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НАУЧНЫЙ ЖУРНАЛ  
**СИБИРСКИЙ ВЕСТНИК  
СЕЛЬСКОХОЗЯЙСТВЕННОЙ НАУКИ**  
*SIBIRSKII VESTNIK SEL'SKOKHOZYAISTVENNOI NAUKI*

УЧРЕДИТЕЛИ: СИБИРСКИЙ ФЕДЕРАЛЬНЫЙ НАУЧНЫЙ ЦЕНТР АГРОБИОТЕХНОЛОГИЙ РОССИЙСКОЙ АКАДЕМИИ НАУК;  
СИБИРСКОЕ ОТДЕЛЕНИЕ РОССИЙСКОЙ АКАДЕМИИ НАУК

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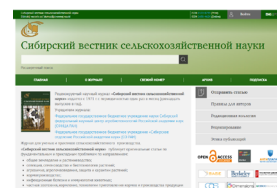
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## Модели машинного обучения для прогнозирования урожайности яровой пшеницы с использованием вегетационных индексов

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Исследовано применение вегетационных индексов, полученных с помощью дистанционного зондирования, для прогнозирования урожайности яровой пшеницы с использованием методов машинного обучения. Тестовой площадкой служил полевой опыт по возделыванию яровой пшеницы по интенсивной агротехнологии в течение 2019–2023 гг. на участке, расположенном в Новосибирской области. Почва – чернозем выщелоченный. Использовали ежегодные снимки за период июнь – июль спутника Sentinel-2 с пространственным разрешением 10 м в пикселе. Предварительный анализ связи вегетационных индексов с урожайностью пшеницы четырьмя методами выявил, что наиболее значимыми, показавшими наивысшие интегральные значения важности, были NDVI (0,63), GCI (0,47), RECI, NGRDI и NDRE (0,40). Для создания моделей прогнозирования урожайности пшеницы применяли случайный лес (RF), экстремальный градиентный бустинг (XGBoost) и метод опорных векторов для регрессии (SVR). В моделях использовали три набора данных: полный набор (21 вегетационный индекс), выборочный набор (пять вегетационных индексов) и с одним NDVI. Наилучшие результаты достигнуты моделью XGBoost, которая показала высокую эффективность ( $R^2 = 0,75$ ) как на наборе из пяти признаков, так и при использовании только NDVI, причем в последнем случае достигнута наименьшая средняя абсолютная ошибка (MAE = 0,24 т/га). Модель RF также показала хорошие результаты на сокращенных наборах данных ( $R^2 = 0,75$  на пяти вегетационных индексах и  $R^2 = 0,70$  на NDVI). Для модели SVR отмечено существенное снижение эффективности при уменьшении количества признаков (от  $R^2 = 0,74$  до  $R^2 = 0,64$ ). Результаты исследования имеют практическое значение для оптимизации дистанционного мониторинга посевов, демонстрируя возможность эффективного прогнозирования урожайности на основе минимального набора спектральных данных.

**Ключевые слова:** дистанционное зондирование, вегетационные индексы, прогнозирование, машинное обучение, урожайность яровой пшеницы

## Machine learning models for predicting spring wheat yield using vegetation indices

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The study explores the application of vegetation indices derived from remote sensing for forecasting spring wheat yield using machine learning methods. The test site was a field experiment on

intensive spring wheat cultivation conducted from 2019 to 2023 at the plot located in the Novosibirsk region. The soil type is leached chernozem. Annual Sentinel-2 satellite images with a spatial resolution of 10 meters per pixel for the June-July period were used. A preliminary analysis of the relationship between vegetation indices and wheat yield using four methods revealed that the most significant indices, with the highest integral importance values, were NDVI (0.63), GCI (0.47), RECI, NGRDI, and NDRE (0.40). To develop yield forecasting models, Random Forest (RF), Extreme Gradient Boosting (XGBoost), and Support Vector Regression (SVR) were used. The models used three datasets: the full set (21 vegetation indices), a selected subset (5 vegetation indices), and a single-index set (NDVI only). The best results were achieved with the XGBoost model, which demonstrated high efficiency ( $R^2 = 0.75$ ) for both the five-index subset and the NDVI-only dataset, with the latter achieving the lowest mean absolute error (MAE = 0.24 t/ha). The RF model also performed well on reduced datasets ( $R^2 = 0.75$  with five indices and  $R^2 = 0.70$  with NDVI). The SVR model showed a significant decline in performance as the number of features decreased (from  $R^2 = 0.74$  to  $R^2 = 0.64$ ). The study results have practical significance for optimizing remote crop monitoring, demonstrating the feasibility of effective yield forecasting using a minimal set of spectral data.

**Keywords:** remote sensing, vegetation indices, forecasting, machine learning, spring wheat yield

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## INTRODUCTION

The advantages of spectral remote sensing are speed, non-destructiveness and scalability. Over the past decades, the use of spectral reflectance data for forecasting various parameters of agricultural crops and lands obtained using remote sensing technologies has been constantly expanding [1, 2]. These data are currently used to obtain objective information on the condition of crops, identify various deviations in their development, as well as forecast crop yields and their possible losses due to unfavorable conditions and factors [3, 4].

One common approach to analyzing vegetation reflectance data is to calculate vegetation indices (VI). Vegetation indices are mathematical combinations of wavelengths that correlate with specific biophysical parameters of the plants [5, 6].

The choice of an appropriate VI plays a key role in the studies related to crop yield forecasting. The VI most frequently used for this pur-

pose is NDVI [7–9]. For example, a review [10] shows that NDVI for 24 years (2000–2023) has been used in 2200 studies. This index is easy to calculate, has the widest dynamic range of the common VIs, and is the most sensitive to changes in vegetation cover. It is also moderately sensitive to changes in soil and atmospheric background, except in cases with poor vegetation (e.g., NDVI should not be used if the vegetation cover is less than 30%) [11].

Other VIs are also used to forecast crop yields. For example, EVI, SAVI, GNDVI, GCI [12], RECI, NGRDI, RNDVI [13], GRVI, GBVI, GCI, NDREI [14], etc. According to some estimates, there are more than 150 of them. These VIs help determine the condition of plants and allow obtaining more accurate data on potential yields. Each VI has its own characteristics and can be effective in different conditions, for example, when assessing the general condition of the vegetation cover or determining physiological stresses and the development of plant

diseases. The use of VIs in a comprehensive analysis makes it possible to predict the future yield of agricultural crops and promptly respond to emerging problems [15].

It is known that the relationships between VI and crop yield depend on the spectral reflectance of crops, which varies depending on plant species, pigment concentration, soil moisture, biomass structure, light absorption, the presence of pests and diseases at different growth stages, as well as management effects on crops [16, 17]. In addition, the possibility of using VI to predict crop yields is severely limited by the fact that most of their calibrations are valid only for certain crops and growth periods [18].

Due to the difficulties that arise when using VIs in forecasting crop yields, artificial intelligence methods, in particular machine learning (ML), have recently begun to be actively used in global practice [19–21]. The use of ML algorithms allows not only to accurately predict crop yields, but also to identify hidden patterns that are inaccessible to traditional analysis methods [22]. ML models are capable of taking into account various dependencies and multiple features simultaneously, which increases the accuracy of forecasts. These models identify patterns without making preliminary assumptions about the distribution of data, effectively analyzing nonlinear relationships between variables [23]. The following algorithms are used to forecast crop yields using VI: decision tree (DT), support vector machine (SVM), Gaussian process regression (GPR), random forest (RF), k-nearest neighbors (k-NN), naive Bayes (NB), least absolute shrinkage and selection operator (Lasso), gradient boosting regression tree (GBRT), extreme gradient boosting (XGBoost), etc. [24–26].

Remote sensing technology is one of the key success factors in smart farming and offers potentially effective ways to obtain information on crop conditions for monitoring growth and predicting crop yields. A key advantage of spectral imaging is that it can also be used to non-de-

structively obtain phenotypic information over a large spatial range and a given time period. Using the information for complex data-driven analysis allows these results to be used to make technological decisions to improve agricultural productivity.

The purpose of the study is to create models for forecasting the yield of spring wheat based on the analysis of vegetation indices using machine learning algorithms.

## MATERIAL AND METHODS

The studies were conducted in the forest-steppe zone of the Novosibirsk Priobye, which is characterized by a moderately cold climate with uneven precipitation and varying degrees of aridity during the growing season. The territory belongs to the risky farming zone with sharp and frequent changes in weather conditions, leading to significant variability in the yield of grain crops. The test site was a field experiment located in the ES “Elitnaya” of the Siberian Federal Scientific Centre of Agro-Bio-Technologies of the Russian Academy of Sciences (SFSCA RAS), Novosibirsk Region (54 ° 55'27.45 "N, 82 ° 57'14.05" E), where spring wheat was cultivated during 2019–2023 on medium-deep leached medium-loamy chernozem. The humus content in the arable layer is 5.8%, total nitrogen is 0.35%, the reaction of the environment is close to neutral. The soil is well supplied with phosphorus and potassium, the content of  $P_2O_5$  and  $K_2O$  (according to Chirikov) is 23 and 18 mg / 100 g of soil, respectively. The experiment was a permanent sowing of spring wheat of the Novosibirskaya 31 variety, which was cultivated against the background of the use of nitrogen fertilizers, seed dressing, herbicides, retardant and fungicide. For the calculations of the vegetation indices, Sentinel-2 satellite images with a spatial resolution of 10 m per pixel obtained using the sentinel-hub were used (<https://www.sentinel-hub.com>), which are publicly available. Annual images for June and

July were used for the analysis. The obtained materials (46 cloudless images) were processed using Quantum GIS (QGIS) with open-source code (<https://qgis.org/ru/site/>). Data containing weighted average values of vegetation indices were calculated using the "zonal statistics" function in QGIS.

The following VIs were used in the studies: CVI (chlorophyll vegetation index), DVI (difference in vegetation index), ENDVI (enhanced normalized difference vegetation index), GCI (green chlorophyll index), GLI (green leaf index), GNDVI (green normalized difference vegetation index), LAI (leaf area index), MCARI (modified chlorophyll absorption in reflectance index), MTVI (modified triangular vegetation index), NDMI (normalized difference moisture index), NDRE (normalized red boundary difference index), NDVI (normalized difference vegetation index), NDWI (normalized difference water index), NEXG (normalized excess green index), NGRDI (normalized green-red difference index), NPCI (normalized pigment chlorophyll index), RECI (Red edge chlorophyll index), RERI (Red edge relative index), RGVI (red-green ratio vegetation index), RVI (ratio vegetation index), SIPI (structure-independent pigment index). The formulas for calculating the VI are taken from the work [27]. The calculated values of the vegetation indices were linked to a single coordinate system 2505 Pulkovo 1942/ Gauss-Kruger CM 87E to construct a data set.

To assess the relationship between the VIs, which act as features in the ML models, and wheat yield and to select the most important ones, a preliminary analysis was carried out using four methods.

The Pearson correlation coefficient was used to determine the linear relationship between the features and the target variable. It is calculated using the formula

$$r = \frac{\sum_n^i ((x_i - \bar{x})(y_i - \bar{y}))}{\sqrt{\sum_n^i ((x_i - \bar{x})^2 (y_i - \bar{y})^2)}} \quad (1)$$

where  $x$  and  $y$  – feature values and target variable;  $\bar{x}$  and  $\bar{y}$  – their average values [28].

The mutual information (MI) method was used to identify both linear and nonlinear relationships between the features and the target variable. It is calculated as follows:

$$MI(X; Y) = \sum_{y \in Y} \sum_{x \in X} P_{(X, Y)}(x, y) \times \log \left( \frac{P_{(X, Y)}(x, y)}{P_X(x)P_Y(y)} \right) \quad (2)$$

where  $p_{(x, y)}$  – joint probability  $X$  and  $Y$ ;  $p(x)$  and  $p(y)$  – marginal probabilities [29].

Random forest (RF) is an ensemble machine learning method based on the construction of multiple decision trees. The importance of feature  $j$  is estimated by the formula

$$VI(j) = \frac{1}{ntree \sum_{t=1}^{ntree} (err_t^{OOB_j} - err_t^{OOB})} \quad (3)$$

where  $ntree$  – the number of trees,  $err_t^{OOB}$  – out-of-bag error for the tree  $t$ ;  $err_t^{OOB_j}$  – out-of-bag error after mixing the feature  $j$  values [30].

Gaussian process (GP) is a probabilistic model that defines a probability distribution over functions. The importance of features is estimated through the change in the marginal likelihood of the model:

$$\log p(y|X) = -\frac{1}{2} y^T (K + \sigma^2 I)^{-1} y - \frac{1}{2} \log |K + \sigma^2 I| - \frac{n}{2} \log(2\pi) \quad (4)$$

where  $y$  – target values vector;  $X$  – feature matrix;  $K$  – covariance matrix;  $\sigma^2$  – noise dispersion;  $n$  – number of observations [31].

Machine learning algorithms were used to develop predictive models.

Random Forest, RF – is an ensemble approach based on the creation of multiple decision trees:

$$\hat{y} = \frac{1}{N} \sum_{i=1}^N tree_i(X), \quad (5)$$

where  $\hat{y}$  – predicted value;  $N$  – number of trees  $tree_i$  –  $i$ -e tree [32].

eXtreme Gradient Boosting, XGBoost – is an advanced boosting technique that optimizes the following loss function:

$$L = \sum_{i=1}^N l(\hat{y}_i, y_i) + \sum_{k=1}^K \Omega(f_k), \quad (6)$$

where  $L$  – the objective function that the algorithm seeks to minimize;  $N$  – number of observations in the training set;  $K$  – number of trees in the ensemble;  $\hat{y}_i$  – predicted value for the  $i$ -th observation;  $y_i$  – actual value for the  $i$ -th observation;  $l$  – loss function (e.g. mean squared error for regression or logistic loss for classification);  $\Omega$  – a regularization term that controls the complexity of the model;  $f_k$  –  $k$ -th tree in the ensemble [33].

Support Vector Regression, SVR – is an algorithm based on the principle of structural risk minimization:

$$f(x) = \sum_{i=1}^N (\alpha_i - \alpha_i^*) \cdot K(x_i, x) + b, \quad (7)$$

where  $f(x)$  – the regression function;  $\alpha_i$  and  $\alpha_i^*$  – Lagrange multipliers;  $K(x_i, x)$  – kernel function;  $b$  – bias [34].

Statistical calculations and graphical plots were performed using the Python programming language in an interactive Jupyter notebook. A single partitioning strategy was used for all algorithms and data sets. Each data set was pre-divided into two subsets: 80% of the data was used to train predictive models, the remaining 20% - to evaluate their effectiveness on a test sample.

