
%	0,85	5,12	1,70	7,67	2,56	1,70	0,85	12,78
Viability, %	97,14	94,01	92,30	94,48	89,74	91,45	87,17	87,17

During lambing, the temperature in the heated winter shelter was maintained at 15–17 ºC thanks to heaters, while in the equipped section it was 7–9 ºC, and in the room it fluctuated between 4–7 ºC.

During the lambing process over 21 days, 10 additional sections were filled and 10 in the unheated room.

A strict mortality count was carried out, the results of which are presented in Table 2 and Fig. 3.

Based on the data obtained, illustrating the results of the second stage of research conducted on ewes of the same flock, but a year older, it can be stated that the equipment of an additional section during the transition period from an individual winter shelter to drop herd groups, and then after 10-15 days to a common sheepfold shed helps to reduce mortality by almost

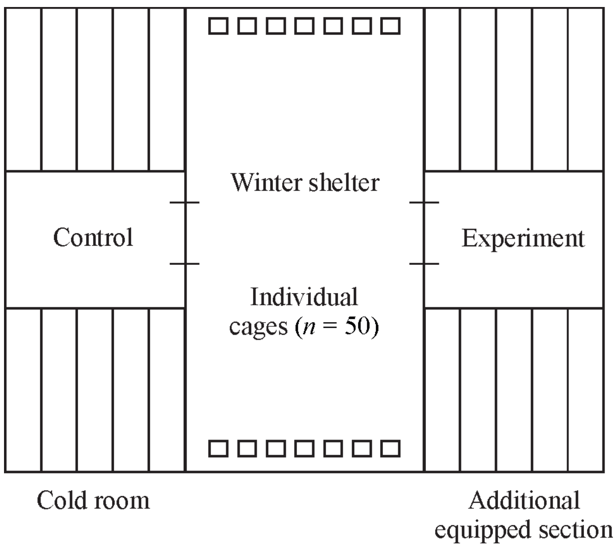

Рис. 2. Внутрикошарное оборудование

Fig. 2. Intra-barn equipment

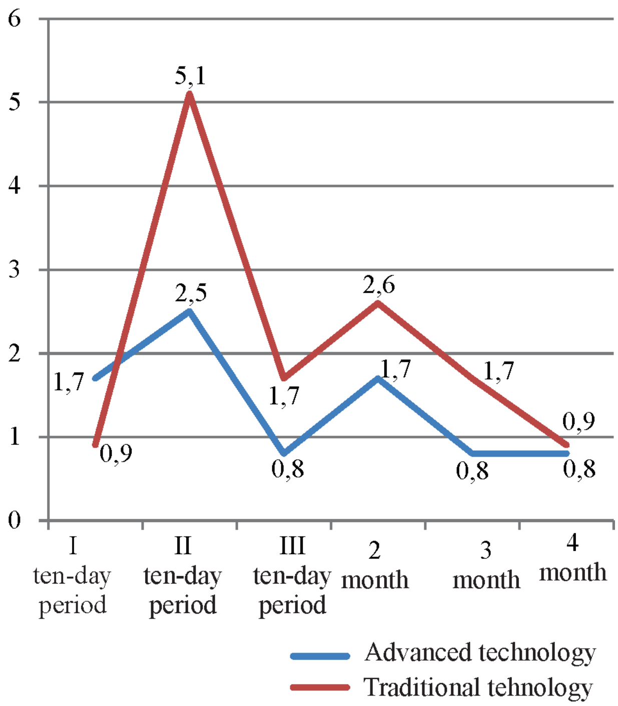

Рис. 3. Динамика падежа при разной технологии выращивания ягнят от рождения до отъема от матери, %

Fig. 3. Dynamics of mortality under different technologies of lamb rearing from birth to weaning, %

Табл. 3. Живая масса (кг) ярок при разных способах выращивания

Table 3. Live weight (kg) of ewe lambs under different rearing methods

Indicator	Advanced technology	Traditional technology
n	20	20
Live weight at birth	3,79 ± 0,14	3,80 ± 0,10
At weaning	21,84 ± 0,20	20,74 ± 0,17

2 times. Ultimately, by weaning, the survival rate of the lambs with the improved technology was 91.52%, with the traditional technology – 89.75% (stage I) and 87.17% (stage II).

The increased survival rate of lambs at weaning (almost 5 lambs per 100 ewes) provides an additional source of lamb production. If the average slaughter weight of four-month-old lambs is 8.0–9.5 kg, then for every 100 ewes, an additional 45.0–47.5 kg of meat can be obtained. Given the current lamb prices in the Trans-Volga region, this translates into additional revenue of 27,000–30,000 rubles. In addition, a slight advantage in live weight was noted in young animals raised with their mothers until weaning (4 months) using improved technology.

In order to evaluate the live weight of ewes intended for rearing using improved and traditional technologies, 20 newborn individuals with a live weight in the range of 3.79–3.8 kg were selected (see Table 3).

The difference in live weight at weaning was 5.31% (p> 0.95), or 1.10 kg in absolute terms, which is another 306.2 rubles of additional revenue from one ewe lamb.

CONCLUSION

Improving the conditions for keeping ewes with lambs by equipping an additional section for adaptation to group housing at a lower air temperature than in a winter shelter and higher than in a general sheepfold shed, as well as reducing drafts, contributes to an increase in the yield of lambs at weaning by 4.9% and an increase in their live weight due to a decrease in stress during the transition period by 5.3%, which ensures additional production and profit.

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Агротехнические показатели технологического процесса работы рыхлителя почвы ПРП-5,6

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В статье представлены результаты исследования, посвященного эксплуатационно-технологической оценке работы прицепного рыхлителя почвы ПРП-5,6 «Титан» (производитель – Омский экспериментальный завод). Изучено изменение твердости почвы в зависимости от ее влажности и глубины обработки. Определены агротехнические показатели технологического процесса, дана энергетическая оценка работы трактора К-744Р4 в агрегате с рыхлителем ПРП-5,6. Исследование проходило на полях крестьянско-фермерского хозяйства, расположенного в Павлоградском районе Омской области. Полученные данные показывают, что на нетронутом залежном поле наибольшая влажность почвы сохраняется в верхнем дерновом слое, который задерживает влагу и не пропускает ее в нижние слои. На глубине 20 см влажность почвы, находящейся в залежи, на 8% ниже, чем у обработанной. На глубине 40 см показатели влажности выравниваются. Максимальная твердость залежных земель наблюдается на глубине 30 см. В общем виде изменение твердости почвы в зависимости от глубины обработки представлено уравнением полинома второй степени. Установлено, что по тяговым и мощностным показателям трактор К-744Р4 в агрегате с рыхлителем ПРП-5,6 обеспечивает устойчивое выполнение технологического процесса во время осенней обработки почвы при глубине хода рабочих органов 22 см на скорости движения до 9,05 км/ч, при глубине хода рабочих органов 31 см – на скорости до 5,54 км/ч. Сохранение стерни на поверхности поля достигает 61–66%. Тяговое сопротивление агрегата при глубине хода рабочих органов 21 см с повышением скорости от 5,60 до 9,05 км/ч увеличилось на 12%. При глубине обработки 31 см с увеличением скорости от 3,90 до 5,54 км/ч оно возросло на 11%. Производительность агрегата за час основного времени при глубине обработки 21 см и скорости 9,05 км/ч составила 5,06 га/ч, при глубине обработки 31 см и скорости движения 5,54 км/ч – соответственно 3,10 га/ч. Удельный расход топлива составил 36,1 кг/га.

Ключевые слова: влажность и твердость почвы, обработка почвы, рыхлитель, сферические диски, агрегат, скорость

Agrotechnical indicators of the technological process of operation of the soil ripper PRP-5,6

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The article presents the results of a study devoted to the operational and technological evaluation of the work of the trailed soil ripper PRP-5,6 "Titan" (manufacturer – Omsk Experimental Plant). The change in soil hardness depending on its moisture content and tillage depth was studied. The agrotechnical parameters of the technological process were determined, and the energy assessment of the K-744R4 tractor operation in combination with the PRP-5,6 ripper was given. The study took place in the fields of a peasant farm located in the Pavlograd district of the Omsk region. The data obtained show that in an undisturbed fallow field the greatest soil moisture is retained in the upper sod layer, which retains moisture and does not allow it to pass into the lower layers. At a depth of 20 cm, the moisture content of fallow soil is 8% lower than that of the cultivated soil. At a depth of 40 cm, the moisture levels level out. The maximum hardness of fallow lands is observed at a depth of 30 cm. In general, the change in soil hardness depending on the depth of cultivation is represented by a second-degree polynomial equation. It has been established that, in terms of traction and power performance, the K-744R4 tractor in combination with the PRP-5,6 ripper ensures stable performance of the technological process during autumn soil cultivation at a working depth of 22 cm at a speed of up to 9.05 km/h, and at a working depth of 31 cm at a speed of up to 5.54 km/h. The retention of stubble on the field surface reaches 61–66%. The unit's traction resistance increased by 12% at a working depth of 21 cm with a speed increase from 5.60 to 9.05 km/h. At a working depth of 31 cm with a speed increase from 3.90 to 5.54 km/h, it increased by 11%. The unit's hourly productivity at a working depth of 21 cm and a speed of 9.05 km/h was 5.06 ha/h, and at a working depth of 31 cm and a speed of 5.54 km/h, it was 3.10 ha/h. Specific fuel consumption was 36.1 kg/ha.

Keywords: soil moisture and hardness, soil tillage, ripper, spherical discs, aggregate, speed

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INTRODUCTION

In agricultural production, a contradiction has arisen between the need to increase labor productivity through the use of energy-intensive machinery and the agronomic requirements of crop cultivation. This has necessitated the development of technologies and machinery that, in addition to primary soil cultivation, enable measures to eliminate the causes of water and wind erosion and create conditions for the accumulation and retention of productive soil moisture [1, 2].

With the development of agricultural mechanization and the intensification of production processes, the problem of the negative impact of machine and tractor units on the soil has arisen, the numerous passes of which contribute to the compaction of the soil, a decrease in fertility and the effectiveness of traditional methods of land cultivation [3, 4]. When soil is compacted, the water-air regime and conditions for mineral nutrition of plants worsen, the yield of agricultural crops decreases, erosion processes intensify, crop infestation and infection by diseases and pests increase, the effectiveness of fertilizers decreases, and the costs of material resources for soil cultivation increase. Therefore, in compacted fields, it is advisable to recurrently (every 3–4 years) loosen the soil to a depth of 22–27 cm, especially in the northern zone of the solonetz forest-steppe of the Omsk region. Deep loosening prevents salts from rising into the root zone and increases yields by 15–19% [5, 6].

The most effective methods for combating compaction of the topsoil and subsoil are deep loosening and paraplowing. Loosening the topsoil and the so-called plow pan is accomplished with chisel plows or other cultivators. However, loosening deeper soil layers (more than 40 cm) has not yet been sufficiently developed and substantiated.

Mechanical tillage is closely linked to both the ecological stability of the arable horizon and the overall ecology of the environment. Excessive use of moldboard plows and repeated passes of various machinery and tractor units lead to the erosion and deforestation of the fertile soil layer, as well as the contamination of the water bodies with fertilizer and chemical residues [7].

The formation of soil microaggregates occurs under the influence of chemical processes, while macroaggregates result from the joining of microaggregates under the influence of the adhesive capacity of biological particles. Therefore, the strength of macroaggregates is an order of magnitude lower than the cohesive strength of soil particles in microaggregates. Therefore, plowing primarily leads to the destruction of soil macroaggregates. This can be either direct physical disruption of the soil structure during mechanical tillage or indirect disruption (for example, disruption of root fragments and mycorrhizal hyphae, which are the primary binding agents for macroaggregates)[1, 2] [8].

By now, many countries around the world have accumulated significant experience in the use of deep loosening. This agricultural technique is particularly effective in the areas prone to water erosion. In Russia, almost a third of all arable land requires loosening. In addition, more than 4.4 million hectares of agricultural land are fallow, which also need to be brought into crop rotation [9]. The total annual need for implements for deep soil loosening and cultivation of fallow lands is more than 10,000 units.

Subsoilers with passive working elements have become widespread in most countries. They are simple in design and reliable in operation[3] [10, 11]. Their disadvantage is their high energy consumption: when loosening to a depth of 0.6–0.7 m, one working element consumes from 20 to 40 kW of traction power, and up to 40 kg of fuel is consumed to process 1 hectare.

At the same time, periodic deep loosening of compacted soils using deep rippers helps to increase soil permeability and increase the yield of spring wheat grain from 1.58 to 1.76 t/ha (11.4%) relative to the option with minimum soil tillage [12].

At this stage of scientific and technological development, the problem of soil compaction cannot be completely resolved. Therefore, the development of new methods for deep soil loosening and the improvement of the design of working parts of machine and tractor units to reduce their energy consumption are important and pressing national economic issues.

The purpose of the study is an operational and technological assessment of the work of the PRP-5.6 unit during autumn tillage of stubble.

The research objectives are:

1) study of the changes in soil hardness with depth of cultivation depending on its moisture content;

2) determination of agrotechnical indicators of the technological process;

3) energy assessment of the unit's operation.

MATERIAL AND METHODS

To date, a number of issues remain unresolved regarding the choice of deep soil loosening modes (strip or solid), as well as the arrangement and configuration of working tools. The PRP-5.6 'Titan' towed soil looseners (manufacturer – Omsk Experimental Plant) are designed for loosening soil on both non-moldboard and mouldboard backgrounds, with the processing depth of the horizon up to 45 cm, aiming to break the plow pan of the plowed field and to treat soils with various mechanical composi-

[1]*Martynova N.A.* Soil chemistry: soil organic matter: teaching aid. Irkutsk, 2011, 256 P.

[2]*Lisetskiy F.N., Marinina O.A., Rodionova M.E.* Changes in the structural state of soils with differences in soil-climatic conditions and land use history // Izvestiya of the Samara science centre of the Russian academy of sciences, 2013, vol. 15, N 3 (3), pp. 998–1002.

[3]*Leontyev Yu.P., Makarov A.A.* Experimental researches of operating parts models of chisel plows with different designs of side plates // Prirodoobustrojstvo, 2013, N 3, pp. 81–85.

tions[4]. With the help of this machine, it is possible to carry out stubble cultivation, treatment of fallow lands, chopping of perennial grasses, as well as stubble processing, loosening of alcaline soils to ensure the penetration of moisture and air into the deep layers. Deep loosening creates favorable conditions for the development of the plant root system due to the leveling of the topsoil layer by spurred rollers.

The PRP-5.6 soil ripper is compatible with tractors of the 6th–8th traction class (K-744P3, New Holland, Buhler). The ripper consists of two frames (see Fig. 1). The front frame is used to mount the disk gangs. Additionally, the trailer frame, to which the wheel assemblies are mounted, is bolted to it. The rear frame, on which the ripper working elements and dual toothed rollers are mounted, is bolted to the front frame using clamps and bolts.

The ripper's working element consists of a stand to which the chisel is attached using two cotter pins (see Fig. 2). The working element stand is mounted to the frame using two bolts. To prevent damage to the working elements when used on heavy, contaminated, or rocky soils, a smaller diameter shear bolt is provided.

The ripper is converted from transport to working position and back using a hydraulic system. Transport wheels, powered by the tractor's hydraulic system, are provided for transport. The working depth is set by rearranging the adjustment pins in the roller brackets and the adjustment pins of the wheel assembly in the wheel brackets (see Fig. 3). The depth of the disc gang is adjusted by changing the length of the bracket turnbuckle. The set working depth is discretely locked using a pin in the holes in the lever of the transport wheel lifting mechanism.

The ripper's technological process is as follows. At the beginning of the run, the operator switches the tractor's hydraulic system to the "float" position, thereby converting the unit from transport to working position. The ripper, under its own weight, lowers, lowering the working parts and discs to the set depth. At the end of the run, the hydraulic system is switched to the "lift" position, the ripper working parts are lowered, and the ripper is returned to the transport position. After turning, the cycle is repeated.

Рис. 1. Устройство прицепного рыхлителя почвы ПРП-5,6:
1 – передняя рама; *2* – дисковые батареи; *3* – задняя рама; *4* – рабочий орган рыхлителя; *5* – транспортные колеса; *6* – зубчатый каток

Fig. 1. The structure of a trailed soil ripper PRP-5,6:
1 – front frame; *2* – disc batteries; *3* – rear frame; *4* – working element of the ripper; *5* – transport wheels; *6* – toothed roller

[4]*Golovanov D.A., Kem A.A., Chekusov M.S.* Combined implement for primary soil cultivation and moisture accumulation in arid regions of Western Siberia // Achievements of Science and Technology of AIC, 2013, N 2, pp. 53–55.

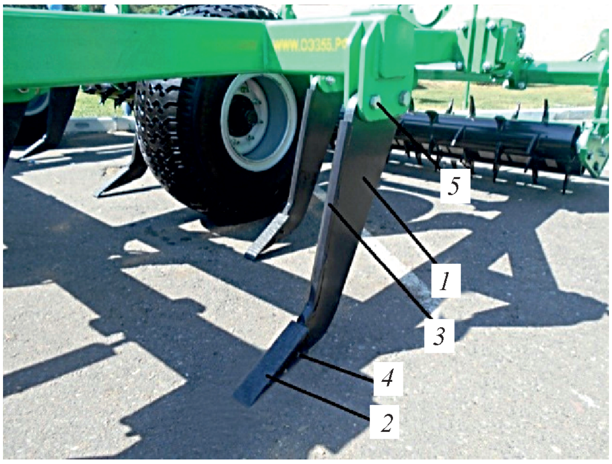

Рис. 2. Рабочий орган рыхлителя:
1 – стойка; *2* – долото; *3* – обтекатель;
4 – шплинты; *5* – срезной болт
Fig. 2. The working element of the ripper:
1 – stand; *2* – chisel; *3* – fairing; *4* – cotter pins;
5 – shear bolt

Рис. 3. Регулировка глубины обработки почвы на кронштейне катка:
1 – регулировочные оси катка; *2* – кронштейны катка
Fig. 3. Adjusting the processing depth on the roller bracket:
1 – roller adjustment axes; *2* – roller brackets

Field studies of the PRP-5.6 unit were carried out in a peasant farm located in the Pavlograd district of the Omsk region, in accordance with the requirements of the Agricultural Machinery and Technology Testers Association Standards STO AIST 10 4.6– 2003[5], STO AIST 4.2–2004[6] and GOST 33687– 2015[7]. The required number of experiments was determined based on the condition of obtaining an error not exceeding 5% with a confidence level of 80%. Before performing the experiments, the working parts of the ripper were adjusted and configured according to the recommendations in the operating manual.

The soil was ordinary medium-deep chernozem, with a medium-loamy texture. Soil moisture content at a 10-cm depth was 24.56%, at a 20-cm depth it was 18.82%, and in the 20-30 cm horizon it was 16.53%. Moisture content measurements were performed in five replicates. Soil hardness was determined using a standard method using an IP-232 mechanical hardness tester and an SC 900 penetrometer [13]. Instrument readings were recorded in an observation log and processed using Microsoft Excel. The field surface ridge was determined using the established method before and after the unit's passage[8].

The field section where the tests were conducted consisted of two sections: a 30-meter acceleration section and a 200-meter measurement section. The required machine speed was set in the acceleration section. Process quality indicators were determined during deep autumn tillage after grain crops. Soil moisture content ranged from 28.21% to 26.92%, and soil hardness in the 10-20 cm layer was 3.62 MPa, while in the 20-30 cm layer it was 5.38 MPa.

The machine consists of a K-744R4 “Kirovets” tractor and a PRP-5.6 “Titan” subsoiler. The tillage speed was selected based on technological feasibility and the tractor's traction and power capabilities. When tilling to a depth of 20 cm, the speed was taken to be 9.05, 7.70,

[5]STO AIST 10 4.6–2003. Organization standard. Testing of agricultural machinery. Tillage machines. Performance indicators. General requirements. Novokubansk: Publishing house of RosNIITiM, 2004, 27 p.