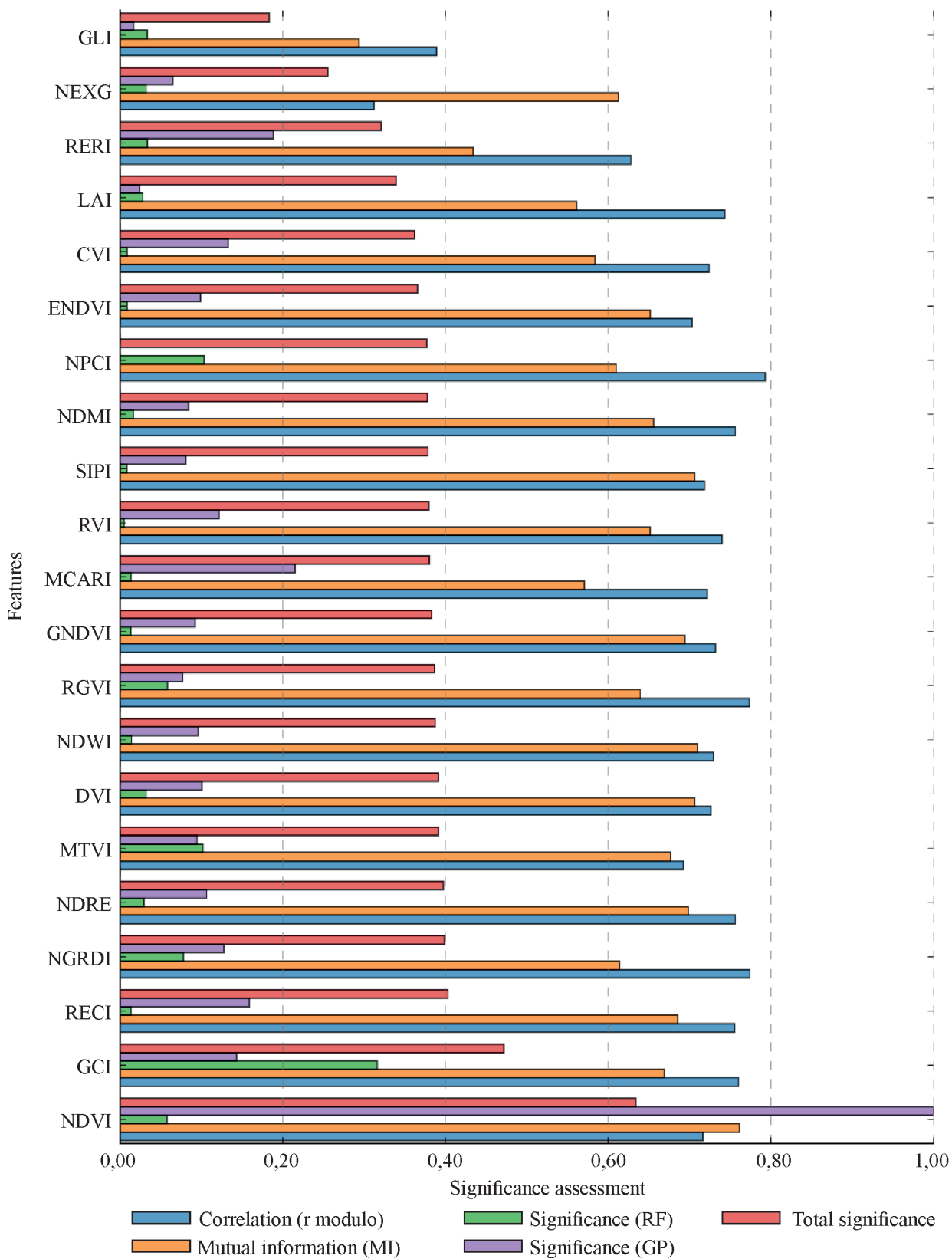
## RESULTS AND DISCUSSION

The vegetation periods of 2019–2023 differed in moisture conditions, which affected the crop yield. In the moderately moistened years of 2019–2022 with Selyaninov's HTC being 0.91–1.09, the yield of spring wheat in the vari-

ant without fertilizer application ( $N_0$ ) averaged 1.87 t/ha over these years; with an increase in the nitrogen dose from  $N_{30}$  to  $N_{90}$ , the yield increased by 1.4 and 2.4 times, respectively. In 2023 (HTC 0.69), the crop yield decreased significantly. Under conditions of insufficient moisture, the yield was on average 1.5 times lower in the experiment than in years with moderate moisture.

To build yield forecast models, its actual values obtained during a stationary field experiment were used, as well as the data from objective monitoring of spring wheat crops. The VI values, characterizing the state of the vegetation cover, demonstrated significant variability during the vegetation period and across years of research. In moderately wet years, the NDVI value in June fluctuated within the range of 0.2–0.7 units, increasing to 0.3–0.8 units in July. GCI varied from 0.3 to 2.6 units in June and from 1.3 to 3.0 units in July. RECI ranged from 0.3 to 1.7 units in June and from 1.2 to 2.7 units in July. NGRDI modified from 0.1 to 0.3 units in June and from 0.1 to 0.3 units in July. NDRE changed from 0.2 to 0.6 units in June and from 0.4 to 0.6 units in July. In a dry year, NDVI values in June ranged from 0.1 to 0.3 units and in July – from 0.3 to 0.7 units. GCI fluctuated from 0.2 to 0.8 units in June and from 0.6 to 1.7 units in July. RECI differed from 0.2 to 0.6 units in June and from 0.8 to 1.6 units in July. NGRDI ranged from -0.01 to 0.2 units in June and from 0.1 to 0.2 units in July. NDRE ranged from 0.1 to 0.2 units in June and from 0.3 to 0.6 units in July. Comparative analysis of the VI values helps to better understand how different environmental conditions affect vegetation development and allows for the creation of more accurate and reliable crop yield forecast models.

The results of a preliminary comprehensive analysis of the relationship between the VI and spring wheat yield based on the use of four assessment methods showed their varying importance (see Fig. 1).



**Рис. 1.** Оценка значимости вегетационных индексов

**Fig. 1.** Assessment of the significance of vegetation indices

Correlation analysis at a significance level of  $p < 0.05$  revealed the presence of strong statistically significant relationships. The highest negative correlation was found for NPCI ( $r = -0.79$ ), and positive for NGRDI and RGVI ( $r = 0.77$ ). High positive correlations were also found for GCI, RECI, NDRE, and NDMI ( $r = 0.76$ ).

The mutual information method, which takes into account both linear and nonlinear dependencies, showed maximum values for NDVI (0.76), as well as for DVI and SIPI (0.71). These results complement the findings of the correlation analysis, indicating the presence of significant nonlinear relationships.

Random forest analysis identified a GCI with an importance score of 0.32, which significantly exceeds the values of the remaining VIs, which did not exceed the threshold of 0.1.

Probabilistic assessment using the Gaussian process method determined the maximum values for NDVI (1.00) and MCARI (0.22). This method, taking into account the uncertainty in the data, confirmed the high significance of the previously identified VIs.

When considering the integral importance calculated as the average value of the indicators of all methods, the significance of the data set of five VIs was higher than 0.4. The highest importance was shown by NDVI (0.63), followed by GCI (0.47). Then came RECI, NGRDI and NDRE (0.40). The lowest integral importance was shown by GLI (0.18), which indicates its limited applicability for yield forecasting in the studied conditions. The obtained results demonstrate that these VIs have the greatest potential for yield forecasting, which is confirmed by the consistency of their importance assessments by different analysis methods. These results can serve as a basis for developing effective predictive models of spring wheat yield.

For a more objective assessment of the ML predictive models and taking into account the significant importance of NDVI (0.63), it was decided to conduct a comparative analysis of

the effectiveness of the models on three data sets:

- on a full set of 21 VIs (CVI, DVI, ENDVI, GCI, GLI, GNDVI, LAI, MCARI, MTVI, NDMI, NDRE, NDVI, NDWI, NEXG, NGRDI, NPCI, RECI, RERI, RGVI, RVI and SIPI).

- on a sample set of five VIs (GCI, NGRDI, NDRE, NDVI and RECI).

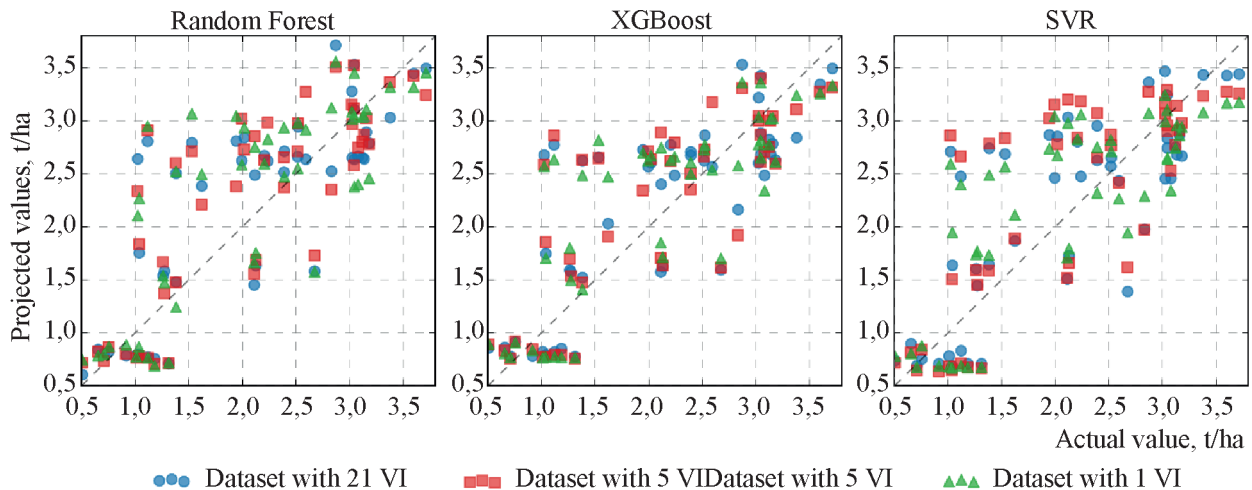
- on a sample set of one VI (NDVI).

This approach allows estimating how effective crop yield forecasting can be when a minimal set of data as features for ML is used.

Comparison of actual and predicted crop yield values showed that ML models using a full set of features provide fairly high forecasting accuracy, but the discrepancies in predicted and actual values are slightly higher than those of models using selected features (see Fig. 2). Models using five vegetation indices demonstrate a denser arrangement of points relative to the ideal forecast line. The NDVI-based model also shows high consistency with actual values, confirming the significant role of NDVI in yield forecasting.

For a comprehensive comparison of the effectiveness of the models, data on actual yields and their forecasts are presented for all ML models (see Fig. 3).

Analysis of the graphs in Fig. 3 shows the dynamics of the ML models' results when using different sets of features. The XGBoost model demonstrates the most stable dynamics on all three datasets, with models trained on selected sets of features showing a more accurate following of the actual values compared to models trained on the full set of features. The RF model also demonstrates good performance on all datasets, with particularly accurate predictions when using the five selected features. When using only NDVI, this model preserves the overall dynamics of yield changes, although with slightly larger deviations at individual points. In contrast, the SVR model shows a significant change in the quality of forecasts when the number of features is reduced. While the fore-



**Рис. 2.** Сравнение фактических и прогнозных значений урожайности

**Fig. 2.** Comparison of the actual and forecasted yield values

casts follow the actual values quite accurately on the full data set, larger deviations were observed when switching to selected features and especially NDVI. The graph in Fig. 3 shows that SVR forecasts on limited data sets have more pronounced deviations from the actual values, especially in the areas of minimum and maximum yield values.

The results of visual analysis of the plots suggest that using a sample set of features or even NDVI alone is an effective approach when using XGBoost and RF models, while using the full set of features is preferable for SVR.

Quantitative indicators of the ML model accuracy for forecasting the yield of spring wheat are presented in the table.

The analysis of the accuracy indicators of the ML models for forecasting the yield of spring wheat crops demonstrates the different behavior of the algorithms when using different data sets. The XGBoost model showed an equally high determination coefficient ( $R^2 = 0.75$ ) both on a set of five VIs and when using only NDVI. Using only NDVI allowed us to achieve the lowest MAE value of 0.24 t/ha, which is better than the results on both the full set (0.28 t/ha) and five features (0.26 t/ha).

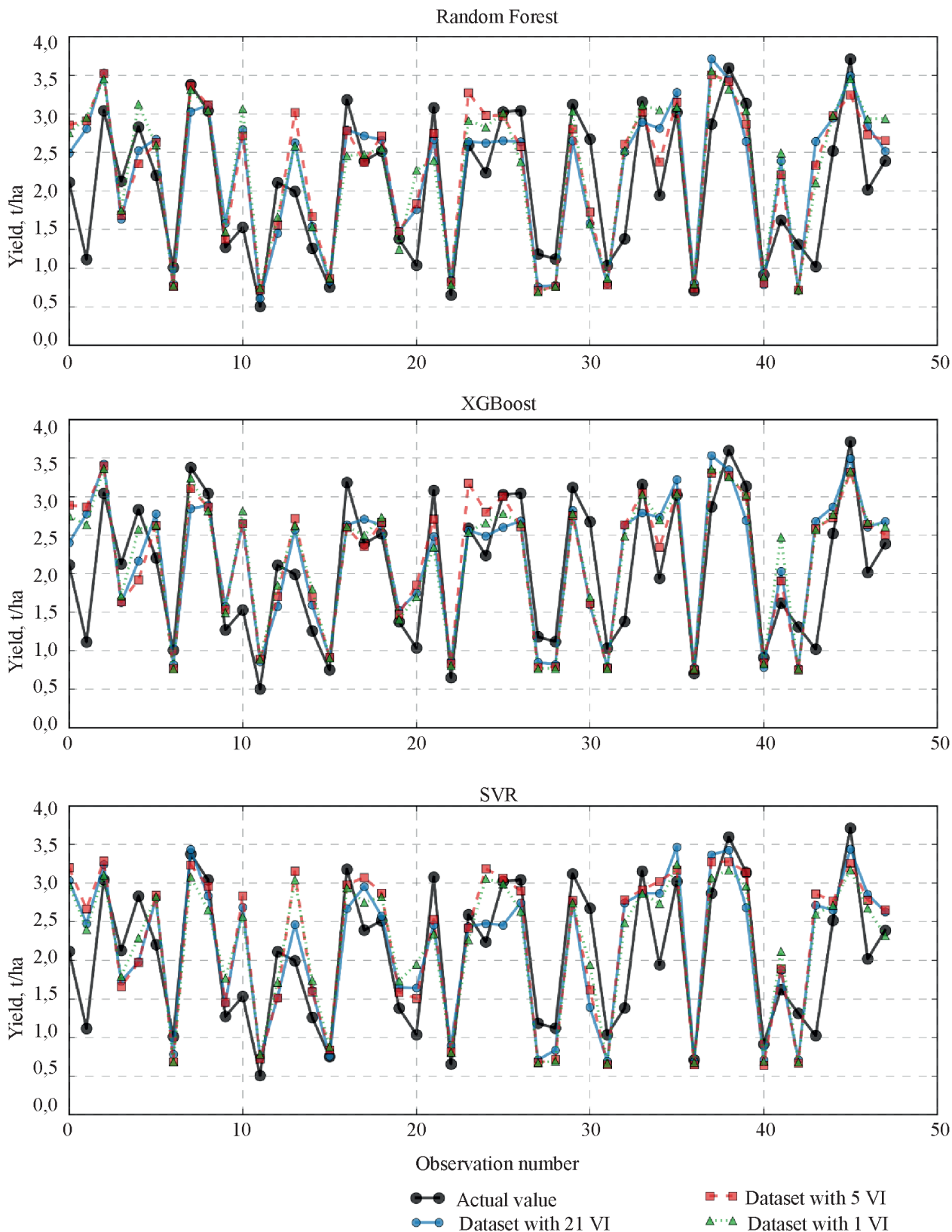
The RF model performed best on the five-feature set ( $R^2 = 0.75$ , RMSE = 0.40 t/ha), but a

slight decrease in accuracy was observed when using only NDVI ( $R^2 = 0.70$ , RMSE = 0.43 t/ha). However, even these figures remain quite close to the results on the full data set ( $R^2 = 0.72$ ).

The SVR model, on the contrary, showed a significant decrease in forecast efficiency with a decrease in the number of features. If on the full data set it had high accuracy ( $R^2 = 0.74$ , RMSE = 0.38 t/ha), then when using five features, the accuracy decreased to  $R^2 = 0.66$ , and when using only NDVI, it was  $R^2 = 0.64$ . This indicates that SVR is more sensitive to the number of input features and can lose important relationships when reducing the dimensionality of the data.

The mean absolute percentage error (MAPE) also confirms these patterns: the XGBoost model showed stable results of about 24% on all datasets, RF was the best on five features (23.63%), SVR showed a significant increase in error with feature reduction (up to 27.12% on NDVI).

The results of the analysis of the accuracy of spring wheat yield forecasting models demonstrated that using only NDVI can be an effective approach when using the XGBoost model, which showed consistently high accuracy. This is of great practical importance, as it allows to significantly simplify the process of data collection and processing without losing the accuracy



**Рис. 3.** Прогнозные значения урожайности яровой пшеницы и соответствующие значения из тестовой выборки

**Fig. 3.** Forecasted yield values of spring wheat and corresponding values from the test dataset

Показатели точности моделей МО прогнозирования урожайности яровой пшеницы  
Accuracy metrics of machine learning models for spring wheat yield forecasting

Model	Data set	R <sup>2</sup>	RMSE	MAE	MAPE
XGBoost	21 VI	0,73	0,42	0,29	24,74
	5 VI	0,75	0,40	0,26	24,06
	1 VI	0,75	0,41	0,24	24,11
RF	21 VI	0,72	0,42	0,29	24,33
	5 VI	0,75	0,40	0,27	23,63
	1 VI	0,70	0,43	0,27	24,48
SVR	21 VI	0,74	0,39	0,27	23,27
	5 VI	0,66	0,46	0,31	26,40
	1 VI	0,64	0,47	0,32	27,12

of yield forecasting. The RF model also showed acceptable results on reduced data sets, while the SVR model is recommended to be used only when a full set of features is available.