[6]STO AIST 4.2–2004. Testing of agricultural machinery. Machines and tools for shallow and shallow tillage. Methods for assessing functional indicators. Moscow: Ministry of Agriculture of the Russian Federation, 2004, 36 p.

[7]GOST 33687–2015. Machines and tools for surface tillage. Test methods. Moscow: Standartinform, 2016, 42 p.

[8]*Sakhabiev I.A., Giniyatullin K.G., Kadyrova R.G.* Field methods for studying the physical properties of soils: educational and practical work. ed., Kazan, 2022, 36 p.

and 5.60 km/h, while when tilling to a depth of 30 cm, the speeds were 5.54, 4.80, and 3.90 km/h. When the tillage depth increased to 32 cm, it was impossible to carry out the technological process at a speed higher than 5.54 km/h due to tractor wheel slippage.

The quality indicators of the technological process were determined at the maximum possible speed of movement according to the STO AIST 1.12–2006[9]. The working depth of the working tools was set in accordance with the technological requirements for the work under the existing conditions and was tested with the ripper operating at a setting processing depth of 20 and 30 cm. The studies were conducted in conjunction with an agronomic assessment during autumn soil cultivation. The main agronomic indicators of the technological process were determined by the GOST 33736– 2016[10].

RESULTS AND DISCUSSION

Soil hardness has a significant impact on the traction resistance of tillage machines and, consequently, on the economic performance of the entire technological process. To evaluate the operational and technological performance of a machine, it is necessary to know the physical condition of the soil layer throughout the entire tillage depth. Soil hardness and moisture are interrelated. The process of soil moisture change depending on its condition is presented in the graphs in Fig. 4, *a*.

The study results show that in an undisturbed fallow field, the highest moisture content is retained in the upper sod layer, which traps moisture and prevents it from reaching the lower layers. At a depth of 20 cm, the moisture content of fallow soil is 8% lower than that of cultivated soil, and only at a depth of 40 cm does the moisture content equalize. Consequently, this affects the soil's firmness and density (see Fig. 4, *б*, *в*).

The maximum hardness of fallow soil is recorded at a depth of 30 cm. A significant increase in hardness was observed at depths greater than 15 cm, and the maximum density was found at a depth of 20 cm, which corresponds to the minimum soil moisture content. Generally, changes in soil hardness can be described by a second-degree polynomial equation:

$$y = -11{,}17x^2 + 289{,}13x - 237{,}18,$$

where y – soil hardness, kPa; x – soil layer depth, cm.

The same picture is observed in cultivated soils. Maximum hardness and density are observed at a depth of 15–30 cm. At a depth of approximately 40 cm, the values for all soil parameters become equal and are independent of the condition of the upper cultivated layer.

Analysis of the obtained results showed that at a tillage depth of 20 cm and a travel speed of 5.60 to 9.05 km/h, the average tillage depth was 20.2–21.0 cm (see Table 1). The standard deviation was ±1.39 and ±1.68 cm, respectively, with a variation coefficient of 6.62–8.00%. The soil surface ridge after tillage was 2 cm. At the same time, erosion-hazardous particles decreased by a maximum of 1.30%. Soil crumbling (fraction size less than 50 mm) was 100%, and stubble preservation was 61–63%.

At a tillage depth of 30 cm and a travel speed of 3.90 to 5.54 km/h, the average tillage depth was 31.3–32.0 cm with a standard deviation of ±1.69 and ±2.01 cm and a variation coefficient of 5.28–6.42% (see Table 1). After passing at this depth, the soil surface ridgeness was 3 cm. The proportion of erosion-hazardous particles decreased (1.08–2.96%). Soil crumbling was 100%, stubble preservation was 64–66%.

Laboratory and field studies have shown that the ripper ensures soil loosening with a deepening of the arable horizon up to 32 cm, as well as preventing wind erosion of the soil by preserv-

[9]STO AIST 1.12–2006. Testing of agricultural machinery. Agricultural tractors, tillage machines, seeding and planting machines, and plant protection machines. Performance and reliability indicators. Moscow: Federal State Institution "State Testing Center", 2006, 68 p.

[10]GOST 33736–2016. Agricultural machinery. Machines for deep soil cultivation. Test methods. Moscow: Standartinform, 2017, 36 p.

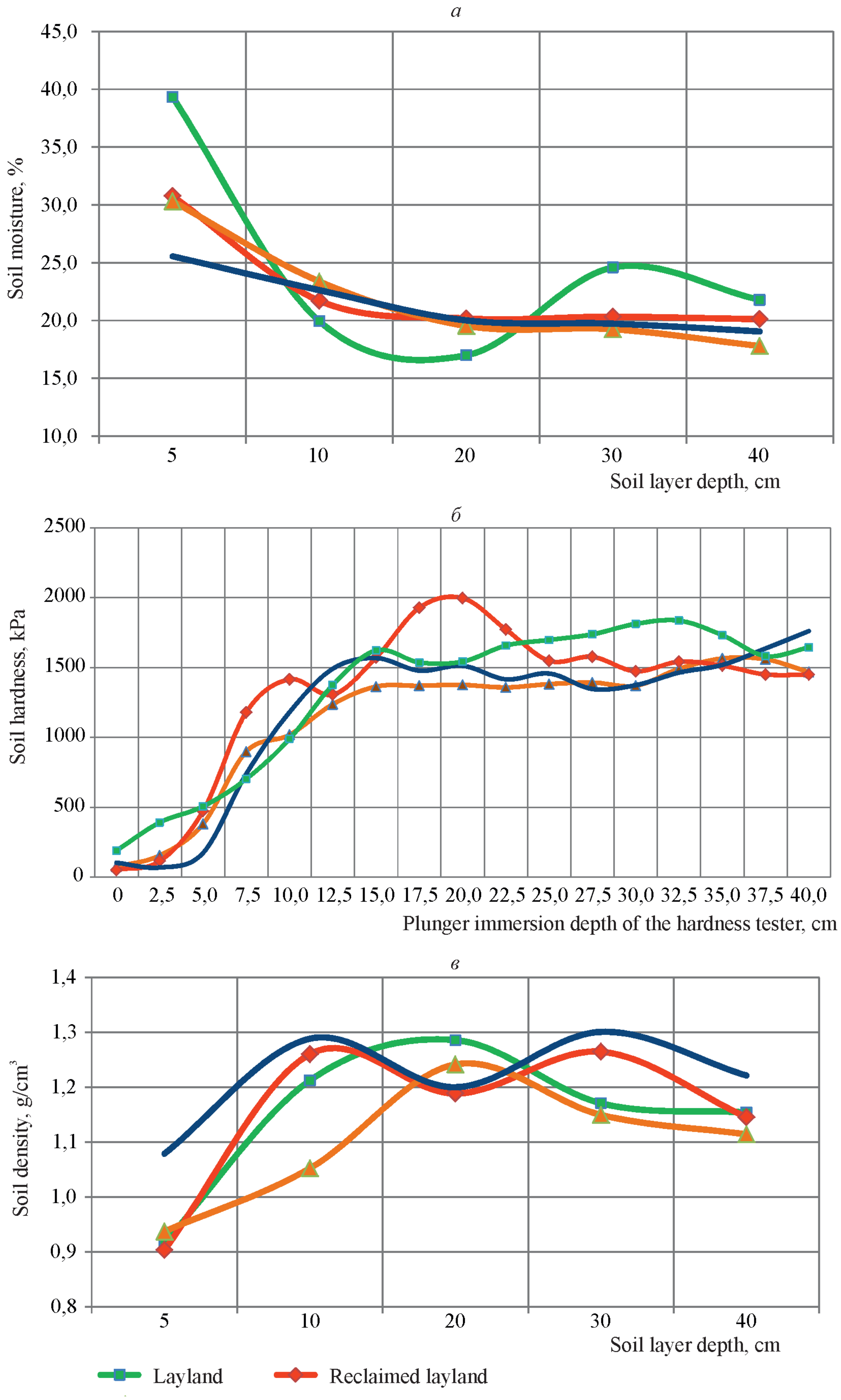

Рис. 4. Изменение влажности (*а*), твердости (*б*) и плотности (*в*) почвы в зависимости от ее состояния
Fig. 4. Changes in soil moisture (*а*), hardness (*б*), and density (*в*) depending on the soil condition

Табл. 1. Агротехнические показатели при лабораторно-полевых испытаниях
Table 1. Agrotechnical indicators in laboratory and field tests

Indicator	Value					
Travel speed, km/h	9,05	7,70	5,60	5,54	4,80	3,90
Tillage depth: specified, cm	20,0	20,0	20,0	30,0	30,0	30,0
arithmetic mean value, cm	20,2	21,0	21,0	31,3	31,3	32,0
standard deviation, cm	± 1,55	± 1,68	± 1,39	± 1,86	± 2,01	± 1,69
coefficient of variation, %	7,68	8,00	6,62	5,95	6,42	5,28
Average ridge height (ridgeness of the soil surface), cm	2,0	2,0	2,0	3,0	3,0	3,0
Preservation of stubble, %	61,0	63,0	62,0	64,0	65,0	66,0
Increase (+) or decrease (-) of erosion-hazardous soil particles in the 0–5 cm layer, %	–0,84	–0,72	–1,30	–2,96	–2,03	–1,08

ing stubble on the surface of the field and reducing erosion-hazardous particles.

Energy assessment of the ripper's operation was carried out to determine energy costs and assess its compliance with the traction and power performance of the K-744R4 tractor in combination with the PRP-5.6. The data are presented in Table 2 and Fig. 5.

According to the obtained results, with a working depth of 21–22 cm and an increase in the travel speed from 5.60 to 9.05 km/h, the traction resistance increased from 47.47 to 59.71 kN (12%), specific energy consumption – from 84.96 to 106.65 MJ/ha (25%). With a working depth of 31.3–32.0 cm and an increase in travel speed from 3.90 to 5.54 km/h, the traction resistance increased from 86.89 to 90.31 kN, specific energy consumption – from 154.89 to 161.54 MJ/ha.