## CONCLUSIONS

1. The application of four different methods of feature importance analysis for ML models (correlation analysis, mutual information estimation, random forest method and Gaussian processes) allowed us to identify the most important vegetation indices for use in predictive models of wheat yield. In this case, NDVI showed the highest integral importance – 0.63, followed by GCI – 0,47 and RECI, NGRDI, NDRE – 0,40.

2. Comparative analysis of ML models revealed different efficiency of the algorithms when using different datasets. The XGBoost model demonstrated the most stable results with the determination coefficient  $R^2 = 0.75$  both on the set of five VIs and when using only NDVI, and in the latter case the smallest mean absolute error (MAE) was 0.24 t/ha. The RF model also showed good results on reduced datasets ( $R^2 = 0.75$  on five VIs and  $R^2 = 0.70$  on NDVI), while the SVR model showed a significant decrease in efficiency with a decrease in the number of features (from  $R^2 = 0.74$  to  $R^2 = 0.64$ ).

3. The obtained results indicate the possibility of effective forecasting of spring wheat crop yield based on a minimum set of spectral remote sensing data using appropriate ML algorithms. Further research can be aimed at adapting the developed approach to other agricultural crops.

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## Современное состояние плодородия деградированных почв Республики Тыва

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Нерациональное использование пастбищ Республики Тыва привело к депрессии аграрных угодий на фоне деградации почвенного покрова. В 2023 г. проведены почвенно-геоботанические исследования в шести районах (кожуунах) Республики Тыва, целью которых являлось установление текущего статуса плодородия деградированных почв республики в условиях аридизации климата. В связи с поставленной целью решались следующие задачи: выделение типичных деградированных участков (полигонов) для изучения эрозионных процессов в различных почвенно-климатических зонах – в горной степи Хемчикской котловины (полигон (п.) Аксы-Барлык, п. Алдан-Маадыр, п. Сук-Аксы, п. Теве-Хая) и в предгорьях Сангилена (п. Самагалтай); на равнинных участках степи Улуг-Хемской котловины (п. Сукпак, п. Тос-Булак), сухой степи и опустыненных степей Убсунурской котловины (п. Морен, п. Эрзин); морфологическое описание почвенных разрезов полигонов исследования; проведение геоботанического обследования территории выделенных полигонов; оценка агрохимических свойств нарушенных почв; определение путей восстановления плодородия деградированных земель. Исследованиями установлено, что нарушенные каштановые и аллювиальные почвы маломощны, характеризуются очень низким содержанием органического вещества. Также эти почвы обладают слабощелочной реакцией среды, обусловленной близким залеганием карбонатного горизонта Вк и преимущественно выпотным водным режимом. Содержание аммонийного азота очень низкое, подвижные формы фосфора и калия значительно варьируют по исследуемым участкам. Для восстановления потенциального плодородия этих почв необходимо внедрение пастбищеоборота, проведение мероприятий поверхностного улучшения и водной мелиорации.

**Ключевые слова:** Тыва, деградированные почвы, морфология почв, агрохимия, геоботаника

## The current state of fertility of degraded soils in the Republic of Tyva

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The irrational use of pastures in the Republic of Tyva has led to the degradation of pasture lands against the background of soil degradation. In 2023, soil and geobotanical studies were conducted in six districts (kozhuuns) of the Republic of Tyva, which aimed at determining the current fertility status of degraded soils in the republic under conditions of climate aridization. In connection with this goal, the following tasks were solved: identification of typical degraded sites (polygons) to study the erosion processes in various soil and climatic zones – in the mountainous steppe of the Khemchik basin (polygons Aksy-Barlyk, Aldan-Maadyr, Suk-Aksy, Tev-Khaya) and in the foothills of Sangilen (Samagalтай); on the flat areas of the steppe of the Ulug-Khem basin (Sukpak, Tos - Bulak), the dry steppe and desolate steppes of the Ubsunur basin (Moren, Erzin); morphological description of soil sections of the study sites; conducting a geobotanical survey of the territory of the identified polygons; assessing the agrochemical properties of disturbed soils; determining ways to restore the fertility of the degraded lands. The investigations have established that the disturbed chestnut and alluvial soils are low-yielding, characterized by a very low content of organic matter. These soils also have a slightly alkaline reaction

of the environment due to the close occurrence of the BCa carbonate horizon and the predominantly exudational water regime. The content of ammonium nitrogen is very low, and the mobile forms of phosphorus and potassium vary significantly across the studied sites. To restore the potential fertility of these soils, it is necessary to introduce pasture rotation, surface improvement measures and water reclamation.

**Keywords:** Tyva, degraded soils, soil morphology, agricultural chemistry, geobotany

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#### Конфликт интересов

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#### Conflict of interest

The authors declare no conflict of interest.

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## INTRODUCTION

Global climate change towards aridization is noted in the studies of many world scientists [1, 2]. The climate in the 21st century, according to forecasts of the General Circulation Models (GCMs), will be warm and dry, which will lead to a reduction in forests, the disappearance of tundra and a significant increase in the area of grassland (forest-steppes, steppes and semi-deserts) [3]. Warming in Siberia will occur faster than in the Northern Hemisphere as a whole [4], therefore, the study of unstable ecosystems of arid landscapes in such territories as the Republic of Tuva has been very relevant in recent years. Relatively few works have been published on the current state of fertility of degraded soils of the Republic of Tuva. In general, further development of monitoring of agricul-

tural land productivity in all regions of Russia is necessary<sup>1</sup>.

The Republic of Tuva is part of the Siberian Federal District and the East Siberian Economic Region of the Russian Federation. As of January 1, 2021, the Republic of Tuva's land fund amounted to 16,860,357 hectares, with the total area of agricultural land being 3,361,400 hectares, or 19.9% of the republic's total area. This agricultural land consists of 135,500 hectares of arable land, 61,400 hectares of fallow land, 54,800 hectares of hayfields, and 2,401,900 hectares of pastures<sup>2</sup>.

It was established that agricultural land decreased by 1.3 times between 1970 and 2020, including arable land by 3.6 times, hayfields by 2.0 times, and pastures by 1.7 times<sup>3</sup>. Agricultural lands in the Republic of Tyva are mainly located in intermountain basins and river val-

<sup>1</sup>Lipski S. The increase the fertility of agricultural land and monitoring // RJOAS, 2014, N 25, p. 17.

<sup>2</sup>Report on the status and use of land in the Republic of Tuva in 2020, 2021. / URL: <https://rosreestr.gov.ru> (date of reference: 09.01.2024).

<sup>3</sup>Semcentennial dynamics of arable lands and fertility arable soils of the Republic of Tyva / A. Sambuu, O. Ajunova, L. Golubyatnhikov [et al.] // IOP Conference Series: Earth and Environmental Science: 8, Syktyvkar, July 19–24, 2021. Syktyvkar, 2021. P. 012108. DOI 10.1088/1755-1315/862/1/012108.

leys, where light chestnut, chestnut, and dark chestnut soils, southern chernozems, and ordinary chernozems, formed under various steppe floristic communities, are common. Thus, large areas of the Ulug-Khem basin are occupied by petrophytous vegetation developing on steep rocky southern slopes on poorly formed rank soils<sup>4</sup>. The following large sod-forming floristic communities grow in this basin: desert-oat grass, feather grass, pediform-sedge and secondary forbs, as well as small sod-forming communities: fescue, thin-legged, wheat grass, cereal-small-herb and cereal-sedge<sup>5</sup>. In the northern part of the Ubsunur basin, desertified steppes are formed on light chestnut soils, mainly with nanophyton and pebble-feather grass communities<sup>6</sup> (see footnote 4). An analysis of the ecological spectrum of the flora of these steppes showed the predominant importance of the xerophyte group, as well as mesoxerophytes and xeropetophytes, which in total constitutes 81% of all species<sup>7</sup> [5].

I.M. Gadzhiev, A.Yu. Korolyuk, A.A. Titlyanova, and other scientists have previously studied in detail the vegetation of the Tuva basins, the impact of grazing on productivity, and the dynamics of plant matter reserves in pasture ecosystems (see footnote 4). Neighboring Mongolia is also systematically studying the degradation of agricultural lands, changes in the growth of phytocenoses, plant classification, plant identification, plant distribution, the de-

velopment of ecological history, and plant morphological characteristics [6, 7].

The soil cover of the republic's forest-steppe zone is represented mainly by southern and ordinary chernozems, while the steppe zone is represented by chestnut soils. Arable land is located mainly on chestnut soils (65%) and chernozems (27%) (see footnote 3). Chestnut soils of Tuva have provincial characteristics: stoniness, a light texture, shallowness, often powdery carbonate deposits, the absence of permafrost, and the absence of salinity and solonetzic conditions on watersheds and slopes<sup>8</sup>. Research by M.V. Evdokimova [8] showed that Tuva's soils tend to degrade only as a result of water erosion and deflation, as the region is not densely populated or industrially polluted. Agroecological monitoring of the soils of Tuva's agricultural territories confirmed that erosion and desertification have led to soil degradation and a sharp decline in fertility<sup>9</sup>. Thus, a comparative assessment of Siberian chernozems using the Soil-Ecological Index (SEI) revealed that the chernozems of the Republic of Tyva are more susceptible to erosion processes due to the light granulometric composition of the soils [9]. Land degradation is a global problem that leads to consequences such as a decrease in the gross domestic product of countries, a deterioration in the economic situation of the local population, a decrease in food security, climate change and loss of biodiversity<sup>10</sup> [10].

<sup>4</sup>Steppes of Central Asia / I.M. Gadzhiev, A.Yu. Korolyuk, A.A. Titlyanova et al. – Novosibirsk: Publishing House SB RAS, 2002, 299 p.

<sup>5</sup>Kuminova A.V. Vegetation cover of the Ulug-Khem region of the Tuva ASSR // Plant communities of Tuva, Novosibirsk: Nauka, 1982, pp. 5–28.

<sup>6</sup>Hilbig W., Korolyuk A. Ju. Sanddunenvvegetation im Uvs-nuur-Becken (Mongolei und Tuva/Russland // Feddes Repertorium, vol. 11, N 1–2, 2000, pp. 29–37.

<sup>7</sup>Dubrovsky N.G. Steppe and fallow phytosystems of Tuva: structural and functional organization and optimization of nature management: Extended abstract of Doctor's thesis in Biology: 03.00.05, 03.00.16 / Dubrovsky Nikolay Grigorievich, Ulan-Ude, 2009, 48 p.

<sup>8</sup>Zhulanova V.N. Agroecological assessment of the soils of Tuva: Extended abstract of Doctor's thesis in Biology: 03.02.13 / Zhulanova Valentina Nikolaevna, Moscow, 2013, 47 p.

<sup>9</sup>Belek A.N. Agroecological monitoring of soils of the agricultural territory of the Republic of Tyva / A.N. Belek, V.M. Solovyova, E.A. Poryadina // Agrochemical Bulletin, 2017, N 2, pp. 55–58.

<sup>10</sup>Lee H., Honda Y., Lim Y.-H., Guo Y.L., Hashizume M., Kim H. Effect of Asian Dust Storms on Mortality in Three Asian Cities // Atmospheric Environment, 2014, N 89, p. 309317.

The ecological and economic assessment of degraded agricultural lands in Tuva based on their cadastral valuation was conducted by A.D. Sambuu et al. [11]. The degree of land degradation by the area of eroded and saline soils was 25.6% in the Bai-Taiginsky kozhuun, 40.2% in the Dzun-Khemchiksky, 70.2% in the Kyzylsky, 55.9% in the Sut-Kholsky, 71.5% in the Tandinsky, 61.1% in the Chaa-Kholsky, and 60.5% in the Chedi-Kholsky kozhuun, respectively. The authors also found that the dormant period of degraded lands for the complete restoration of natural steppe vegetation is 11–25 years, when stage IV of self-restoration of abandoned lands occurs [12]. Similar conclusions were previously reached by other researchers of the flora of Tuva (see footnote 6) [5].

It is known that the characteristics of soil and plant complexes in degraded areas are reliable edaphic and floristic indicators of land degradation. The scientific novelty of our study lay in documenting the current state of soil systems in close connection with the phytocenoses growing on them, supplementing data on the edaphic component of natural ecosystems and agro-cenoses against the backdrop of negative climatic trends. Proposals for restoring the fertility of degraded lands were also developed. In 2023, soil and geobotanical studies were conducted in various districts of Tuva, the purpose of which was to establish the current fertility status of degraded soils in the republic under conditions of climate aridization. In connection with this goal, the following tasks were addressed:

1. Identification of typical degraded areas (polygons) for studying soil degradation processes in various regions of Tuva.
2. Morphological description of soil sections of research sites and assessment of agrochemical properties of disturbed soils.
3. Conducting a geobotanical survey of the territory of the designated testing sites.

4. Identifying ways to restore the fertility of degraded lands.

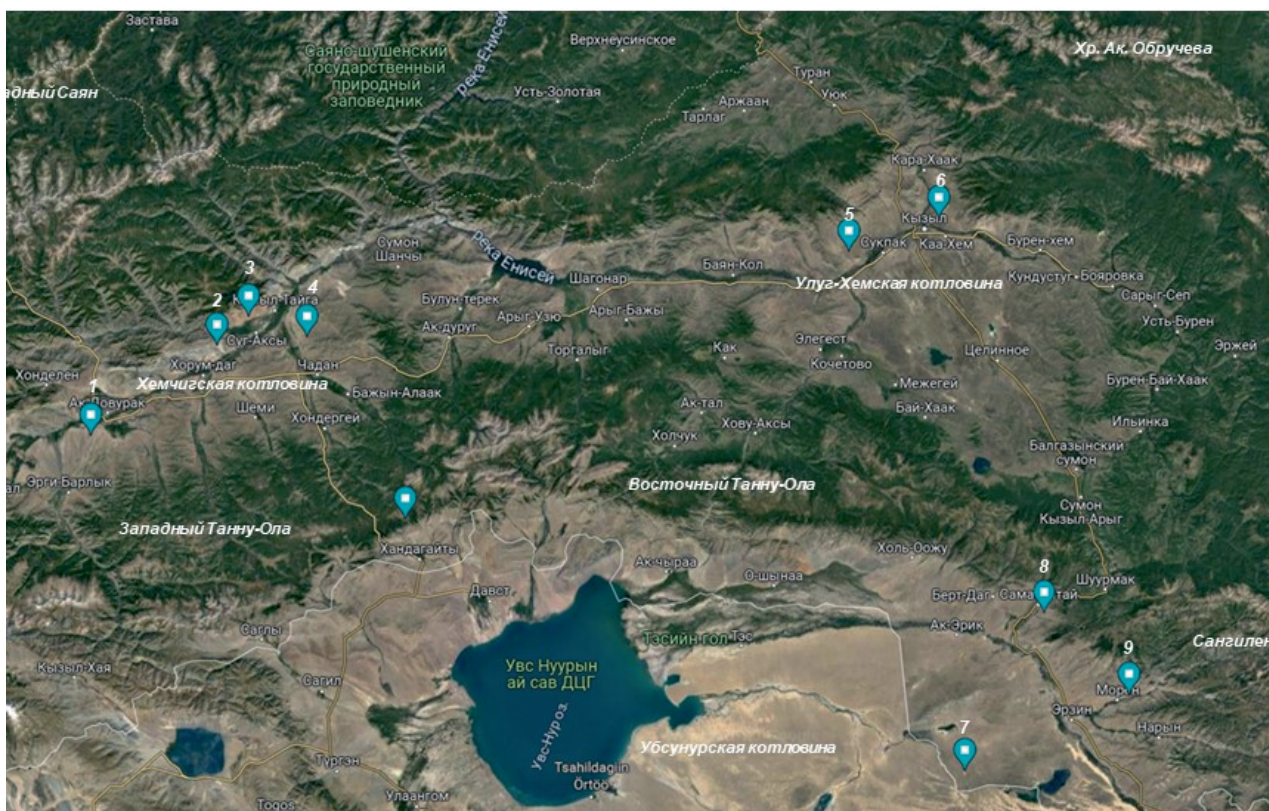
## MATERIAL AND METHODS

The Buryat Research Institute of Agriculture, a branch of the Siberian Federal Scientific Centre of the Russian Academy of Sciences, as part of the work on the topic “National action programs to combat desertification,” established nine reference sites on the territory of the republic at the areas selected using the remote sensing method and subsequent route soil-geobotanical survey (see Fig. 1). The survey sites were located in key erosion-prone landscapes in seven districts of the republic (see Tables 1 and 2). The area is characterized by a complex topography, alternating mountains and intermontane depressions, a sharply continental climate, intense wind activity, and insufficient precipitation. The combination of these natural and climatic conditions creates a high risk of water and wind erosion on light soils with low organic matter content.