In terms of traction and power performance, the K-744R4 tractor in combination with the PRP-5.6 ripper ensures stable performance of the technological process during autumn soil cultivation with a working depth of 21–22 cm at a speed of up to 9.05 km/h, and with a working depth of 31–32 cm at a speed of up to 5.54 km/h. During the operational and technological assessment, productivity per hour of prime time was 3.10 hectares at a travel speed of 5.54 km/h. Productivity per hour of non-primary time was 2.19 hectares. The decrease in productivity per hour of non-primary time, compared to productivity per hour of prime time, was due to the loss of shift time for turning, setup, and adjustment of the unit.

Табл. 2. Энергетическая оценка работы агрегата
Table 2. Energy assessment of the unit operation

Indicator	Value					
Operating speed, km/h	5,60	7,70	9,05	3,90	4,80	5,54
Tillage depth, cm	22,0	21,0	21,0	32,0	31,3	31,3
Productivity per 1 hour of main time, per hour	3,14	4,31	5,06	2,18	2,68	3,10
Machine power consumption, kW	74,1	106,1	149,9	93,8	117,9	139,1
Machine specific energy consumption, MJ/ha	84,96	88,62	106,65	154,89	158,37	161,54
Machine traction resistance, kN	47,47	49,56	59,71	86,89	88,63	90,31

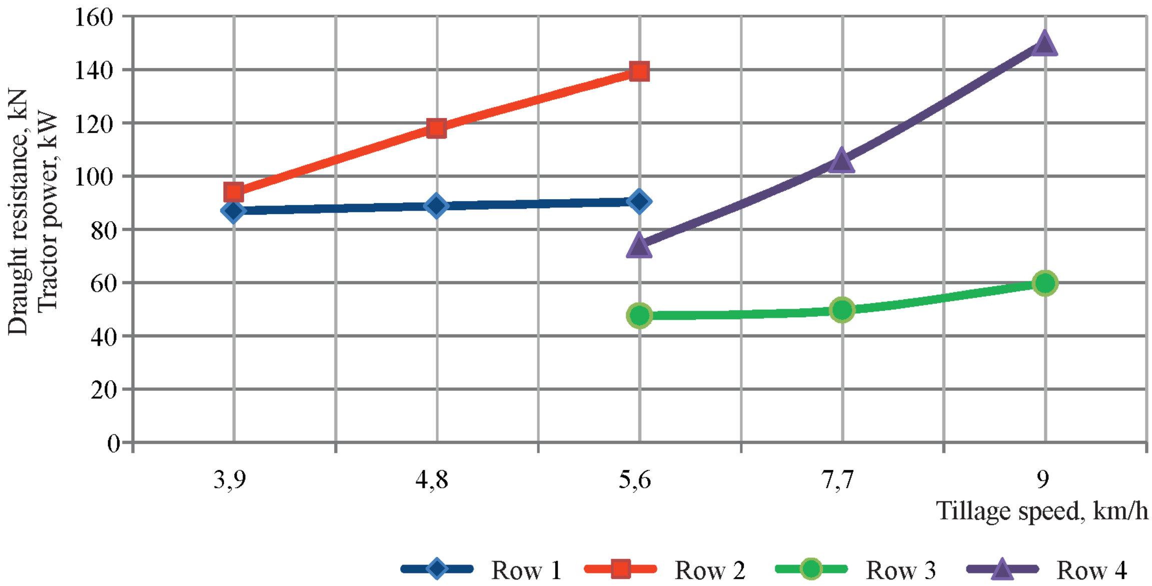

Рис. 5. Тяговые и мощностные показатели трактора К-744Р4 в агрегате с рыхлителем ПРП-5,6: ряды 1, 2 – глубина обработки 30 см; ряды 3, 4 – глубина обработки 20 см

Fig. 5. Traction and power indicators of the K-744R4 tractor in combination with the PRP-5,6 soil ripper: row 1,2 – processing depth of 30 cm; row 3, 4 – processing depth of 20 cm

CONCLUSION

The results of the studies revealed that at a depth of 20 cm, the moisture content of fallow soil is 8% lower than that of the cultivated soil. At a depth of 40 cm, the moisture content levels out. The maximum hardness of fallow soil is observed at a depth of 30 cm. Generally, the change in soil hardness with cultivation depth is represented by a second-degree polynomial equation.

In terms of traction and power performance, the K-744R4 tractor in combination with the PRP-5.6 ripper ensures stable performance of the technological process during autumn soil cultivation with a working depth of 22 cm at a speed of up to 9.05 km/h, and with a working depth of 31 cm at a speed of up to 5.54 km/h. Stubble retention on the field surface reaches 61–66%. The unit's traction resistance at a working depth of 21 cm increased by 12% (from 47.47 to 59.71 kN) with a speed increase from 5.60 to 9.05 km/h. At a working depth of 31 cm, with a speed increase from 3.90 to 5.54 km/h, this figure increased by 11% (from 86.9 to 90.3 kN). The unit's hourly productivity at a working depth of 21 cm and a speed of 9.05 km/h was 5.06 ha/h, and at a loosening depth of 31 cm and a speed of 5.54 km/h, it was 3.1 ha/h, respectively. Specific fuel consumption was 36.1 kg/ha.

СПИСОК ЛИТЕРАТУРЫ

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«Единое здоровье»

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Медицина лечит человека,
а ветеринария оберегает человечество.
С.С. Евсеенко

Обсуждена глобальная концепция «Единое здоровье» («One health»), основанная на взаимозависимости здоровья человека и здоровья животных и связи со здоровьем экосистем, в которых они существуют. Риски универсального характера становятся тотальным явлением эпидемиологии/эпизоотологии и принципиально касаются всего живого на земле. Основной движущей силой возникновения и распространения заболеваний среди животных и людей становятся процессы скорее социальной, чем биологической природы. Угрозы возрастают с глобализацией торговли, тотальным потеплением, изменениями стандартов социального поведения человека, участившимися межгосударственными конфликтами вплоть до военных. Концепция, принятая в начале 2000-х годов МЭБ/ФАО/ВОЗ/ЮНЕП в синергетическом сотрудничестве с более чем 70 другими международными организациями, которые играют ключевую роль во взаимодействии человека, животных и экосистем, успешно реализуется во многих странах мира с различным социально-экономическим уровнем при поддержке правительств и международных банков развития. Ветеринарная отрасль в «Едином здоровье» занимает одну из ключевых позиций. Концепция предоставляет возможность значительно увеличить возможности ветеринарии в национальных и межгосударственных масштабах, профессиональное влияние в удовлетворении современных потребностей общества и в конечном итоге выполнить свое величайшее профессиональное призвание в истории. Вектор перспективного развития и фундаментальной трансформации ветеринарии во всем масштабе ее социального, экономического, гуманитарного значения – необходимость уделять больше внимания междисциплинарному и межотраслевому сотрудничеству и исследованиям – может обеспечить тотальный прогресс от здоровья животных и тривиальной ветсанэкспертизы до «Единого здоровья» как сферы, действительно «оберегающей человечество».

Ключевые слова: «Единое здоровье», ветеринария, эпизоотология

"One health"

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Medicine cures people, and veterinary science protects humanity.
Evseenko S.S.

The global concept of “One Health” has been discussed, based on the interdependence of human and animal health and the connection with the health of the ecosystems in which they exist. Risks of a universal nature are becoming a total phenomenon of epidemiology/epizootology and fundamentally affecting all living things on earth. The main driving force behind the emergence and spread of diseases among animals and humans are processes of a social rather than biological nature. Threats are increasing with the globalization of trade, global warming, changes in human social behavior standards, and the increasing frequency of interstate conflicts, including military ones. The concept, adopted in the early 2000s by OIE/FAO/WHO/UNEP in synergistic collaboration with more than 70 other international organizations that play a key role in the interaction between humans, animals and ecosystems, is being successfully implemented in many countries of the world with different socio-economic levels with the support of governments and international development banks. The veterinary industry occupies a key position in the "One Health" program. The concept provides an opportunity to significantly increase the capabilities of veterinary medicine on a national and international scale, the professional influence in meeting the modern needs of society and ultimately to fulfill its greatest professional calling in history. The vector of promising development and fundamental transformation of veterinary science across the full scope of its social, economic, and humanitarian significance – the need to pay greater attention to interdisciplinary and intersectoral collaboration and research – can ensure total progress from animal health and trivial veterinary examination to "One Health" as a sphere that truly "protects humanity."

Keywords: "One Health," veterinary science, epizootology

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The global situation regarding infectious diseases in the 21st century is characterized by unprecedented apocalyptic phenomena. Concepts have emerged that designate the current period as the “era of pandemics”[1].

Its most pronounced feature is the progressive emergence of new dangerous infections of animals and humans, previously unknown to science and practice. In addition, a number of existing diseases adapt and slip out of control in altered patterns (new hosts, ranges, serotypes, pathotypes) (see Fig. 1).

Dangerous zooanthroponoses with extraordinary potential have emerged, such as avian influenza H5 – highly pathogenic and widely spread low pathogenicity pathotypes, paramyxoviral

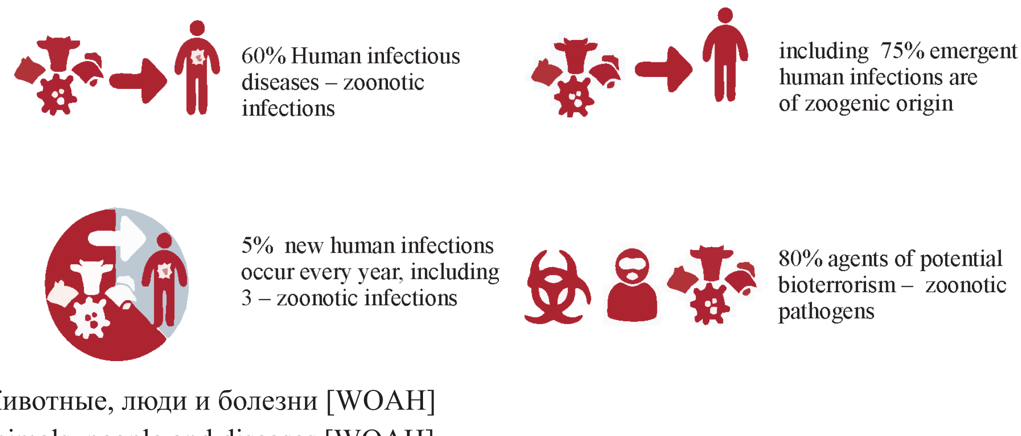

Рис. 1. Животные, люди и болезни [WOAH]
Fig. 1. Animals, people and diseases [WOAH]

[1]A pandemic era. The lancet planetary health. URL: https://www.thelancet.com/journals/lanplh/article/piis2542-5196(20)30305-3/fulltext.

diseases Hendra and Nipah, numerous new infections of coronavirus origin identified to this day, particularly severe acute and Middle Eastern respiratory syndromes. The pandemics of swine flu H1N1 (2009–2010) and Zika fever (2015–2017) have passed. Western Europe experienced a ten-year crisis of new prion diseases (1986–1996) and a serious epizootic of exotic bluetongue (2006–2013), which began spreading again in the northwest of the continent.