Anticyclonic, dry, and clear weather prevails throughout the year in the republic, with cold winters and hot summers. The greatest amount of precipitation falls in the northeastern regions, while less precipitation falls in the west and south of Tuva. Average temperatures increase from north to south. The distribution of heat and moisture resources across natural and climatic zones is presented in Table 2.

Mixed soil samples were collected from the 0–20 cm soil layer. The soil description is given according to classification 1977<sup>11</sup>. Chemical analyses of the soils were performed in the accredited testing laboratory of the Federal State Budgetary Institution State Station of Agrochemical Service “Tuvinskaya” according to

<sup>11</sup>Classification and diagnostics of soils of the USSR. / V.V. Egorov, E.N. Ivanova, V.M. Friedland. Edition: Colossus, 1977, 225 p.



**Рис. 1.** Размещение реперных участков:  
1 – Аксы-Барлык; 2 – Алдан-Маадыр; 3 – Суг-Аксы; 4 – Теве-Хая; 5 – Сукпак; 6 – Тос-Булак; 7 – Эрзин;  
8 – Самагалтай; 9 – Морен

**Fig. 1.** Location of the reference sites:  
1 – Aksy-Barlyk; 2 – Aldan-Maadyr; 3 – Sug-Aksy; 4 – Teve-Khaya; 5 – Sukpak; 6 – Tos-Bulak; 7 – Erzin;  
8 – Samagaltai; 9 – Moren

**Табл. 1.** Общегеографическая и ландшафтная характеристики территории размещения реперных участков

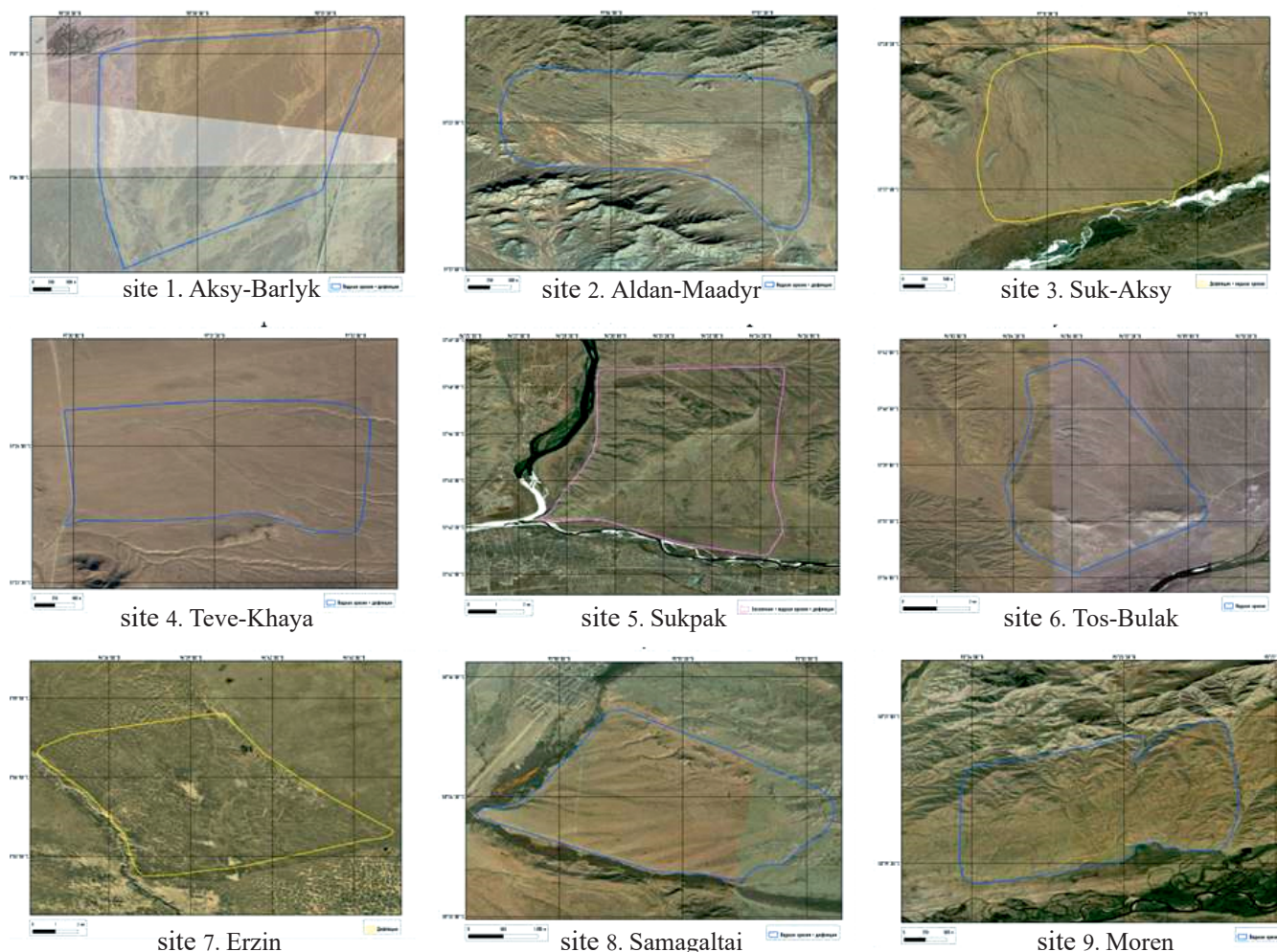
**Table 1.** General geographical and landscape characteristics of the reference sites area

Testing site	Kozhuun	Landscape	Soil	Degradation type
1. Aksy-Barlyk	Barun-Khemchiksky	Steppe mountain, floodplain	Chestnut, alluvial	Water erosion + deflation
2. Aldan-Maadyr	Sut-Kholsky	The same	Chestnut	The same
3. Suk-Aksy	»	»	»	Deflation + water erosion
4. Teve-Khaya	Dzun-Khemchiksky	»	»	Water erosion + deflation
5. Sukpak	Kyzylsky	Steppe	Dark chestnut	Salination + water erosion + deflation
6. Tos-Bulak	»	»	»	Water erosion
7. Erzin	Erzinsky	Semi-arid	Light chestnut	Deflation
8. Samagaltai	Tes-Khemsy	Steppe mountain	Chestnut	Water erosion + deflation
9. Moren	Erzinsky	Dry steppe, floodplain	»	Water erosion

**Табл. 2.** Климатические условия основных сельскохозяйственных районов Республики Тыва (среднегодовые данные)

**Table 2.** Climatic conditions of the main agricultural regions of the Republic of Tyva (average annual data)

Soil and climate zone	Snow cover depth, cm	Duration of frost-free period, days	Sum of active temperatures during the growing season, °C	Annual precipitation, mm	HTC
Forest-steppe	30–40	90–100	1400–1900	250–350	0,9–1,6
Steppe	10–20	100–110	1500–2000	250–350	0,8–1,4
Dry steppe	7–15	100–120	2000	180–290	0,6–1,0
Semi-arid	5–10	100–120	2100	177	0,5–0,8



**Рис. 2.** Космоснимки полигонов (п.)

**Fig. 2.** Satellite images of the polygons (sites)

standard methods adopted by the agrochemical service<sup>12–16</sup>.

## RESULTS AND DISCUSSION

The fertility of degraded soils was studied at sites in various soil and climatic zones of the republic. In the mountain steppe of the Khemchik Basin (Aksy-Barlyk, Aldan-Maadyr, Suk-Aksy, Teve-Khaya villages) and in the foothills of Sangilen (Samagaltai village); in the flat steppe areas of the Ulug-Khem Depression (Sukpak, Tos-Bulak villages), and the dry steppe and desert steppe of the Ubsunur Depression (Moren, Erzin villages).

### *Morphological description of typical soils of the research sites*

**The Aksy-Barlyk testing site** is located on the floodplain and supra-floodplain terraces of the Barlyk and Khemchik rivers. To characterize the soil morphology, a transect was established 2.5 km east of the village of Aksy-Barlyk and southwest of an elevation of 921 m above sea level. The land is pasture. Vegetation includes bitter and one-year fringed sagebrush, bunch grass, tough-leaved hair grass, couch grass and spring cinquefoil. The projective cover is 30%. The transect consists of the following horizons:

A 0–18 cm – fresh, light brown, sandy loam, structureless, penetrated by thin roots, the transition is noticeable.

B 18–26 cm – dry, light brown, sandy loam, structureless, single roots, inclusion of pebbles, clear transition.

BCk 26–29 cm – dry, whitish, sandy loam, structureless, inclusion of pebbles, clear transition.

Ck 29–79 cm – dry, yellow, structureless sand.

The soil is alluvial, steppe-forming, thin, sandy loam on alluvial deposits, slightly eroded, moderately deflated.

**The Altan-Maadyr testing site** is located on the floodplain terraces of the Khemchik River and on gently sloping foothills. To describe the morphological features, a transect was laid on the gently undulating surface of the foothills, 1.5 km southeast of an absolute altitude of 766 m above sea level. Vegetation is represented by pygmy pea shrub, spring cinquefoil, and cold and bitter wormwood. The soil transect is represented by the following horizons:

A 0–12 cm – fresh, chestnut, structureless, sandy, compacted, up to 60% of debris and crushed stone, weakly penetrated by roots, bubbles up, the transition is noticeable by color.

B 12–20 cm – fresh, grayish-brown, structureless, sandy, compacted, inclusions of crushed stone and grit up to 30%, single roots.

Bk 20–60 cm – fresh, whitish-burnt, compacted, mealy due to abundant release of CaCO<sub>3</sub>, bubble up violently, crushed stone and grit up to 50%, gradual transition in color.

Ck 60–150 cm – sandy-gravelly deluvium, fine earth up to 20%, fine earth saturated with CaCO<sub>3</sub>.

Chestnut soil, thin, sandy, slightly eroded on deluvial-proluvial deposits.

**The Suk-Aksy testing site** is located in intermountain valleys, on foothill slopes and in the Khemchik River valley.

To characterize the chestnut soils morphologically, a description is provided of a section located 750 m north of an elevation of 702 m above sea level. The microrelief is characterized by furrows, smoothed in places by blown sand resulting from wind erosion. The site is a fallow land. Vegetation is represented by grey-blue sagebrush, pygmy pea shrub and fringed sagebrush.

A 0–17 cm – dry, brown, sandy loam, structureless, loose, many roots, no bubbling, clear transition.

<sup>12</sup>GOST 26423–85 Soils. Methods for Determining Specific Electrical Conductivity, pH, and Solid Residue of Aqueous Extracts.

<sup>13</sup>GOST 26205–91 Determination of mobile compounds of phosphorus and potassium by the Machigin method as modified by CSRIASA.

<sup>14</sup>GOST 26213–2021 Soils. Methods for Determining Organic Matter.

<sup>15</sup>GOST 26487–85 Soils. Determination of exchangeable calcium and exchangeable (mobile) magnesium by CSRIASA methods.

<sup>16</sup>ГОСТ 26489–85 Soils. Determination of exchangeable ammonium using the CSRIASA method.

В 17–30 cm – dry, brown, sandy loam, structureless, slightly compacted, rare thin roots, no bubbling, clear transition in color and in bubbling.

BCк 30–60 cm – dry, whitish-brown, sandy loam, structureless, weakly compacted, single thin roots, boils strongly from 30 cm, clear transition.

Ск 60–130 cm – dry, whitish, sandy loam, structureless, compacted, inclusions of single cartilage.

Chestnut soil, shallow, sandy loam, moderately deflated on deluvial-proluvial deposits.

*The Teve-Khaya testing site* is located on the right-bank floodplain terrace of the Khemchik River. The excavation is located 3 km southeast of the town of Chadan, 250 km south of the road. The area is a rolling plain. The microrelief is expressed by furrows. Vegetation includes Siberian cheegrass, bitter sagebrush, lamb's-quarters, crested wheatgrass, agrestal hemp, Alpine aster and pygmy pea shrub. The soil is composed of horizons:

А 0–19 cm – sandy loam, fresh, brownish-gray, structureless, slightly compacted, no bubbling, many roots, gradual transition.

В 19–32 cm – sandy loam, fresh, light brown, structureless, compacted, few roots, clear color transition.

BCк 32–44 cm – sand, fresh, brownish-fawn, structureless, not compacted, with inclusions of crushed stone, many white powdery spots, bubbles vigorously from HCl, the transition is noticeable.

Ск 44–60 cm – sand, fresh, whitish-fawn, structureless, not compacted, lots of crushed stone, bubbles.

The soil is light chestnut, medium-deep, sandy loam, moderately eroded, slightly deflated on deluvial-proluvial deposits.

*The Samagaltai testing site* is located on the gentle foothills of the Sangilen Range. A soil profile was created 100 meters north of the road junction and 1,500 meters northeast of the village of Saigan. The land is a pasture. The herbage consists of wild leek, feather grass, pygmy

pea shrub, crested wheatgrass and sage-leaf mullein.

А<sub>0</sub> 0–1 cm – the turf is loose and not continuous.

А<sub>1</sub> 1–9 cm – fresh, chestnut brown, light loamy, finely lumpy-dusty, densely penetrated by plant roots, gradual transition in color.

В<sub>1</sub> 9–21cm – fresh, brownish- chestnut brown, light loamy, loosely lumpy, compacted, well penetrated by roots, the transition is clear in color and bubbling.

BCк 21–58 cm – fresh, whitish-pale, sandy loam, structureless, highly compacted, rare plant roots, inclusions of crushed stone and rock 20–30%, bubbles violently from HCl, transition is clear in color.

Ск 58–63 cm – fresh, whitish with a fawn tint, sandy loam, structureless, dense, bubbles violently from HCl.

Chestnut soil, thin, light loamy, slightly gravelly, slightly deflated on proluvial deposits.

*The Sukpak testing site* is located on a piedmont apron in the northern part of the Ulug-Khem Basin. To characterize typical soils, a pit was dug 750 m south of elevation 795.2 on a gentle slope (3–4°). The land is pasture. Vegetation includes pygmy pea shrub, fringed sagebrush, feather grass, acaulescent cinquefoil, couch grass and nanophyton. The projective cover is 35–40%.

А 0–10 cm – fresh, chestnut, sandy loam, structureless, slightly compacted, penetrated by thin roots, the transition is noticeable.

В 15–24 cm – fresh, light chestnut, sandy loam, compacted, single roots, clear transition in color and bubbling.

BCк 24–39 cm – fresh, whitish, sandy loam, structureless, dense, cartilaginous, noticeable transition.

Ск 39–78 cm – dry, whitish, sandy loam, structureless, dense.

Chestnut soil, shallow, sandy loam, moderately deflated, slightly stony, slightly gravelly on deluvial-proluvial sandy loam deposits.

*The Tos-Bulak testing site* is a gently rolling plain located in an intermontane depression.