In the last decades of the 20th century, a new forest "fox" ecotype of rabies emerged in Europe, currently representing a hyperenzootic state in the European part of the Russian Federation with a tendency to further spread eastward. Since 2007, the African swine fever (ASF) panzootic has been progressing, evolving into a fundamentally new natural focal infection of wild boars across Eurasia. The notorious COVID-19 pandemic is difficult to control. The growing tensions surrounding plague and smallpox in small ruminants pose a real panzootic threat, and bovine leukemia continues to spread worldwide[2].

To the above should be added the fatal unfavorable situation in the world, especially in the Russian Federation, in a number of well-known chronic problems in veterinary medicine, first of all the stalemate with infections of factor-endogenous nature, which arose in the second half of the 20th century with the transfer of animal husbandry to an industrial basis and remains insoluble to this day without encouraging prospects for a solution[3].

The emergence of infectious diseases has become a commonplace phenomenon in epidemiology and epizootology. It is important that this total phenomenon fundamentally affects all living things on Earth. Demonstrative examples are exotic events that put the existence of susceptible animals as biological species under fatal threat. These are exclusively malignant: the white-nose syndrome mycotic disease of bats, the viral white spot syndrome of shrimp of the Penaeidae family, or the retroviral immunodeficiency of koalas [1]. Unfortunately, the specific causes of emergent phenomena, a priori related to the ecology of parasitic systems, are mostly not determined or remain unknown, except for the observation of unexpected activity of natural reservoirs with obviously inexhaustible potential, where a special place belongs to representatives of the order Chiroptera [1–3].

In response to these challenges, a special modern **category of socially significant infectious animal diseases** is being formed, the emergence and spread of which, regardless of the scale of economic damage, negatively affects the social structure of certain groups and segments of the population. In particular, this includes African swine fever under the conditions of the current panzootic, avian influenza, bovine leukemia and rural residents, rabies as a dangerous zooanthroponosis.

Such a situation is illustrated by a number of negative indicators of general significance. Human activity has seriously altered three-quarters of the terrestrial and two-thirds of the marine environment. Three-quarters of the billion people living on less than $2 a day depend on subsistence farming and livestock breeding to survive. Animal diseases pose a direct threat to the economy of rural communities that depend on livestock farming. One fifth of global livestock losses are associated with animal diseases. People and their domestic livestock more often come into contact with wildlife when more than 25% of the original forest cover is lost. These contacts increase the likelihood of the spillover[4] of natural focal and other wildlife infections[5].

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[2]Databases of the FSBI 'Veterinary Center', the World Organisation for Animal Health (WAHIS), FAO (EMPRES), and others.

[3]*Makarov V.V., Stekolnikov A.A., Sochnev V.V.* Factor-Endogenous Doctrine of the Main Pathology of Productive Animals: Textbook for Universities. St. Petersburg: Lan, 2025, 64 p.

[4]Spillover and spillback refer to the transmission of a natural focal infection from biotopes to domestic animal or human populations, literally "overflowing", and the return of the infection from domestic conditions to natural foci, literally "draining back". In eco-epidemiology, these are two mutually opposite vectors of infection spread "there and back".

[5]Global health risks and tomorrow's challenges. URL: https://www.woah.org/

Risks of a universal nature are increasing with the globalization of trade, total warming, changes in human social behavior standards, and more frequent interstate conflicts, up to military ones, which provides pathogens with numerous opportunities to colonize new territories and evolve into new forms. Although in most cases the risk is focused on the transmission of pathogens from animals to humans, animal health is also affected by diseases transmitted from humans. COVID-19, tuberculosis, various strains of influenza, and other anthroponotic infections are potentially dangerous and even deadly for animals of different species[6].

Management of global health risks – from combating individual diseases to total warming, other natural-climatic, anthropogenic, and technogenic phenomena with negative consequences – is impossible without full cooperation from the sectors of animal, human, and environmental health, multifaceted interstate and supranational partnerships, the development and implementation of global strategic and tactical solutions in combating major diseases and broader health threats, for example, drug resistance to antimicrobial agents (see Fig. 2).

All of this, as well as the undeniable fact that the main driving force behind the emergence and spread of diseases among animals and humans are processes of a social rather than biological nature, prompted OIE/FAO/WHO/UNEP[7] in synergistic cooperation with more than 70 other international organizations, which play a key role in the interaction of humans, animals, and ecosystems, to formulate and adopt in the early 2000s **a fundamental concept in their activities called "One Health"** (see Fig. 3)[8, 9].

Its essence is that human health and animal health are interdependent and connected to the health of the ecosystems in which they exist. The increasing interdependence with animals and animal products can become the most critical risk factor for human well-being concerning infectious disease incidence, to the point that the current generation may become the first in human history whose life expectancy and overall health decline.

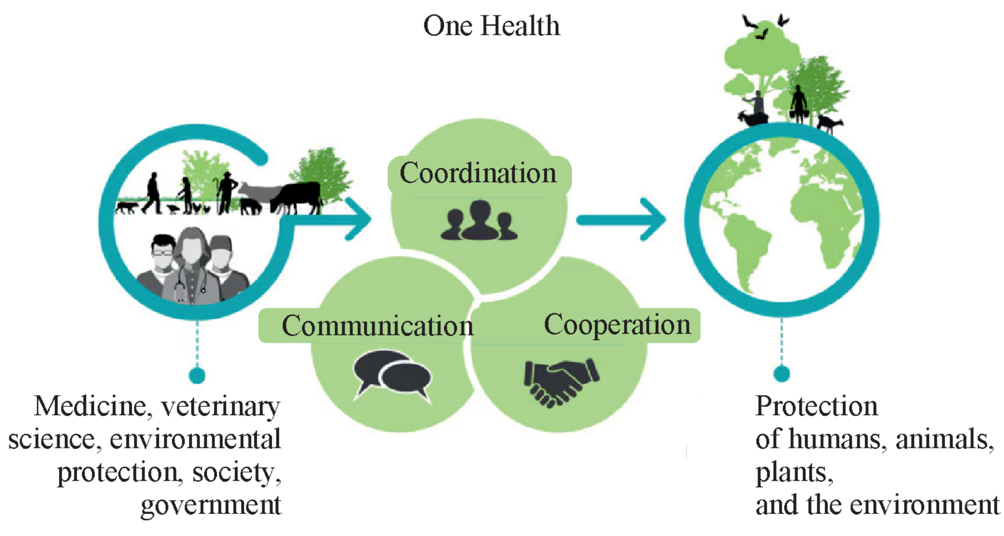

Рис. 2. «Единое здоровье» [CDC]
Fig. 2. One Health [CDC]

[6]FAO. World Livestock 2011 – Livestock in food security. Rome, FAO. 2011.

[7]UNEP, United Nations Environment Programme. Программа Организации Объединенных Наций по окружающей среде.

[8]A momentous, milestone presentation at the American Veterinary Medical Association Convention by L.J. King. URL: https://onehealthinitiative.com/a-critical-need-for-veterinary-medicines-fifth-transformation-american-veterinary-one-health-society-avohs-presentation-at-2025-american-veterinary-medical-association-convention.

[9]"One Medicine-One Health": An Historic Perspective. URL: https://onehealthinitiative.com/wp-content/uploads/2023/06/WMJ_2023_02_one_health_one_medicine.pdf.

The concept of 'One Health' is aimed at maintaining balance and optimizing the health of humans, animals, and ecosystems, therefore the problems addressed are predominantly global in nature. It is implemented as a unifying, collaborative global approach to understanding the risks to human and animal health (both domestic and wildlife) and the health of ecosystems as a whole, relying on intergovernmental standards, global health information, networks of international experts, and programs for strengthening national services. At all levels, not only the organs of veterinary and human medicine are actively involved, but also all interested and responsible agencies that carry out and regulate socio-economic activities on a national scale — legislative, administrative, law enforcement, natural resource management, public, educational, fundamental academic and applied science (see Fig. 3) [4].

The concept of "One Health" **implies a holistic integrated interpretation of the notion of 'health'** without isolating human health, animal health, environmental health, and traditional dis-

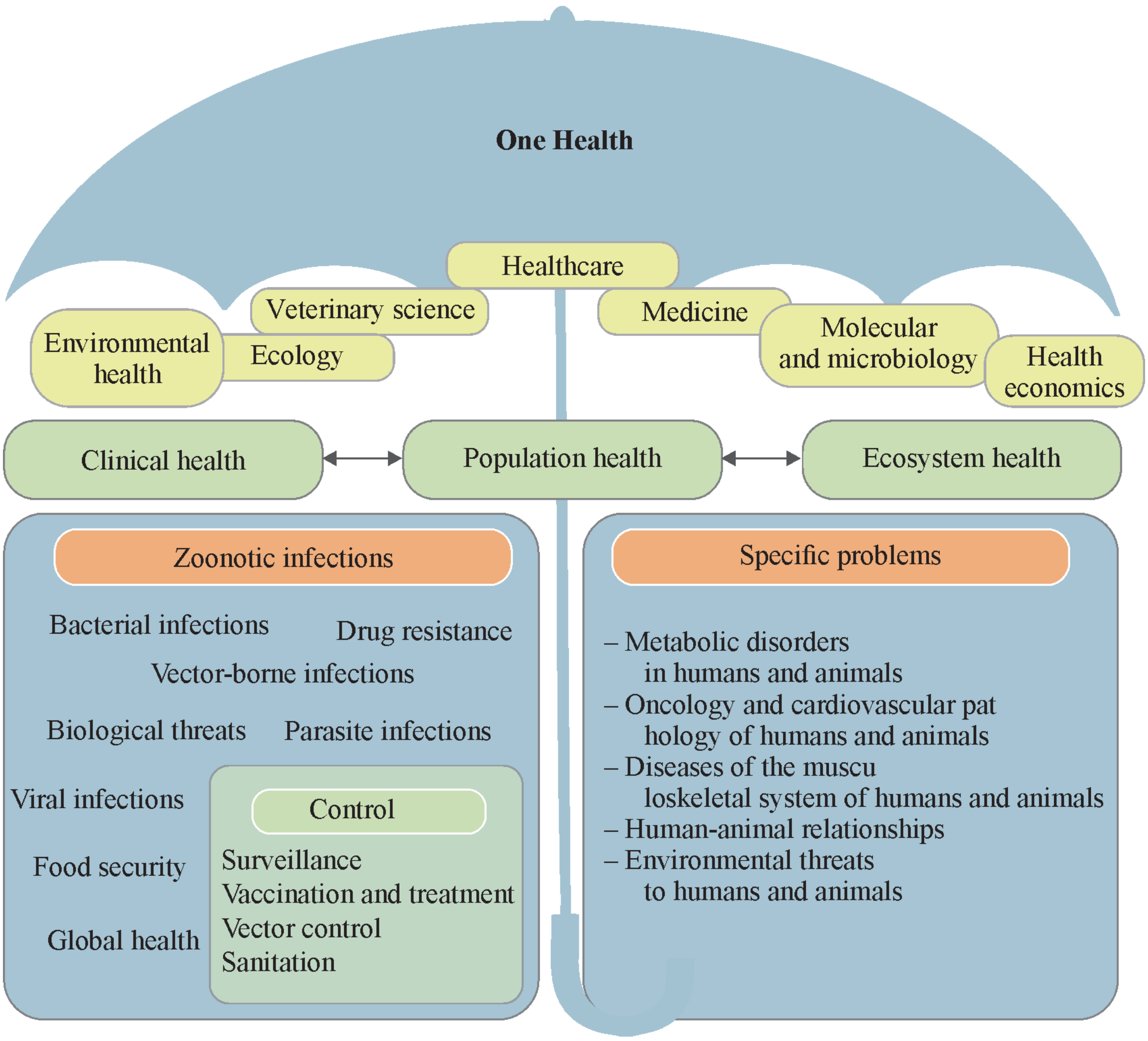

Рис. 3. «Зонтик», иллюстрирующий сферу применения концепции «Единое здоровье»[10]

Fig. 3. "Umbrella" illustrating the scope of application of the "One Health" concept[10]

[10] *Muraille E., Godfroid J.* Le concept «One Health» doit s'imposer pour permettre l'anticipation des pandémies // Published: 2020. June 24. 11.18pm CEST. DOI: 10.64628/AAK.xtnhedcxk.

ciplinary selfishness, with the aim of a full, deep, and comprehensive understanding and use of the complex connections and relationships between these three spheres of science, practice, and education. It is based on interdisciplinary equal cooperation, collaboration, and communication between veterinary, medical, and other specialists in the field of animal and human health, nature conservation and environmental protection, ecologists, zoologists, theriologists, anthropologists, economists, sociologists, and others[11] [5].

The idea of a unified view of health and the importance of the environment has ancient roots, dating back at least to Ancient Greek times, especially to Hippocrates with his treatise "On Airs, Waters, and Places." In the modern sense, this movement in the mid-20th century first identified itself with the phrase "One Medicine" and developed by integrating concepts of environmental hygiene and eco-epidemiology, later being renamed "One World – One Health." Ultimately, under its modern name, this movement originated in the early 2000s in the USA (see footnote 9) [6].

The concept of "One Health" did not arise out of nowhere. Among other things, the moral and theoretical basis was formed by the well-known "Iron Laws of Conservation" of the American ecologist and demographer Paul Ehrlich[12, 13], where, in the most general form, the situation in which the world's population found itself is reflected.

(*i*) In nature conservation, only successful defense or retreat is possible. Offense is impossible: a species or ecosystem, once destroyed, cannot be restored. (*ii*) The continuing growth of the population and nature conservation contradict each other. Preserving and further increasing the population is fundamentally incompatible; the population directly displaces biodiversity. (*iii*) The economic system, gripped by a growth mania, and nature conservation also oppose each other. Nature preservation and a growth-oriented economy are fundamentally incompatible. The type of growth must change: from extensive it must move to intensive, from quantitative to qualitative, from spatially expanding to contracting. (*iv*) The idea that when making moral decisions about the use of the Earth, one should consider only the short-term goals and immediate happiness of *Homo sapiens* is deadly not only for non-human organisms but also for all of humanity. (*v*) Arguments in favor of the right of non-human life forms to exist and calls for compassion toward those who may be our only living companions in the Universe are currently mostly unheard. Until ethical and aesthetic views change, nature conservation must remain a matter of human welfare and survival. Nature protection should be considered a matter of well-being in a more distant perspective as well.

The same goal is served by the "Manhattan Principles 'One World – One Health'", formulated by the Wildlife Conservation Society and agreed upon in 2004 at a symposium on the spread of infectious diseases among humans, domestic and wild animals, which was attended by representatives of numerous international organizations competent in this area (WHO, FAO, etc.). The essence of their twelve postulates is as follows[14].

A significant connection is asserted between the health of humans, domestic and wild animals, and the threats they pose to humans, food security, the economy, as well as the maintenance of a healthy environment and functioning ecosystems. It is recommended *to include wild animal health issues as a significant component of global prevention of human and domestic animal diseases, surveillance, monitoring, control, and mitigation of their consequences. Human health protection should involve a significant contribution to nature conservation.* Particular attention is required for the development of adaptive

[11]One Health. URL: https://fr.wikipedia.org/wiki/One_Health.

[12]Conservation Biology: Monograph; translated from English / edited by M. Suleya, B. Wilcox. Moscow: Mir, 1983, 430 p.

[13]*Ehrlich P., Ehrlich A.* Ecoscience: Habitat and Biodiversity Conservation Save Species From Extinction. URL: motherearthnews.com/sustainable-living/nature-and-environment/habitat-and-biodiversity-conservation-zmaz82sozgoe/

[14]The Rockefeller University, Caspary Auditorium Conference Summary One World, One Health: Building Interdisciplinary Bridges to Health in a Globalized World. 2004. 29.

and forward-looking approaches in relation to emerging and re-emerging infections associated with complex interspecies interactions.

It is necessary to increase investment in global and national human and animal health infrastructures, based on the scale and nature of emerging and re-emerging threats of this type, to improve monitoring of human and animal health, timely information exchange, coordination of response measures among governmental and non-governmental agencies, public and veterinary institutions, vaccine and pharmaceutical manufacturers, and other stakeholders. It is also necessary to develop cooperation between governments, the population, and the private and public sectors in addressing global health and environmental protection issues.

It is fundamentally important to invest in education and raising awareness among people around the world, in influencing the political process for a better understanding of the interconnection between health and the integrity of ecosystems to improve the prospects of "planetary health"**.**

The health problems of animals and humans are currently primarily associated with new emergent, re-emerging, endemic, neglected exotic infections, transmissible diseases, the progressive drug resistance of pathogens, food safety and food security, environmental pollution, climate change, and other health threats faced by humans, animals, and the environment (see Fig. 3)[15].

In particular, the widespread creation of livestock farms with high animal density and the use of prophylactic pharmaceutical drugs to maintain health and increase growth rates significantly increases the likelihood of developing antibiotic resistance and thereby reduces their effectiveness. Pathogens resistant to antimicrobial drugs can spread rapidly in the microbiomes of populations and communities, as well as in the surrounding environment (soil, water), hindering the treatment of diseases in agricultural animals and humans. The nosoareals of transmissible infections are expanding due to increasing environmental temperatures and the expansion of the habitats of vectors. Diseases of productive animals can threaten livelihoods and the economy[16].

The implementation of the "One Health" concept (better to say – doctrine) is fundamentally supported by the governments of economically developed countries (USA, UK, France, etc.), the UN, the World Bank for development, and other political and economic institutions. It is reflected in numerous national and international programs aimed at addressing pressing issues of general importance. Achievements and problems are widely published abroad and discussed at international congresses and other scientific and technical events. For example, the "European Joint Programme EJP One Health" (France) coordinates the collaboration of dozens of scientific laboratories and educational institutions in the fields of veterinary, medical, environmental, and biotechnological studies, carrying out more than 30 projects on combating foodborne zoonoses, antibiotic resistance, emerging zoonoses, and other emerging risks[17]. The expected benefits of implementing the concept for the global community are estimated at approximately $40 billion per year. The projected annual expenditure requirement is less than 10% of this amount of benefits, with a 'loss/profit' ratio of 1 to 10[18].

In general, the place of veterinary medicine in the 'One Health' concept defines the specific roles and responsibilities of veterinary specialists (see Table 1).

The educational component of the "One Health" concept is of special interest. Its goals and means are positively received by the veterinary community. The concept has gained wide recognition and support, and has become the basis

[15]*Microbial Threats to Health: Emergence, Detection, Response* // Institute of Medicine. 2003. Washington, DC: The National Academies Press. DOI: 10.17226/10636.

[16]One Health. URL: https://www.who.int/news-room/fact-sheets/detail/one-health

[17]Conférence scientifique annuelle 2019. 22–24 mai, 1re conférence scientifique annuelle de l'EJP One Health [archive], Dublin, Irlande.

[18]About One Health. URL: https://www.cdc.gov/one-health/about/index.html.

for the daily work of veterinarians and the training of students worldwide (see footnote 8) [6].

As the veterinary sector develops, it should take key positions in “One Health”, which is why veterinary medicine stands on the threshold of the greatest period of opportunities in its history, considering the changing needs of the global society. It is assigned an important role in five overlapping areas of the concept – public health, biomedical research, global food security, ecosystem health, and traditional veterinary animal medicine (see Table 1). The concept touches on each of these areas, so understanding and applying the principles of “One Health” should be at the core of the veterinary profession – the history of veterinary medicine is inextricably linked to them. Although recently veterinary medicine has moved away from its historical roots due to excessive focus on specialization, 'One Health' will once again become the driving force and the meaning of veterinary existence, since the turning point has already been passed (see footnote 8) [6].