To characterize typical soils, a transect was dug 300 meters northwest of the winter road and 200 meters southwest of the paddock. The microrelief is characterized by depressions. The land is a pasture. Vegetation includes fringed sagebrush, wormwood, sheep's fescue, couch grass and Alpine aster. The transect is composed of horizons:

A 0–13 cm – dry, light brown, few small roots, rare larger taproots, structureless, sandy loam, compacted, clear transition in color and bubbling.

B 13–30 cm – fresh, light brown, darker in places, compacted, few taproots, structureless, sandy loam, cartilaginous, clear transition.

BCк 30–70 cm – fresh, whitish, sandy loam, structureless, dense, gritty- crushed stony.

Ск 70–100 cm – fresh, light fawn sand, structureless, dense, gritty- crushed stony.

The soil is light chestnut, shallow, sandy loam, slightly stony, slightly gravelly, moderately deflated on sandy deluvium-proluvium.

*The Moren testing site* is located on the floodplain of the Moren River. The quarry is located 300 meters south of the village of Moren. The site is a shrubby pasture. Vegetation includes pygmy pea shrub, fringed sagebrush, feather grass, spring cinquefoil and wild leek.

A<sub>0</sub> 0–6 cm – dry, gray, loose, sandy, structureless, many roots, bubbles violently from the surface, clear color transition.

A<sub>1</sub> 6–19 cm – fresh, grayish-yellow, sand, structureless, compacted, fewer roots than in horizon A<sub>0</sub>, bubbles violently from HCl, gradual transition.

B 19–26 cm – moist, lighter than horizon A<sub>1</sub>, sandy loam, structureless, dense, few roots, bubbles violently, transition is clear in color.

BCк 26–40 cm – damp, grayish, sandy, structureless, few roots, bubbles violently, gradual transition.

Ск 40–75 cm – damp, darker than the BCк horizon, sandy loam, structureless, bubbles violently, very few roots.

The soil is alluvial, thin, layered, carbonate, sandy, slightly deflated on alluvium.

*The Erzin testing site* is located in an intermontane undulating valley. The quarry was located southeast of the village of Bulun-Bazhi, 200 meters southeast of the gullies. The intermontane undulating valley slopes westward. The land is a pasture. Vegetation includes wormwood, feather grass, fescue and pygmy pea shrub.

A 0–12 cm – fresh, brown, compacted, sand, finely lumpy, dusty, many roots, no bubbling, sand blown on the surface up to 5 cm, clear transition in density.

B 12–24 cm – fresh, lighter than horizon A, denser, finely lumpy, sandy loam, few roots, no effervescence from HCl, clear transition in color.

BCк 24–58 cm – dry, gray, dense, gravelly, lumpy, sandy loam, few roots, bubbles violently with HCl.

The soil is chestnut, shallow, sandy, strongly deflated on sandy loam deluvial deposits.

The landscape of the study region is predominantly mountainous, with rivers and streams. Typical testing sites are located on the slopes of varying aspect and gradient, on floodplain and above-floodplain terraces. Therefore, the soils are prone to erosion, subject to varying degrees of deflation and water erosion. Lands located near the populated areas are more susceptible to pasture degradation, becoming overgrazed and mounded.

#### *Geobotanical survey of the testing site areas*

The testing grounds are located in areas where year-round nomadic livestock farming is common, with the livestock structure being represented by small animals (sheep, goats), cattle, and horses. Steppe productivity depends on grazing pressure, meteorological conditions, and soil fertility<sup>17, 18</sup> (see footnote 4). Pasture pressure is traditionally regulated by migra-

<sup>17</sup>Gorshkova A.A., Mongush L.T. Steppe pastures of Tuva. Kyzyl: Publishing House of the Tuva Institute of Integrated Development of Natural Resources SB RAS, 1992, 112 p.

<sup>18</sup>Titlyanova A.A., Kyrgyz Ch.S., Sambuu A.D. The influence of pasture load and weather conditions on the productivity of dry steppes of Tuva / Soils and Environment, 2020, vol. 3, N 2, pp. 1–14.

tions; irrational use leads to overgrazing of these lands. As a result, not only the botanical composition of the steppe vegetation changes but also the productivity of the lands is significantly reduced. Long-term grazing has resulted in the formation of a specific vegetation cover in the testing grounds (see Table 3).

Plants of the steppe and dry-steppe formations belong to the meso-xerophytic and xerophytic types. The composition of the associations depended mainly on grazing intensity.

Grass associations predominate in the areas with low grazing pressure; as the grazing pressure increases they are replaced by more grazing-tolerant species – fringed sagebrush, pygmy pea shrub, nanophyton, etc.<sup>19</sup> [13] (see footnotes 5, 17).

The main cause of the degradation processes is overgrazing by sheep and goats. Small ruminants are more likely to consume lower-story plants (small-turf grasses, sedges, etc.) than cows and horses, thereby exposing the soil.

**Табл. 3.** Растительные ассоциации полигонов исследования (справочник геоботаника – формы оформления наименования сообществ)

**Table 3.** Plant associations of research polygons (Geobotanics Handbook – the forms of community name registration)

Testing site name	Community	Dominant species in the plant community	Projective coverage, %
<i>Mountain steppe</i>			
Aksy-Barlyk	Cold wormwood-feather grass-nanophyton steppes	Fringed sagebrush, bunch grass, couch grass, nanophyton, pygmy pea shrub	40
Aldan-Maadyr	Wormwood-forb-cereal steppe	Cereals: fringed sagebrush, pygmy pea shrub, blue-gray wormwood	25
Suk-Aksy	Shrub-wormwood rocky sparse steppe	Pygmy pea shrub, blue-gray wormwood, fringed sagebrush	30
Teve-Khaya	Shrub-wormwood-cereal-forb steppe	Pygmy pea shrub, Siberian chee grass, common wormwood, lamb's-quarters, crested wheatgrass, weed hemp	45
Samagaltai	Shrub-forb-cereal stony-gravelly steppes	Pygmy pea shrub, ковыль, fringed sagebrush, ramp, crested wheatgrass	30
<i>Steppe</i>			
Sukpak	Cold wormwood-feather grass-nanophyton steppes	Pygmy pea shrub, fringed sagebrush, bunch grass, acaulescent cinquefoil, couch grass, nanophyton	40
Tos-Bulak	Fescue-wormwood-feather grass steppes	Sheep fescue, fringed sagebrush, bunch grass	60
<i>Dry steppe</i>			
Moren	Grass-wormwood - nanophytic stony-gravelly dry steppes	Pygmy pea shrub, травяной ярус, fringed sagebrush, bunch grass, spring cinquefoil, nanophyton	30
<i>Semi-arid steppe</i>			
Erzin	Wormwood-forb-rhizome-cereal-nanophytic semi-desert steppe	<i>Nanophyton erinaceum</i> , <i>Cleistogenes squarrosa</i> , willow shrub, wormwood, pebble feather grass, <i>Gypsophila desertorum</i>	30

<sup>19</sup>Ershova E.A. On the characteristics of the steppe vegetation of the mountains of Western Tuva / Plant communities of Tuva. Novosibirsk: Science, 1982, pp. 109–121.

At the same time, they also produce a large specific load on its surface, compacting the soil and destroying its structure<sup>20</sup>.

The impact of high wind loads and heavy rainfall lead to the blowing out and/or surface washout of the lightest fractions and, ultimately, to sandification of the surface layer.

#### *Agrochemical indicators of degraded soils*

The fertility of the degraded soils is very low, due to both soil formation factors and natural and anthropogenic degressive processes (see Table 4).

Acid basic properties are among the key physicochemical parameters of soils, determining their productivity. Environmental conditions largely determine the microbiological and enzymatic activity of soils and plant root nutrition. The close proximity of carbonates to the soil surface (20–35 cm) with low precipitation and a predominantly exudative water regime has led to alkalization of the upper (0–20 cm) soil layer. In this regard, all soil types were characterized by a slightly alkaline pH (7.4–8.0). Calcium pre-

dominated among the absorbed bases, with its content three times or more higher than that of magnesium. The exception was the alluvial sandy loam soil of the Aksu-Barlyk village, where, despite a low total base content, the magnesium content was twice that of calcium.

The degraded soils of the study sites are light in texture and have low water-holding capacity and moisture capacity. Under conditions of moisture deficit and prolonged seasonal frost, they have low productivity and are incapable of accumulating significant amounts of organic matter<sup>21</sup>.

The most fertile soils contain up to 2.5% organic matter. With increasing deflation due to high grazing pressure, organic matter content decreases to critical levels (0,2–0,9%).

The content of mobile phosphorus and potassium in the soils depended on the mineral composition of the parent rocks and the degree of their weathering. Medium and high content of mobile P<sub>2</sub>O<sub>5</sub> was found at the Aldan-Maadyr and Aksy-Barlyk testing sites on alluvial and chestnut soils located on the floodplain terrac-

**Табл. 4.** Агрохимические показатели почв полигонов исследования

**Table 4.** Agrochemical indicators of the soils at research sites

Testing site, soil	pH <sub>water</sub>	OB (C <sub>org</sub> ), %	N-NH <sub>4</sub>	P <sub>2</sub> O <sub>5</sub> mobile	K <sub>2</sub> O exchangeable	Ca <sup>2+</sup>	Mg <sup>2+</sup>
Aksy-Barlyk, alluvial shallow sandy loam	8,0	0,20	4,0	45	4,4	2,4	5,5
Aldan-Maadyr, chestnut minor sandy	7,8	2,43	7,2	27,0	138	37,0	5,0
Suk-Aksy, chestnut minor sandy loam	8,0	2,41	6,6	9,0	97,0	7,8	2,2
Teve-Khaya, light chestnut medium-thick sandy loam	7,0	0,94	6,7	8,0	121,0	33,0	9,0
Samagaltai, chestnut minor light loamy	7,8	2,31	8,9	7,0	113,0	36,0	6,0
Sukpak, chestnut minor sandy loam	7,8	0,57	5,2	8,0	163,0	32,0	8,0
Tos-Bulak, light chestnut minor sandy loam	7,8	1,31	4,2	12,0	384,0	26,0	8,0
Moren, alluvial minor sandy	7,4	2,59	11,0	8,0	223,0	35,0	7,0
Erzin, chestnut minor sandy	7,6	0,74	7,9	3,0	142,0	6,6	2,6
LSD <sub>05</sub>	0,19	1,21	0,64	10,68	36,28	12,06	4,11

<sup>20</sup>Taishin V.A. Assessment of the state and technology for increasing the productivity of dry pastures (recommendations) / V.A. Taishin, A.I. Dorzhiev, A.S. Biltuev, A.K. Ulanov - Ulan-Ude: Publishing house of the BSC SB RAS, 2017, 28 p.

<sup>21</sup>Biltuev A.S. Climate, soil fertility and productivity of grain crops in arid conditions of Transbaikalia: state and forecast / A.S. Biltuev, T.P. Lapukhin, L.V. Budazhapov. - Ulan-Ude: Publishing house of the Bashkir State Agricultural Academy named after V.R. Filippov, 2015, 141 p.

es of the Khemchik and Barlyk rivers; low - on light chestnut soils in the village of Tos-Bulak, very low - on chestnut and alluvial soils in the villages of Suk-Aksy, Teve-Khaya, Samagaltai, Sukpak, and Moren. The lowest amount (3 mg/kg) was found in the semi-desert steppe of the village of Erzin.

The exchangeable potassium content also varied significantly, ranging from very low (4.4 mg/kg in Aksy-Barlyk) to high (223.0 mg/kg in Moren) and very high (384.0 mg/kg in Tos-Bulak). The soils of other sites were within the range of moderate to high levels of this element. A moderate correlation was found between exchangeable  $K_2O$  and the content of calcium and magnesium oxides ( $r = 0,40$ ).

Low potential fertility is characteristic of all degraded soils in the study areas. Improving their agrochemical properties and increasing productivity requires the use of agronomic, cultural, and organizational measures.

The conservation and restoration of dry agricultural lands, as well as increasing their productivity, should proceed in the following directions<sup>22</sup>:

1. Rationalization of their use based on the pasture rotation system.
2. Application of the techniques for superficial improvement of unproductive and degraded lands.

The introduction of pasture rotation fundamentally changes the technology of free-range grazing, opening up the possibility of planned pasture management, differentiating the standardized load on agricultural lands based on their productivity, i.e., ultimately, managing grazing technology (see footnote 20) [14]. A thin humus horizon precludes the use of radical improvement technologies that involve disturbing the upper (0–20 cm) layer. On these lands, superficial improvement within a pasture rotation system is most appropriate, while the choice of measures must be approached selectively, taking into account local specifics based

on a geobotanical and agrochemical survey of the area. Mandatory application of mineral nitrogen fertilizers is essential, applied during grass establishment and during spring grass growth. Potassium and phosphorus fertilizer rates should be calculated based on the content of mobile nutrients. The use of organic fertilizers is limited due to free-range livestock. Mountainous areas are well-covered by a network of water sources. Water reclamation in these areas will significantly increase land productivity and improve the fertility of degraded areas.

## CONCLUSION

Studying the causes of natural land degradation and its consequences forms the basis for developing a restoration plan. For this purpose, nine testing sites with the most severe degradation of natural lands have been identified in six districts of the republic. The disturbed soils are located in the steppe, dry steppe, and semi-desert zones on chestnut and alluvial soils with a light texture. The soils are shallow with very low organic matter content. Available nitrogen levels are very low, and available phosphorus and potassium levels vary significantly across the study sites.

The degradation of much of Tuva's agricultural land is occurring under the influence of a combination of negative anthropogenic and secondary natural factors. The primary cause of soil degradation is the violation of permissible soil load standards for forage lands, which leads to the destruction and compaction of the organogenic horizon, resulting in negative vegetation succession. Low-value and weedy vegetation predominates in the vegetation cover. To restore the potential fertility of these soils, it is necessary to implement pasture rotation, surface improvement measures, and water reclamation. Since the conducted studies only determine the current status of soils and vegetation, monitoring surveys of the territories using spectral landscape analysis and Earth remote sensing are

<sup>22</sup> *Boykov T.G.* Rational use of steppe pastures in Transbaikalia (recommendations) / T.G. Boykov, K.I. Osipov, Yu.D. Kharitonov, M.N. Bashinov, A.I. Dorzhiev. - Ulan-Ude: Publishing house of the BSC SB RAS, 1989, 40 p.

necessary to determine the direction of degradation processes.

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## Оценка экологической пластичности и стабильности льна масличного в лесостепи Среднего Поволжья

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В статье представлены результаты сравнительной оценки экологической пластичности и стабильности сортов и селекционных линий льна масличного по признаку «урожайность». Исследования проводили в условиях юга лесостепи Среднего Поволжья в 2019–2023 гг. Объектами изучения являлись восемь перспективных селекционных линий льна масличного. За стандарт был принят районированный сорт Кинельский 2000. В исследование также был включен сорт ВНИИМК 620 как наиболее распространенный на производственных площадях региона. Наиболее благоприятными для формирования высокой урожайности семян при положительном значении индекса среды были два года из пяти – 2020 и 2021. В среднем за весь период изучения урожайность семян варьировала в пределах 1,39–1,77 т/га. Максимальные показатели урожайности обеспечили линии Кин × Wal/2011 к/с, Л-4764, Л-4910, Л-7309/14-9 со статистически значимым превышением относительно стандарта на 11,9–23,8%. Наиболее стабильной урожайностью по годам отличались линии Кин × Лин/2011 к/с, Кин × Wal/2011 к/с, Кин × Лин/2010 ж/с и Л-619223, коэффициент вариации которых был наименьшим среди изучаемых сортов и линий (24,46–30,92%). При анализе показателя экологической пластичности выделены линии, наиболее отзывчивые на улучшение условий выращивания: Л-4910 и Л-7309/14-9, коэффициент регрессии которых превышал единицу. Высокой средней урожайностью, экологической пластичностью, а также стабильностью по годам характеризовались линии Л-4764, Л-619223, Л-7309/14-9. Высокопластичные линии Л-4910, Кин × Wal/2011 к/с, отличавшиеся значительной отзывчивостью на изменения условий среды, перспективны для включения в селекционные программы по созданию высокопродуктивных сортов льна масличного интенсивного типа.