Thanks to its history and the training of specialists, veterinary medicine is better suited than other professions to promote, lead, and implement this concept. Specializations within the profession and significant changes in veterinary school curricula indicate a sharp need to improve the level of training for both students and practicing veterinarians so that the profession can effectively implement the principles of “One Health”. Veterinary medicine must be a leader here in partnership with human medicine, public health, biomedicine, productive animal husbandry, ecology, and theriology. This could become the most important opportunity for the progress of the profession in the foreseeable future, especially for academic veterinary medicine (see footnote 8) [6].

"One Health" as a rapidly developing subject area fully meets the general requirements for a new specialization and the professional competence of a veterinarian in terms of social demand, the substantive, scientific, and practical level of the knowledge and skills communicat-

Табл. 1. Роли и обязанности ветеринаров в концепции «Единое здоровье» [6]
Table 1. Roles and responsibilities of veterinarians in the “One Health” concept [6]

Human health	Domestic animal health	Environmental health
Reducing global famine	Ensuring animal welbeing	Protecting biodiversity
Fight against zoonoses	Disease prevention	Wildlife resource management
Quality control and food safety	Production of safe food products of animal origin	Control of traffic of exotic species and disease vectors
Biomedical research	Ensuring the security of livestock product exports	Disease prevention in wild animal populations
Disease surveillance	Veterinary medicine, diagnostics and disease control	Surveillance of wild animal diseases and zoonoses
Biosecurity	Veterinary-sanitary and epidemiological examination of animals and animal products	Veterinary medicine in the conservation of natural resources
Human-animal bonding and companion animal health	Monitoring of pathogen resistance to antimicrobial drugs	Measures to adapt fauna to climate change

ed. For example, The Royal (Dic) School of Veterinary Studies of the University of Edinburgh (Scotland), being a world leader in veterinary education, provides postgraduate education that combines interdisciplinary experience in a specific set of subjects, including veterinary, environmental, sociological, and economic determinants of health. Among them are disciplines absolutely unknown in domestic veterinary practice, such as unified health policy, ecosystem health, applied epidemiology and surveillance in conservation medicine, welfare of wild animals in captivity and in the wild, ecosystem resilience and extreme events, the relationship between the environment and society, emerging infectious diseases, pasture-based livestock farming and herd health, non-communicable diseases in a global context, wildlife disease management, conservation project management and leadership, and others[19]. The One Health Institute of the UC Davis School of Veterinary Medicine (Davis, USA) has been working worldwide for a decade on solving complex issues related to the interaction of animals, people, plants, and the environment, maintaining a global network of interconnected centers, laboratories, programs, and projects, each of which has its own sources of funding and operational structure to address unique challenges, contributing to the global mission of the "One Health" concept[20].

The adoption of the provisions of this concept in relation to the situation in the Russian Federation, general awareness of corporate responsibility in the current situation is the only real direction for solving modern problems of veterinary science, practice, and especially education [5]. A convincing argument should be the pandemic parallels as a kind of synergism of emergent infections. African swine fever, which spread to pandemic proportions in the territory of Eurasia, became a significant factor of negative impact on public welfare infrastructure and vital elements of the economy, in particular, the reduction of access to animal protein for the vast population of Southeast Asian countries, where the COVID-19 pandemic subsequently arose. The concept of "One Health", which implies specific components of universal activity, is presented in Fig. 4.

Agriculture and food are a key foundation for the livelihood of society "from farm to fork", linking into a single chain the elements of social-economic, natural, and geographical order – livestock farming, crop production, processing, nature conservation, epizootics, epiphytotics, epidemics, and the natural focality of infections. Regarding the social sphere, the fundamental importance is unquestionable, primarily of integrating veterinary and human medicine and the necessity of applying joint cross-sectoral approaches in addressing global problems of increasing significance, relating to the competence of both fields and the scope of their practical activities. The ecological significance of wildlife, and more generally of environmental factors, comes down to the reservation and spread of emerging infections as a result of natural, man-made, and anthropogenic changes. The geoeconomic component involves various consequences of the comprehensive mobility of the population, globalization of trade in animals and animal products, and the need for supranational management and control (see Fig. 5).

Table 2 presents the role of socially significant infections in the macro components of "One Health" in a generalized format.

CONCLUSION

The concept of "One Health" is becoming a political doctrine, supported by the governments of the G20 countries, international development banks, and comprehensive approaches are reflected in international financing and trade regulations. At the same time, there is a clear public awareness of the crucial role of veterinary science and practice in analyzing and controlling risks to medical healthcare, in the development of policy, strategy, and tactics for ensuring soci-

[19]One Health // The Royal (Dick) School of Veterinary Studies.
[20]The Institute at UC Davis. URL: https://ohi.vetmed.ucdavis.edu/about.

ety's resilience to potential pandemic threats in the future[21] (see note 8) [6, 9].

In the domestic eLIBRARY.RU over the last decade, there have been several dozen mentions of the topic of “One Health”, mostly in the form of theses from a veterinary perspective. Among them, the haphazard and inappropriate use of historical variations of the name already indicates a lack of fundamental understanding of the essence of this most important matter. In only two publications from the field of medicine are the main elements of the concept simply listed from selfish positions without any analysis [10, 11]. This is a rather sad fact against the backdrop of the exceptionally active and effective global progress of the “One Health” sector, supported by the political will of governments. Such stagnation regarding the coverage, recognition, and even more so the development of the doctrine in our country, given its unquestionable demand, finds no reasonable explanation.

The nature of the health status of domestic and wild animals, emergent diseases, natural focality of infections, the ecology of reservoir species with such negative phenomena as their synanthropization and zoomania, and the importance of veterinary public health, obviously, little concern domestic veterinary science, practice, and education.

The concept provides an opportunity to significantly expand the capabilities of veterinary medicine on national and interstate scales, professional influence in meeting the modern needs of society, and ultimately fulfill its greatest professional vocation in history (see footnote 8).

It is precisely this vector of prospective development and fundamental transformation of veterinary medicine across the entire scale of its social, economic, and humanitarian significance – the need to pay more attention to interdisciplinary and cross-sectoral cooperation and research – that can ensure total progress from animal health and routine veterinary examination to “One Health” as a field truly “safeguarding humanity”.

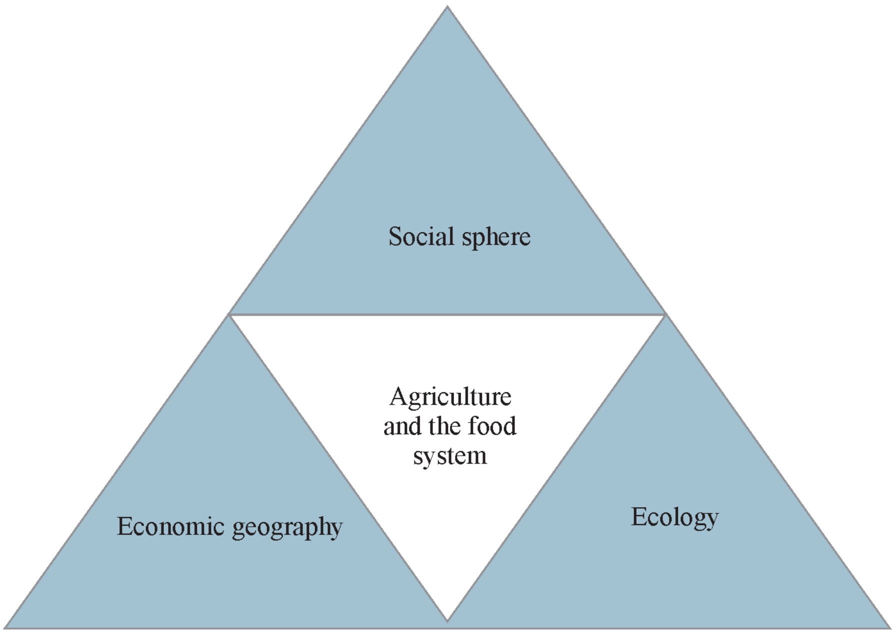

Рис. 4. Макрокомпоненты взаимоотношений между людьми, животными и патогенами в рамках «Единого здоровья» [7]

Fig. 4. Macrocomponents of the relationships between people, animals, and pathogens within the framework of “One Health” [7]

[21] “One Health” Is The New Global Policy Framework // By J. Drake, Contributor. 2025. Aug 25. URL: https://www.forbes.com/sites/johndrake/2025/08/25/