**Ключевые слова:** лен масличный, селекция, пластичность, перспективные линии, урожайность, стабильность

## Assessment of ecological plasticity and stability of oil flax in the forest-steppe of the Middle Volga region

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The article presents the results of a comparative assessment of the ecological plasticity and stability of oilseed flax varieties and breeding lines based on the criterion of "yield". The study was carried out in the conditions of the south of the forest-steppe of the Middle Volga region in 2019–2023. The objects of the research were 8 promising breeding lines of oil flax. The released variety Kinelsky 2000 was adopted as the standard. The study also included the VNIIMK 620 variety as the most common in the region's production areas. Two out of five years – 2020 and 2021 – were the most favorable for the formation of high yields of oil flax seeds with a positive value of the environment index. On average,

over the years of the study, the flax seed yield varied within the range of 1.39–1.77 t/ha. The highest yield indicators were provided by the lines Kin × Wal/2011 k/s, L-4764, L-4910, L-7309/14-9 with a statistically significant excess over the standard variety of 11.9–23.8%. The most stable yield over the years were demonstrated by the lines Kin × Lin/2011 k/s, Kin × Wal/2011 k/s, Kin × Lin/2010 w/s and L-619223, the variation coefficient of which was the lowest among the studied varieties and lines (24.46–30.92%). When analyzing the ecological plasticity index, the lines most responsive to improved growing conditions were identified: L-4910 and L-7309/14-9, the regression coefficient of which exceeded one. Highly plastic lines L-4910, Kin × Wal/2011 k/s, characterized by strong responsiveness to changes in environmental conditions, are promising for inclusion in breeding programs for the creation of highly productive varieties of intensive oil flax.

**Keywords:** oil flax, selection, plasticity, promising lines, yield, stability

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**Conflict of interest**

The authors declare no conflict of interest.

## INTRODUCTION

Oil flax (*Linum usitatissimum* L.), being one of the high-tech and most popular agricultural crops, is a unique plant in terms of its range of uses, the potential of which can be realized in many industries. The seeds of modern varieties of oil flax contain 45–50% drying oil and more than 30% protein. Varnishes and paints based on linseed oil varnish are considered the standard of durability and reliability [1–3]. Currently, interest in the use of linseed oil in various areas of the national economy is growing. Due to its exceptional properties, linseed oil is used in the printing, textile, electrical, paint and varnish, food, medical, perfume and many other industries [4, 5].

This agricultural crop continues to be in demand on the market, demand for oilseeds is growing, and export volumes are maintained. The constant increase in vegetable oil production in Russia and increased demand in industry world markets stimulate the development of domestic selection and seed production of oil flax [6–8].

The issue of ensuring highly profitable production of oil flax, increasing the yield and quality of oil seeds requires the creation of new highly productive varieties adapted to specific soil and climatic conditions<sup>1</sup> [9, 10]. In the contrasting climatic conditions of the forest-steppe of the Middle Volga region, the priority direction of selection is the creation of highly productive ecologically flexible varieties with good resistance to unfavorable environmental factors.

The purpose of the research is to study promising breeding lines of oil flax in the conditions of the southern forest-steppe of the Middle Volga region according to the parameters of ecological plasticity and stability.

## MATERIAL AND METHODS

The studies were conducted in 2019–2023 at the Volga Scientific Research Institute of Selection and Seed-Growing named after P. N. Konstantinov, a branch of the Samara Federal Research Scientific Center of Russian Academy of Sciences. The experimental crops were located

<sup>1</sup>Rozhmina T.A., Zhuchenko A.A., Kishlyan N.V., Kiseleva T.S. Search for new sources of selection-significant traits of oil flax in the VNIIL collection // *Oil Crops*, 2014, N 2 (159–160), pp. 75–81.

in the south of the forest-steppe zone of the Middle Volga region. The soils of the experimental plot are represented by typical medium-humus chernozem with a heavy loamy mechanical composition. The humus content in the arable horizon is 5.2%, mobile potassium and phosphorus (according to Kirsanov) are 292 and 156 mg per 1 kg of soil, respectively, easily hydrolyzed nitrogen (according to Kornfeld) is from 11.6 to 13.2 mg per 100 g of soil [11].

Eight promising oil flax lines were evaluated in the competitive variety testing. The locally bred variety Kinelsky 2000, included in the State Register of Breeding Achievements, was adopted as the standard. The VNIIMK 620 variety was also included in the study as the most common in the region's production areas.

Field experiments were laid out according to the field experiment methodology of B.A. Dospikhov<sup>2</sup> and the state variety testing of agricultural crops<sup>3</sup>. Agricultural technology in the experiments is generally accepted for the Middle Volga region. Sowing was carried out at the optimal time (first ten days of May) with the selection seeder "Klen". The plot area is 25 m<sup>2</sup>, the repetition is fourfold, the location of the plots within the repetition is randomized.

The assessment of the studied varieties and lines for ecological plasticity and stability was carried out according to the method of S.A. Eberhart and W.A. Russel as presented by V.A. Zykin<sup>4</sup>. The yield dispersion analysis was

carried out according to B.A. Dospikhov using the Statistica program.

Hydrothermal conditions during the years of the research were characterized by a wide range of variation and covered a significant spectrum of environmental stress factors typical for the forest-steppe of the Middle Volga region. The prevailing meteorological conditions made it possible to fully assess the reaction of the studied breeding lines to various conditions of heat and moisture supply at all stages of plant development.

In general, over the years of study, the hydrothermal coefficient (HTC) characterized the conditions of the vegetation period of oil flax as very and moderately dry. From May to August, the HTC value reached 0.40–0.56. The exception was 2022, when the HTC of the vegetation period exceeded the average long-term norm and was at the level of 0.91 (see Table 1).

In May (the period of sowing and initial plant development), the HTC varied from 0.14 in 2023 to 2.16 in 2022 in the years of research.

The most optimal conditions were in 2019, when the hydrothermal coefficient was close to the average long-term norm (0.78) and amounted to 0.76. In June, when active growth and development of oil flax plants occurs, quite favorable moisture conditions developed, and the hydrothermal coefficient was close to or exceeded long-term values. The exceptions were 2019 and 2023, when the hydrothermal coefficient was 0.17 and 0.58, respectively.

**Табл. 1.** Гидротермические условия вегетационного периода

**Table 1.** Hydrothermal conditions of the growing season

Year	May	June	July	August	Average for May – August
2019	0,76	0,17	0,52	0,51	0,49
2020	0,38	0,84	0,29	0,73	0,56
2021	0,32	1,05	0,24	0,01	0,41
2022	2,16	0,95	0,17	0,34	0,91
2023	0,14	0,58	0,64	0,25	0,40
Average annual value	0,78	0,98	0,78	0,74	0,82

<sup>2</sup>Dospikhov B.A. Methods of field experiment (with the basics of statistical processing of research results): textbook. Moscow: Kolos, 1985, 352 p.

<sup>3</sup>Methodology of state variety testing of agricultural crops. Moscow, 2019, vol. 1: General part, 384 p.

<sup>4</sup>Zykin V.A., Belan I.A., Yusov V.S., Korneva S.P. Methodology for calculating the parameters of ecological plasticity of agricultural plants in the discipline "Ecological genetics". Omsk, 2008, 36 p.

In July (the period of formation of generative organs of plants), rather harsh conditions developed, the HTC was at the level of 0.17–0.64 and did not reach the average long-term value. In August (during the ripening period of flax plants), the HTC value varied from 0.01 in 2021 to 0.73 in 2020. The most stressful conditions developed in 2021–2023.

## RESULTS AND DISCUSSION

As practice shows, the most popular in production are varieties that form a high average seed yield and have significant resistance to limiting environmental factors, i.e. ecologically plastic. The assessment of varieties by plasticity and stability during their zoning<sup>5</sup> is of great importance for breeders [12, 13].

On average, over five years of study in the conditions of the southern forest-steppe of the Middle Volga region, the average varietal yield of oil flax seeds varied from insignificant (2019,  $V = 4.93\%$ ) to average (2021,  $V = 14.36\%$ ) and amounted to 1.09–2.20 t/ha (see Table 2). The highest productivity of the oil flax line was

noted in 2020 (1.91–2.70 t/ha), the lowest – in 2023 (1.02–1.35 t/ha).

On average, for 2019–2023, the highest seed yield was formed by the lines Kin × Wal/2011 k/s, L-4764, L-4910, L-7309/14-9, the average yield of which was in the range of 1.60–1.77 t/ha, exceeding the standard indicators by 11,9–23,8%.

The lowest variability in yield over the years was recorded in the lines Kin × Lin/2011 k/s, Kin × Wal/2011 k/s, Kin × Lin/2010 w/s, L-619223, for which the coefficient of yield variation was the lowest among the set of studied varieties (24,46–30,92%).

Traditionally, the method of S.A. Eberhart and W.A. Russel as presented by V.A. Zykin is used to assess ecological plasticity, which makes it possible to assess not only the plasticity of the genotype of the studied crops, but also their ability to form a high yield in various conditions, i.e. stability.

This method is based on the calculation of the linear regression coefficient ( $b_i$ ), which provides an estimate of the genetic response of the variety to changes in growing conditions, and the stan-

**Табл. 2.** Урожайность перспективных линий льна масличного в конкурсном сортоиспытании  
**Table 2.** Productivity of promising oil flax lines in a competitive variety trial

Variety/line	Seed yield, t/ha						V, %
	2019	2020	2021	2022	2023	average	
Kinelsky 2000 (standard)	1,20	2,00	1,80	1,10	1,03	1,43	32,75
VNIIMK 620	1,33	2,12	2,00	0,91	1,02	1,48	37,84
Kin × Lin/2011 k/s	1,31	1,91	1,55	1,12	1,08	1,39	24,46
Kin × Lin/2010 w/s	1,38	2,16	1,79	1,16	1,04	1,51	30,46
Kin × Wal/2011 k/s	1,36	2,42	1,62	1,23	1,35	1,60	30,00
L-4989	1,29	2,18	2,02	1,10	1,11	1,54	33,77
L-4764	1,35	2,38	1,93	1,30	1,08	1,61	32,92
L-4910	1,40	2,11	2,44	1,13	1,04	1,62	38,27
L-7309/14-9	1,50	2,70	2,36	1,18	1,09	1,77	40,68
L-619223	1,39	2,06	1,95	1,16	1,03	1,52	30,92
Average	1,35	2,20	1,95	1,14	1,09	1,55	–
LSD <sub>05</sub>	0,04	0,07	0,07	0,02	0,02	–	–
Coefficient of variation (V), %	4,93	10,41	14,36	8,77	8,92	–	–
Environmental conditions index (Ij)	–0,19	0,66	0,42	–0,41	–0,46	–	–

<sup>5</sup>Galitsky D.N., Shamanin V.P. Ecological plasticity of flax varieties in the conditions of the southern forest-steppe of Western Siberia // Scientific and Methodical Electronic Journal of Omsk SAU, 2015, No. 1 (1), p. 1.

standard deviation from the regression line of dispersion ( $\sigma_d^2$ ), which characterizes the stability of the genotype under changing environmental conditions [14, 15].

To calculate the values of the linear regression coefficient of oil flax varieties, it is necessary to establish the index of environmental conditions ( $I_j$ ) in the years of research. The most optimal conditions for plant growth and development are formed in years with positive values of the index of environmental conditions, the worst - with negative ones.

As a result of the calculation, it was determined that out of five years of study, only two years were favorable for the formation of high yields of flax seeds (in 2020  $I_j = 0.66$ , in 2021  $I_j = 0.42$ ), and three were unfavorable (in 2023  $I_j = -0.46$ , in 2022  $I_j = -0.41$ , in 2019  $I_j = -0.19$ ).

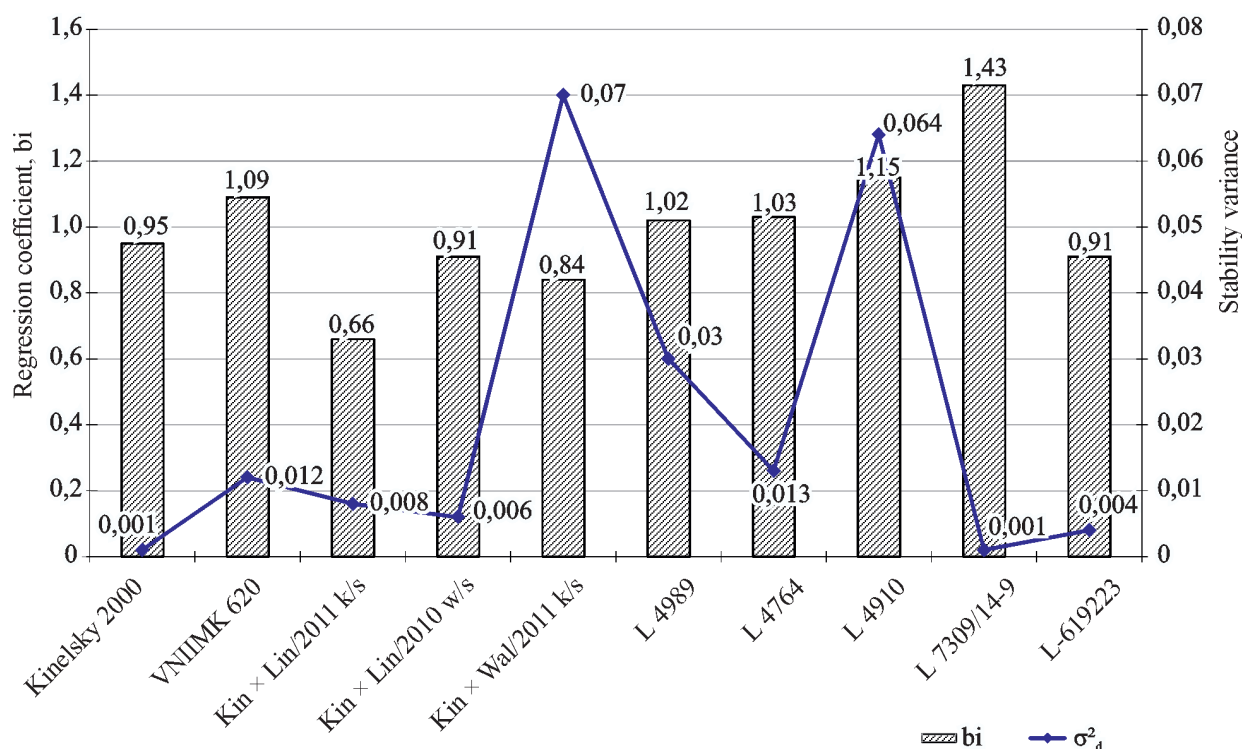
Analysis of the values of the regression coefficients showed that, on average, over the years of research, two lines showed a weak dependence on changes in environmental conditions – these

are Kin × Lin/2011 k/s ( $b_i = 0.66$ ) and Kin × Wal/2011 k/s ( $b_i = 0.84$ ) (see Fig. 1).

Lines L-4910 and L-7309/14-9 with  $b_i > 1$  had significant responsiveness to changes in environmental conditions, which allows classifying them as intensive varieties that are demanding in terms of agricultural technology. The remaining varieties and lines were characterized by high plasticity: their regression coefficient value was close to or equal to 1.

The variance of stability  $\sigma_d^2$  shows the deviation of the actual yield from the theoretical one, the calculation of which is based on the average yield and the index of environmental conditions. A decrease in the variance of yield stability indicates greater variety stability, which is a factor in the better adaptability of the genotype to deteriorating growing conditions. Often, an increase in the plasticity of a variety can contribute to a decrease in its stability [16–18].

The standard variety Kinelsky 2000 ( $\sigma_d^2 = 0.001$ ) and the lines L-7309/14-9 ( $\sigma_d^2 = 0.001$ ), L-619223 ( $\sigma_d^2 = 0.004$ ), Kin × Lin/2010 w/s



**Рис. 1.** Параметры экологической пластичности и стабильности сортов и линий льна масличного в конкурсном сортоиспытании (2019–2023 гг.)

**Fig. 1.** Parameters of ecological plasticity and stability of oil flax varieties in a competitive variety trial (2019–2023)

( $\sigma_d^2 = 0.006$ ), Kin  $\times$  Lin/2011 k/s ( $\sigma_d^2 = 0.008$ ) were characterized by low values of the stability variance, and, consequently, high yield stability. The highest values of  $\sigma_d^2$  (0.064–0.070) were recorded in the lines L-4910 and Kin  $\times$  Wal/2011 k/s, which indicates their strong responsiveness to changes in environmental conditions.

A comprehensive assessment of the ecological plasticity and stability of the studied varieties and lines of oil flax made it possible to differentiate genotypes by the intensity of response to changes in environmental factors.

The most economically valuable are genotypes that respond well to improved growing conditions and form a consistently high seed yield. Line L-7309/14-9 with a high regression coefficient ( $b_i = 1.43$ ) and stability ( $\sigma_d^2 = 0.001$ ) refers to an intensive, high-yielding type that consistently realizes its yield potential in the conditions of the region.

Half of the studied lines belonged to highly plastic, yield-stable genotypes ( $b_i = 0.91$ – $1.09$ ,  $\sigma_d^2 = 0.001$ – $0.013$ ), characterized by an adequate response to changes in environmental conditions. The standard variety Kinelsky 2000 ( $b_i = 0.95$ ,  $\sigma_d^2 = 0.001$ ) also belongs to this group.

Line L-4910, which has  $b_i > 1$ , was highly responsive to improved environmental conditions, but had low yield stability over the years ( $\sigma_d^2 = 0.064$ ).

Extensive varieties with a neutral reaction to changes in cultivation conditions ( $b_i < 1$ ) include Kin  $\times$  Lin/2010 w/s and Kin  $\times$  Wal/2011 k/s, but they differed significantly in stability. The Kin  $\times$  Lin/2010 w/s line was characterized by high stability and, under natural conditions, was capable of providing maximum yield with minimum costs. The Kin  $\times$  Wal/2011 k/s line responded weakly to improved growing conditions, but under unfavorable environmental conditions it had greater resistance to stress factors and formed a fairly high yield.

Based on the calculated regression coefficients, the theoretical yield of seeds of the studied breeding lines was established. The obtained regression lines show the variation in the reaction of the studied varieties and lines in different climatic conditions (see Fig. 2).

The yield of the L-4910, L-4764, Kin  $\times$  Wal/2011 k/s, L-7309/14-9 lines was at the mean above the average for 2019–2023; the regression lines of their yield on the graph intersect the ordinate above the point reflecting the average indicator for the experiment. The average yield of the L-4989 and Kin  $\times$  Lin/2010 w/s lines was at the level of the average for the experiment. The regression lines of the remaining varieties are located below the average value. The slope of the regression line provides more complete information about the behavior of varieties relative to each other and in comparison with the average response to changes in environmental conditions (see footnote 5) [14, 17].

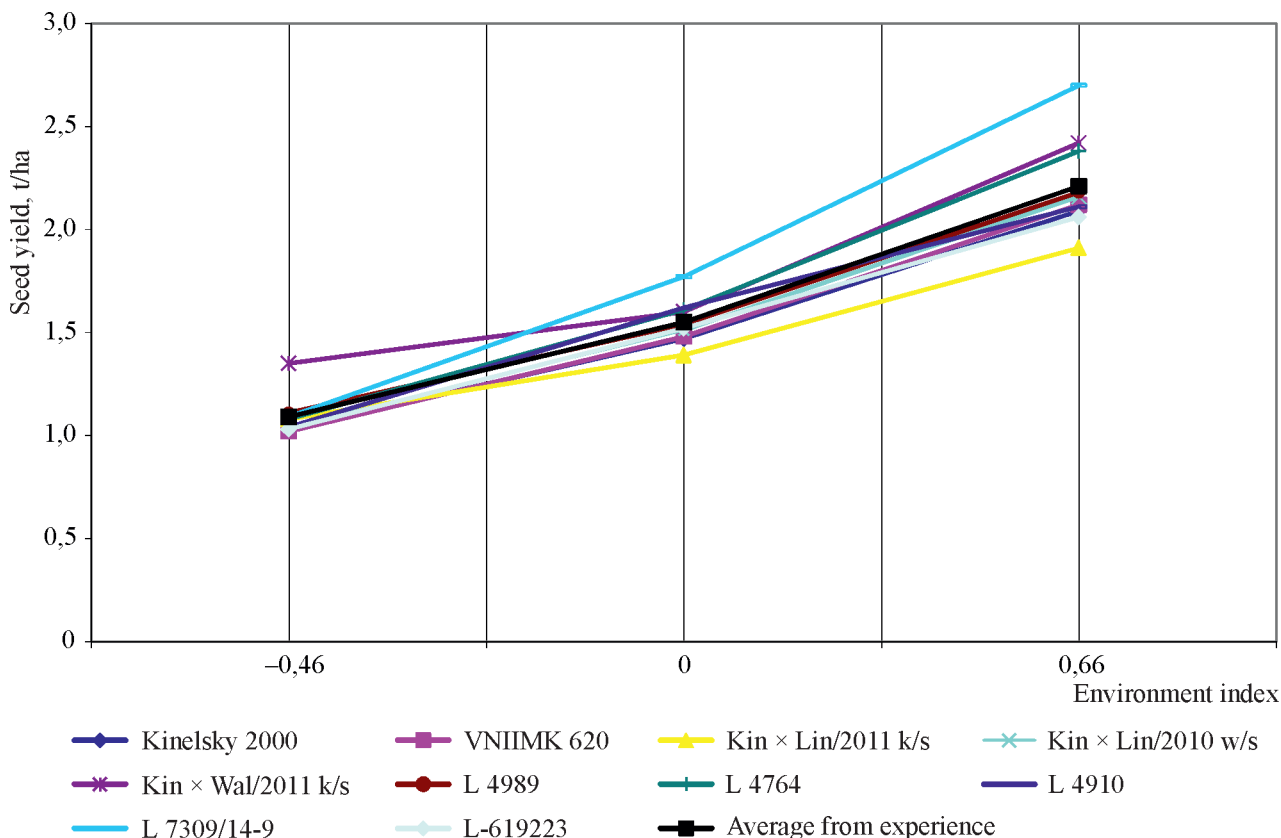
The regression lines of the L-619223, L-4989, Kin  $\times$  Lin/2010 w/s varieties run parallel to the average for the experiment, from which it follows that the yield of these selection lines changes with variations in growing conditions in the same way as on average for all the studied varieties.

It is worth noting the lines that have a high responsiveness to improvements in growing conditions - L-4764 and L-7309/14-9. Their regression lines have the highest slope and are located significantly higher compared to the average long-term yield in favorable conditions, and under stressful conditions, these lines reduce productivity to the average level for the experiment.

The best characteristics in the studied set of varieties were possessed by the line Kin  $\times$  Wal/2011 k/s, which demonstrated the highest yield in unfavorable environmental conditions and high responsiveness to improved growing conditions.

## CONCLUSION

As a result of the studies conducted in 2019–2023, it was established that the highest seed yields when grown in the conditions of the southern forest-steppe of the Middle Volga region were provided by the lines Kin  $\times$  Wal/2011 k/s, L-4764, L-4910, L-7309/14-9, characterized by a statistically significant excess over the standard (11,9–23,8%).



**Рис. 2.** Линии регрессии урожайности семян сортов и линий льна масличного (2019–2023 гг.)  
**Fig. 2.** Regression lines of seed yield of oil flax varieties and lines (2019–2023)

The intensive type ( $bi > 1$ ) includes the selection lines L-4910 and L-7309/14-9, which provide maximum yield increases with improved growing conditions. The lines L-7309/14-9, L-619223, Kin × Lin/2010 w/s and Kin × Lin/2011 k/s were characterized by the greatest stability in yield over the years ( $\sigma_d^2 = 0,001–0,008$ ).

A comprehensive assessment identified the lines that are best suited to the conditions of the Middle Volga region, combining high productivity with ecological plasticity and stability: L-4764, L-619223 and L 7309/14 9.

From the point of view of inclusion in breeding programs, the lines L-4910 and Kin × Wal/2011 k/s are of great interest, possessing high productivity potential in favorable growing conditions and sensitivity to changes in environmental factors.

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## Роль сорта в реализации биологического потенциала при переработке льнотресты

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В статье приведены сведения о биологическом потенциале новых сортов льна-долгунца селекции ФНЦ ЛК в отношении содержания волокна, выхода и номера длинного волокна, размах варьирования значений которых составляет от 26,6 до 37,5%, от 19,1 до 32,5%, от 11,00 до 14,20 номеров соответственно. По результатам контрольных разработок льнотресты различного качества, проведенных в АО «Вышневолоцкий льнозавод» Тверской области с 2019 по 2023 г., определена максимальная степень использования биологического потенциала сортов по признакам волокнистой продуктивности. Установлено, что при размахе варьирования в отношении сортов по выходу длинного волокна от 7,6 до 16,6% степень использования потенциала изменяется от 31,0 до 56,8%. Для номера длинного волокна этот критерий колеблется от 70,4 до 90,9% при варьировании номера от 10,00 до 11,00. Степень использования биологического потенциала по комплексному показателю – процентнономерам длинного волокна, изменение значений которых составило от 31,0 до 182,6, находится в пределах от 9,7 до 48,1%. Доказано, что роль сорта в обеспечении повышения эффективности переработки льнотресты является значимой. Значения по выходу длинного волокна из льнотресты, имеющей номер 1,00, в зависимости от сорта различаются на 6,9%, по его качеству – на 2,00 номера. Размах варьирования значений этих же признаков (льнотреста номера 1,75) составляет 7,5% и 1,00 номера. Такие различия могут привести к снижению стоимости волокнистой продукции на 25%. Несмотря на низкую степень реализации биологического потенциала по процентнономерам длинного волокна, выявлены сорта с оптимальной долей длинного волокна с учетом его номера. Соотношение удельного веса процентнономеров длинного и короткого волокна для лучших сортов льна-долгунца находится в следующих пропорциях: 74 : 26% (Сурский), 73 : 27% (Александрит), 68 : 32% (Визит).

**Ключевые слова:** сорт, льнотреста, выход и номер длинного волокна, процентномера, биологический потенциал, переработка

## The role of the variety in exploiting the biological potential during flax straw processing

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The article provides information on the biological potential of new varieties of fiber flax of the FRC BFC selection in terms of fiber content, yield and number of long fibers, the range of variation of values of which is from 26.6 to 37.5%, from 19.1 to 32.5%, from 11.00 to 14.20 the numbers, respectively. According to the results of the control developments of flax straw of various quality carried out in the AO “Vyshnevolotsky Flax Plant” of the Tver region from 2019 to 2023, the maximum degree of use of the biological potential of the varieties based on fiber productivity was determined. It was found that with the range of variation in the section of varieties in terms of long fiber yield from 7.6 to 16.6%, the degree of potential utilization varies from 31.0 to 56.8%. For a long fiber number, this criterion ranges from 70.4 to 90.9%, with the number varying from 10.00 to 11.00. The degree of use of the biological potential according to a complex indicator - long fiber percentage numbers, the change in values of which was from 31.0 to 182.6, ranges from 9.7 to 48.1%. It has been proved that the role of the variety in ensuring an increase in the efficiency of processing flax is significant. The values for the yield of long fiber from a flax fiber having the number 1.00, depending on the variety, differ by 6.9%, in its quality by 2.00 numbers. The range of variation in the values of the same signs

(flax straw number 1.75) is 7.5% and 1.00 number. Such differences can lead to a 25% reduction in the cost of fiber products. Despite the low degree of realization of the biological potential according to the percentage of long fiber, varieties with the optimal proportion of long fiber, taking into account its number, have been identified. The ratio of the specific gravity of long and short fiber percentages for the best varieties of fiber flax is in the following proportions: 74 : 26% (Sursky), 73 : 27% (Alexsandrit), 68 : 32% (Visit).

**Keywords:** variety, flax straw, yield and number of long fibers, percentage number, biological potential, processing

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#### **Conflict of interest**

The authors declare no conflict of interest.

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## **INTRODUCTION**

Among the strategically important priorities for the country's socio-economic development in the Russian agro-industrial complex is the development of flax cultivation, which is largely determined by the creation of a domestic raw material base capable of providing high-quality raw materials to flax processing enterprises. The successful achievement of this objective is significantly dependent on the development and introduction of new domestic flax varieties into agricultural production, ensuring the production of the required quantity of fiber products of the required quality [1, 2]. In recent years, special attention has been paid to the development of breeding and seed production in Russia. A Federal Scientific and Technical Program<sup>1</sup> has been approved for 2017–2025, which provides for the development of new competitive varieties, in-

cluding fiber flax, primarily aimed at reducing dependence on foreign seeds and planting material. Modern fiber flax varieties must combine high fiber content with good fiber quality [3]. This task is considered difficult to accomplish because, unlike most other agricultural commodities, the significant variability in the properties of fiber flax makes it impossible to compensate for a decline in its quality by increasing its quantity. The textile industry currently experiences a shortage of high-quality long fiber (numbers 11.00 and 12.00)<sup>2</sup>, which can be spun into fine-fiber yarn suitable for producing competitive household fabrics [4]. Despite the complexity of the task set before breeders, during the period from 2011 to 2023, 18 varieties of fiber flax were bred at the Federal Scientific Center for Flax Breeding [5, 6], the biological potential of which makes it possible to expect obtaining

<sup>1</sup>Resolution of the Government of the Russian Federation of August 21, 2017 No. 996 "On approval of the Federal Scientific Technical Program for the Development of Agriculture for 2017–2025" // Federal Scientific Technical Program for the Development of Agriculture for 2017–2025. Moscow, 2017, 52 p.

<sup>2</sup>Federal State Statistics Service. URL: <https://www.grs.ru> (date of reference 15.01.2024).

a sufficient quantity of high-quality fiber products<sup>3</sup>.

Thus, the fiber content of the developed varieties is 26.6–37.5%, the long fiber yield is 19.1–32.5%, and its number ranges from 11.00 to 14.20. However, the realization of the biological potential of the varieties under production conditions during flax straw processing depends on many other factors, including the quality of the original flax raw material of a given variety, which is determined by a number from 0.50 to 4.00 in accordance with GOST 24383–89 "Flax Straw. Requirements for Procurement" [7, 8]. Previous studies have noted that achieving sustainable increases in fiber productivity requires flax processing plants to receive flax straw rated not lower than 1.50 [9–11]. This statement is true for virtually all the varieties of fiber flax in production. At the same time, the influence of variety characteristics on the processing results of flax straw of the same quality cannot be ignored [12, 13].

In this regard, the study of the role of new varieties in ensuring increased efficiency in processing flax straw of various qualities on production equipment, which is determined by the yield of long fiber, its number, as well as a complex indicator - the percentage of the obtained product, is timely, important and relevant [14].

This information can be useful for both flax growers involved in production and for specialists in primary flax straw processing in industrial settings. They will be able to make balanced and informed decisions on optimizing resource use, managing technological processes, improving planning, and, ultimately, contributing to improved technical and economic performance of flax growing and flax processing enterprises.

The objective of the research was to determine the role of flax varieties in increasing the efficiency of processing flax straw of varying quality by identifying the varieties with the highest degree of biological potential in terms

of long fiber yield and quality. The objectives of the research included:

- analysis of flax varieties bred by the Federal Research Center for Bast Fiber Crops (FRC BFC) for their biological potential in relation to the production of fiber products based on the results of State Variety Testing;
- processing of flax straw of various qualities in production conditions using traditional technology to obtain long and short fibers and determine their yield and quality;
- identification of the best varieties of fiber flax in realizing the biological potential in relation to the yield and quality of long and short fiber during the processing of flax straw of various qualities with the determination of the percentage of these products, which are a comprehensive indicator of the efficiency of flax straw processing.

## MATERIAL AND METHODS

Flax straw of various qualities of new varieties of fiber flax bred by the Federal Research Center for Bast Fiber Crops was used as the starting material. It was processed using traditional technology to obtain long and short fiber on the production equipment of the AO "Vyshnevolotsky Flax Plant" in the Tver Region. Flax straw was harvested in the field at flax-growing farms from 2019 to 2023. The sequence of operations during control flax straw processing was implemented in accordance with the scheme shown in Fig. 1. The main regulatory document was a special methodological program<sup>4</sup>, which provides for the processing of flax straw under optimal conditions of technological equipment: flax straw and hards dryers, scutching-and-breaking units and flax tow preparation units.