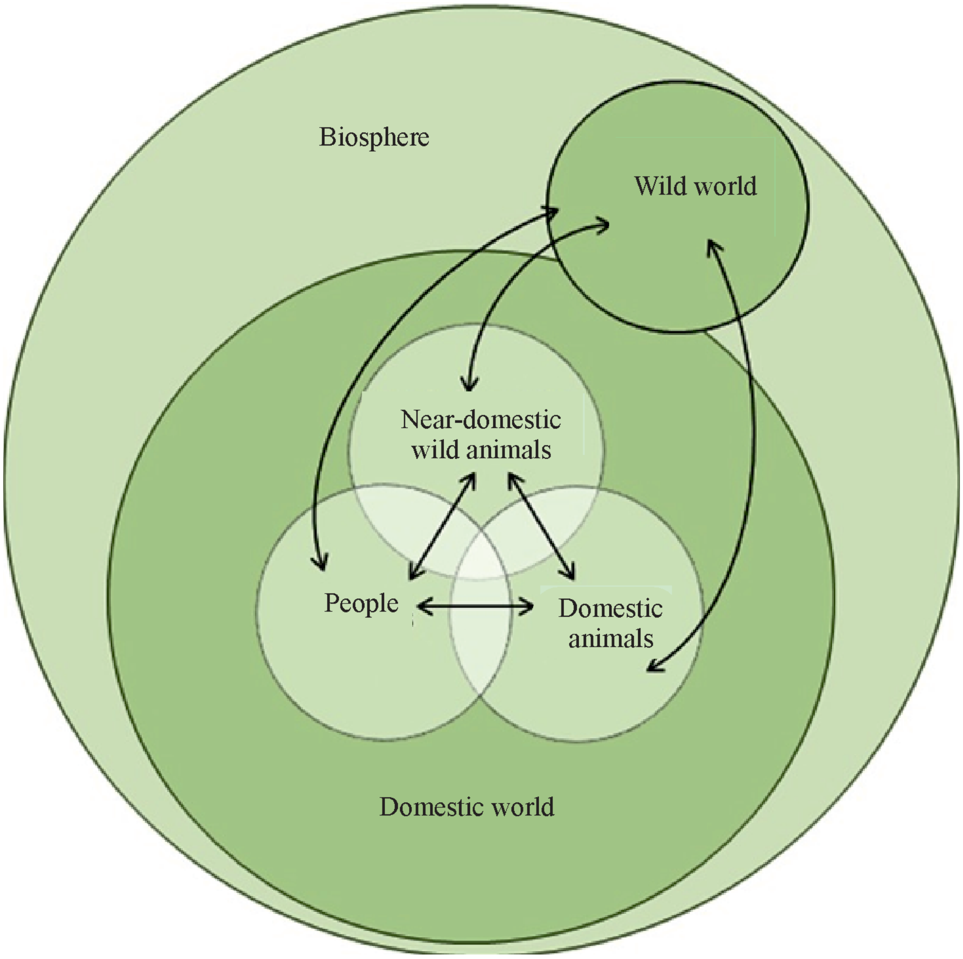

Рис. 5. Эпидемиологические взаимоотношения между дикой природой и домашним миром: потоки патогенов и риск зоонозов [8]

Fig. 5. Epidemiological relationships between wildlife and the domestic world: pathogen flows and zoonotic risk [8]

Табл. 2. Социально значимые инфекции животных и макрокомпоненты «Единого здоровья»

Table 2. Socially significant animal infections and macrocomponents of "One Health"

Infection	"One Health" macrocomponents			
	Agriculture and the food system	Social sphere	Ecology	Economic geography
Foot-and-mouth disease	++++	+++	+	++++
African pig plague	++++	++++	++++	++++
Rabies	–	++++	++++	–
Avian flu	++++	++++	++++	++
Bluetongue	++++	–	+++	+++
Prion diseases	+	+++	+++	++
Swinepox and goat pox	+++	++	++	++
Small ruminant plague	+++	++	++	++
Bovine leukemia	++	+++	–	++

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If authors from different institutions took part in the preparation of the article, it is necessary to indicate the affiliation of each author to a particular institution using the superscript index.

4. Abstract in Russian and English. The size of the abstract should not be less than 200-250 words. The abstract is a brief and consistent presentation of the material of the article on the main sections and should reflect the main content, follow the logic of the presentation of the material and description of the results in the article with the provision of specific data. The abstract should not include the newly introduced terms, abbreviations (with the exception of common knowledge), references to the literature. The abstract should not emphasize the novelty, relevance and personal contribution of the author; the place of research should be indicated to the district (region), specific organizations should not be mentioned.

5. Keywords in Russian and English. There should be up to 5–7 words by the topic of the article. It is desirable that the keywords support the abstract and the title of the article.

6. Information on the conflict of interests or its absence. The author should notify the editor on the real or potential conflict of interests by including the information in the appropriate section of the article. If there is no conflict of interests, the author should also inform the editor about it.

Example wording: "The author declares no conflict of interest".

7. Acknowledgements in Russian and English. This section lists all sources of funding for the study, as well as acknowledgements to people who contributed to the article but are not the authors.

8. The main body of the article. When presenting original experimental data, it is recommended to use subheadings:

INTRODUCTION (problem statement, goal and tasks of the study)

MATERIAL AND METHODS (conditions, methods (methodology) of research, object description, place and time of research)

RESULTS AND DISCUSSION

CONCLUSION

REFERENCES. The number of sources must be at least 12. The list of references includes only peer-reviewed sources: articles from scientific journals and monographs. Self-citation of no more than 10% of the total number. The bibliography list should be designed as a general list in the order of mention in the text, it is desirable to refer to sources 2-3 years old. The rules for the list of references are in accordance with GOST R 7.05-2008 (requirements and rules for compiling a bibliographical reference). In the text the reference to the source is marked by a serial number in square brackets, for example [1]. Literature in the list is given in the languages in which it was published. In the bibliographic description of the publication, it is necessary to include all authors, without abbreviating them by one, three, etc. It is unacceptable to abbreviate the names of articles, journals, publishing houses.

1. If it is necessary to refer to abstracts, dissertations, collections of articles, textbooks, recommendations, manuals, GOSTs, information from websites, statistical reports, articles in socio-political newspapers, etc., such information should be placed in a footnote at the end of the page. Footnotes are numbered in Arabic numerals and placed page by page through continuous page numbering.

Attention! Theoretical, review and problem articles can have any structure, but must contain an abstract, keywords, list of references.

EXAMPLE OF REFERENCES IN RUSSIAN AND ENGLISH AND FOOTNOTES

REFERENCES (in Russian):

Monograph

Klimova E.V. Field crops of Zabaikalya: monograph. Chita: Poisk, 2001. 392 p.

Part of a book

Kholmov V.G. Minimum tillage of coulisse-strip fallow for spring wheat with intensification of arable agriculture in southern forest-steppe of Western Siberia// Resource-saving tillage systems. Moscow: Agropromizdat, 1990. pp. 230-235.

Periodical publication

Pakul A.L., Lapshinov N.A., Bozhanova G.V., Pakul V.N. Technological grain qualities of spring common wheat depending on the system of soil tillage // Siberian Herald of Agricultural Science. 2018. vol. 48. № 4. pp. 27-35. DOI: 10.26898/0370-8799-2018-4-4.

REFERENCES (in English):

References are compiled in the same order as the Russian version, according to the following rules:

Names and surnames of the authors are given in the established way of transliteration, English title of the article, *transliteration of the name of the Russian-language source (for example through the site: https://antropophob.ru/translit-bsi) = English title of the source*. The order of presentation for a monograph is the following: city, English name of the publisher, year, number of pages; for a journal: year, volume, number, pages. (In Russian).

Example: Author A.A., Author B.B., Author C.C. Title of article.

Transliteration of the authors. English title of the article.

Zaglavie jurnala = Title of Journal, 2012, vol. 10, no. 2, pp. 49–54.

Transliteration of the source = English name of the source

Monograph

Klimova E.V. *Field crops of Zabaikalya*. Chita, Poisk Publ., 2001, 392 p. (In Russian).

Part of a book

Kholmov V.G. Minimum tillage of coulisse-strip fallow for spring wheat with intensification of arable agriculture in southern forest-steppe of Western Siberia. *Resource-saving tillage systems*, Moscow, Agropromizdat Publ., 1990, pp. 230–235. (In Russian).

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FOOTNOTES:

Quated text$_1$.

1*Klimova E.V., Andreeva O.T., Temnikova G.P.* Ways to stabilize food production in Transbaikalia // Problems and prospects of perfecting zonal farming systems in modern conditions: materials of the scientific and practical conf. (Chita, October 16-17 2008). Chita, 2009, pp.36-39.

Digital Object Identifier – DOI (when the cited material has it) should be indicated at the end of the bibliographic reference.

Example:

Chu T., Starek M.J., Brewer M.J., Murray S.C., Pruter L.S. Assessing lodging severity over an experimental maize (Zea mays L.) field using UAS images // Remote Sensing. 2017. Vol. 9. P. 923. DOI: 10.3390/rs9090923.

The DOI of the article should be checked on the website http://search.crossref.org/ or https://www.citethisforme.com. To do this, enter the title of the article in English in the search bar.

FIGURES, GRAPHS, TABLES, SCREENSHOTS, PHOTOGRAPHS AND FORMULAS

The figures must be of good quality, suitable for printing. All figures must have captions. The caption must be translated into English. Figures should be numbered in Arabic numerals according to the order in the text. If there is only one figure in the text, it is not numbered. References to figures should be formatted as follows: "Fig. 3 indicates that ..." or "It is indicated that ... (see Fig. 3)". The caption under the figure includes a figure number and its title. "Figure 2. Description of vital processes." The translation of the figure caption should be placed after the figure caption in Russian.

Tables should be of good quality, suitable for printing. Tables suitable for editing are preferred, not scanned or as figures. All tables should have headings. The title of the table should be translated into English. Tables should be numbered in Arabic numerals according to the order in the text. If there is only one table in the text, it is not numbered. References to tables should be formatted as follows: "Table 3 states that ..." or "It is stated that ... (see Table 3)". The title of the table includes a table number and its title: "Table 2. Description of Vital Processes." The translation of the table title should be placed after the table title in Russian.

Photos, screenshots must be uploaded separately as files of the following format*.jpeg files (*.doc and *.docx if the image has additional marks). The resolution of the image should be >300 dpi. The image files should be given a name corresponding to the figure number in the text. In the description of the file a caption should be given separately, which should correspond to the name of the picture placed in the text.

Graphs, charts, histograms, etc. should be attached as a separate file in Microsoft Excel program.

Attention should be paid to the spelling of formulas in the article. All formulas must be editable, i.e. it must be possible to make changes to them. To avoid confusion, it is necessary to write Greek (α, β, π, etc.), Russian (А, а, В, b, etc.) letters and numbers in straight font, Latin letters in italics (*W, Z, m, n*, etc.). Mathematical signs and symbols should also be written in straight font. It is necessary to clearly indicate upper and lower superscript characters (W_1, F_1, etc.).

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The Editorial Board asks the authors to be guided by the above stated rules when preparing the article.

All the articles submitted to "Siberian Herald of Agricultural Science" go through preliminary check for compliance with formal requirements. At this stage the Editorial Board reserves the right to:

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• return the article to the author (authors) for revision with a request to correct the mistakes or add the missing data;

• return the article which is designed not according to the journal's requirements to the author (authors) without consideration;

• reject the article due to its inconsistency to the journal's goals, lack of originality and little scientific significance.

Correspondence with the authors of the manuscript is maintained through a key contact mentioned in the manuscript.

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