Flax straw processing in batches weighing at least 2 tons was carried out separately for each flax straw number of a particular variety participating in the tests. The batch weight was calculated using standardized moisture content (19.0%)

<sup>3</sup>State Register of Breeding Achievements Approved for Use (Plant Varieties): // gossortrf.ru/wp-content/uploads/2022/06/Регистр%20на%20допуск%202022.pdf (date of reference 18.11.2022).

<sup>4</sup>Order of the Ministry of Agriculture of the Russian Federation No. 23-r of March 10, 2016 "Procedure for Determining Standards for the Conversion of Flax and Hemp Straw into Fiber" (As amended by Resolution of the Government of the Russian Federation of June 12, 2008 No. 450). 7 p.

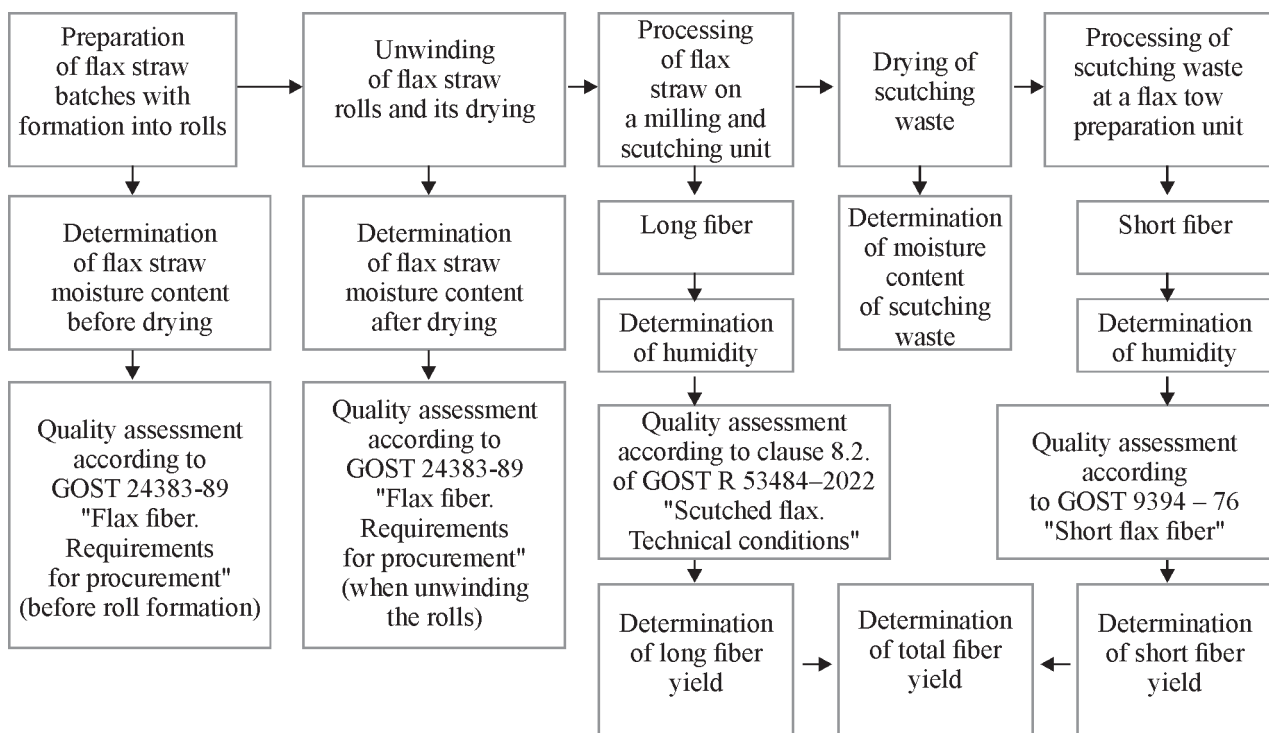
and impurity content (5.0%). The resulting long and short fibers were also recorded and their quality assessed using the standardized moisture content adopted in the current standards for these types of products. The degree of biological potential realization was defined as the ratio of the actual values of the technological quality attributes of flax straw of the new varieties to the potential values, expressed as a percentage. For statistical processing of the experimental data, indicators such as the range of variation and the coefficient of variation were used<sup>5-7</sup>.

## RESULTS AND DISCUSSION

In recent years, FRC BFC breeders have developed a significant number of new flax varieties that exhibit high biological productivity potential, including in relation to such valuable

economic traits as fiber content and the quantity and quality of long fiber. The characteristics of the biological potential of the varieties for these traits are presented in Table 1. The fiber content in the stem material of these varieties ranges from 26.6 to 37.5%, the long fiber yield from 19.1 to 32.6%, and its number from 11.00 to 14.20.

In order to determine the maximum degree of biological potential realization during processing of flax straw of different qualities of nine varieties, control tests were conducted. For the varieties Diplomat, Alexandrit, Caesar, Surskiy, Universal, Nadezhda, Vizit, Fakel, Atlant, 190 batches of flax straw, assessed with the numbers 0.50–2.50, were processed in 2019–2023 under optimal production equipment conditions. Based on the results of the conducted tests, maximum values for the yield of long fiber from flax straw



**Рис. 1.** Схема проведения контрольных разработок льнотресты при переработке по традиционной технологии с получением длинного и короткого волокна

**Fig. 1.** The scheme of the control development of flax during processing using traditional technology to obtain long and short fibers

<sup>5</sup>Nivorozhkina L.N., Arzhapovsky S.V., Rudyaga A.A. Statistical methods of data analysis: textbook. M.: Rif, 2018, 320 p.

<sup>6</sup>"Fundamentals of Scientific Research in Agronomy" in the EXCEL program: Methodological guidelines / R. R. Ustanov. Moscow: Publishing house of the RSAU MSAA, 2013, 47 p.

<sup>7</sup>Dospekhov B.A. Methodology of field experiment (with the basics of statistical processing of research results). Moscow: Alliance, 2011. 150 p.

of a specific number (see Table 2), long fiber number (see Table 3), a comprehensive indicator of processing efficiency – long fiber percentage (see Table 4) were established for each of the presented varieties.

The data presented in Table 2 on the yield of long fiber indicate that the maximum result can be obtained by processing flax straw of the numbers 1.75–2.50.

Moreover, the range of variation of potential values of the trait in relation to the varieties was from 19.1 to 32.6%, during processing – from 7.3 to 16.6%. Thus, the degree of utilization of biological potential of the varieties under production conditions in relation to the yield of long fiber varied from 31.0% (variety Vizit) to 56.8% (variety Surskiy). The best results for this trait of technological quality of flax straw were noted for the varieties Diplomat, Alexandrit and Surskiy, for which the degree of utilization of biological potential was 45.6; 50.0; 56.8%, respec-

tively. When comparing the potential and actual values of the quality of long fiber (see Table 3), it turned out that the potential for obtaining long fiber of high numbers 11.00–14.20 inherent in the flax raw material was realized only by 70.4–90.9%.

It should be noted that even high-quality flax straw did not produce fiber grade 12.00, which is most needed by the textile industry. It is noteworthy that fiber grade 11.00 was obtained from flax straw of various grades, ranging from 1.00 to 2.50. In the practical work of flax processing plants, the technological effect of flax straw fiber processing is assessed using a complex indicator—the percentage of long fiber produced. In this regard, the maximum degree of utilization of the biological potential of this criterion was determined; according to the data in Table 4, it ranged from 9.7 to 48.1% depending on the variety. While the maximum potential values of the criterion ranged from 221.5 to 419.2 percentage

**Табл. 1.** Характеристика биологического потенциала технологического качества волокнистой продукции новых сортов льна-долгунца селекции ФНЦ ЛК

**Table 1.** Characteristics of the biological potential of the technological quality of fibrillose products from new varieties of fiber flax selected by the Federal Research Center for Bast Fiber Crops

Variety	Date of entry into the State Register of Breeding Achievements	Fiber content, %	Long fiber output, %	Long fiber number, N
Diplomat	2012	29,5	24,8	12,30
Alexandrit	2013	29,6	26,0	13,60
Surskiy	2015	35,2	29,2	13,00
Universal	2017	30,3	26,8	13,00
Caesar	2017	34,5	32,5	12,90
Nadezhda	2018	29,0	24,6	11,00
Vizit	2018	32,0	29,0	11,70
Polet	2019	33,9	25,8	12,50
Fakel	2020	26,6	19,1	11,60
Atlant	2020	31,1	20,4	14,20
Krepysh	2022	31,6	28,5	13,20
Deviz	2023	33,6	21,3	12,60
Udalets	2018	32,0	29,0	12,30–12,70
Dobrynya	2011	37,4	30,8	No data
Peresvet	2015	34,8	26,9	» »
Kvartet	2017	37,5	32,6	» »
Fenix	2019	28,0	21,8	» »
Chance	2017	37,5	30,6	» »

**Табл. 2.** Максимальная степень реализации биологического потенциала по выходу длинного волокна из льнотресты различных сортов при ее переработке

**Table 2.** The maximum degree of realization of the biological potential for the yield of long fiber from flax of various grades during its processing

Variety	Flax straw number, N	Long fiber output, %		Degree of implementation, %
		potential	actual	
Diplomat	2,00	24,8	11,3	45,6
Alexandrit	1,75	26,0	13,0	50,0
Surskiy	2,00	29,2	16,6	56,8
Universal	2,50	26,8	10,8	40,3
Caesar	1,75	32,5	13,0	40,0
Nadezhda	1,75	24,6	7,8	31,7
Vizit	1,75	29,0	9,0	31,0
Fakel	1,75	19,1	7,6	38,2
Atlant	1,75	22,4	8,1	36,2

**Табл. 3.** Максимальная степень реализации биологического потенциала по номеру длинного волокна, полученного из льнотресты различных сортов при ее переработке

**Table 3.** The maximum degree of realization of the biological potential by the number of long fibers obtained from flax of various varieties during its processing

Variety	Flax straw number, N	Long fiber number, N		Degree of implementation, %
		potential	actual	
Diplomat	1,00; 1,25; 1,75; 2,00; 2,50	12,30	11,00	89,4
Alexandrit	1,00; 1,25; 1,75	13,60	10,00	76,5
Surskiy	1,50; 1,75; 2,00	13,00	11,00	84,6
Universal	1,50; 2,00; 2,50	13,00	11,00	84,6
Caesar	1,50; 1,75; 2,00	12,90	11,00	85,3
Nadezhda	1,25; 1,75	11,00	10,00	90,9
Vizit	1,75	11,70	10,50	89,7
Fakel	1,00; 1,75	11,60	10,00	86,2
Atlant	0,75; 1,00; 1,75	14,20	10,00	70,4

numbers, under production conditions its values were significantly lower: the range of variation was from 31.0 to 182.6 percentage numbers. The importance of the variety factor for ensuring increased efficiency of flax raw material processing is significant, which is confirmed by empirical data on the yield and quality of long fiber obtained from the same flax straw number, but from different varieties (see Table 5).

Analysis of the data in Table 5 showed that the range of variation of the long fiber yield values was from 3.4 to 10.3% and from 7.3 to 14.8% for flax straw of numbers 1.00 and 1.75, respectively; the values of the long fiber number

for the same quality of flax straw were from 9.00 to 11.00 and from 10.00 to 11.00. Moreover, the variation coefficient is quite high both for the long fiber yield obtained from flax straw of number 1.00 (35.5%) and for the same feature related to flax straw assessed as number 1.75 (27.3%). It is known that with a 1% reduction in long fiber yield and a corresponding increase in short fiber yield, the cost of products made from one ton of flax straw (while maintaining the same average long and short fiber counts) decreases by 5-6%. This means that if the long fiber yield from flax straw of number 1.00 grades Fakel (4.9%) and Alexandrit (9.3%) differs by 4.4%, then the cost

**Табл. 4.** Максимальная степень реализации биологического потенциала по процентонамерам длинного волокна, полученного из льнотресты различных сортов при ее переработке

**Table. 4.** The maximum degree of realization of the biological potential according to the percentage of long fiber obtained from flax of various grades during its processing

Variety	Flax straw number, N	Long fiber percentage number, %N		Degree of implementation, %
		actual	potential	
Diplomat	1,00	113,3	305,04	37,4
	1,25	94,6		31,0
	1,75	92,4		30,3
	2,00	124,3		40,7
	2,50	123,2		40,4
Alexandrit	1,00	93,0	353,6	26,3
	1,25	114,0		32,2
	1,75	132,6		37,5
Surskiy	1,50	157,3	379,6	41,4
	1,75	162,8		42,9
	2,00	182,6		48,1
Universal	1,50	93,5	348,4	26,8
	2,00	104,5		30,0
	2,50	118,8		34,1
Caesar	1,50	127,6	419,2	30,6
	1,75	143,0		34,1
	2,00	126,5		30,2
Nadezhda	1,25	79,0	270,6	29,2
	1,75	78,0		28,8
Vizit	1,75	94,5	339,3	27,9
Fakel	1,00	49,0	221,5	22,1
	1,75	73,0		32,3
Atlant	0,75	31,0	318,1	9,7
	1,00	53,0		16,7
	1,75	81,0		25,5

of the product decreases by 22.0-26.4%, which will lead to a significant decrease in the profitability of the enterprise. Thus, the research revealed that the maximum biological potential of the studied varieties under current conditions when processing flax straw of varying quality, in terms of yield and long fiber count, is low, and for the best varieties, it does not reach 60%. At the same time, the ratio of long to short fiber, which until recently averaged approximately 2:3 or 40:60%, influences the efficiency of flax straw processing. In recent years, the share of long fiber in the total output has decreased to 25% for various reasons. Despite the fact that the level of realization of the biological potential of varieties

in production is clearly insufficient, at this level, as shown in Fig. 2, the ratio of the maximum percentage numbers of long and short fiber is in proportions from 56:44% (variety Nadezhda) to 74:26% (variety Surskiy). Consequently, in increasing the efficiency of flax straw processing, associated primarily with obtaining the maximum possible values of long fiber percentage numbers, the choice of variety plays a significant role. Another important factor in increasing the technical and economic indicators of flax processing enterprises is the search for ways to achieve the maximum degree of utilization of the biological potential of varieties in terms of fiber productivity in the technological process.

**Табл. 5.** Изменчивость значений выхода и номера длинного волокна, полученного из льнотресты номеров 1,00 и 1,75 различных сортов

**Table 5.** Variability of the values of yield and number of long fibers obtained from flax fiber numbers 1.00 and 1.75 of various grades

Variety	Flax straw number 1,00		Flax straw number 1,75	
	Long fiber output, %	Long fiber number, N	Long fiber output, %	Long fiber number, N
Diplomat	10,3	11,00	8,4	11,00
Alexandrit	9,3	10,00	13,0	10,20
Surskiy	4,2	9,00	14,8	11,00
Universal	6,6	10,00	9,2	10,10
Caesar	3,4	11,00	13,0	11,00
Nadezhda	7,4	9,75	7,8	10,00
Vizit	7,3	9,50	9,0	10,00
Fakel	4,9	10,00	7,3	10,00
Atlant	5,3	10,00	8,1	11,00
Average	6,5	10,03	10,1	10,48
Range of variation	3,4–10,3	9,00–11,00	7,3–14,8	10,00–11,00
Dispersion, $S_x$	2,31	0,65	2,76	0,50
Coefficient of variation, V, %	35,5	6,5	27,3	4,8

## CONCLUSIONS

1. The biological potential of new flax varieties in terms of long fiber yield and fiber count obtained from flax straw during processing under traditional production conditions is insufficiently realized. The maximum yield, with long fiber yield varying between 31.0 and 56.8% across varieties, was achieved for the Surskiy variety (56.8%).

2. The established differences in the values of long fiber yield depending on the grade during the processing of medium and high-quality flax straw (number 1.00 and number 1.75) in 6.9; 7.5% confirm the significant role of the grade in ensuring an increase in the efficiency of flax straw processing, ensured by an increase in the cost of the output product by 20.0–25.0%.

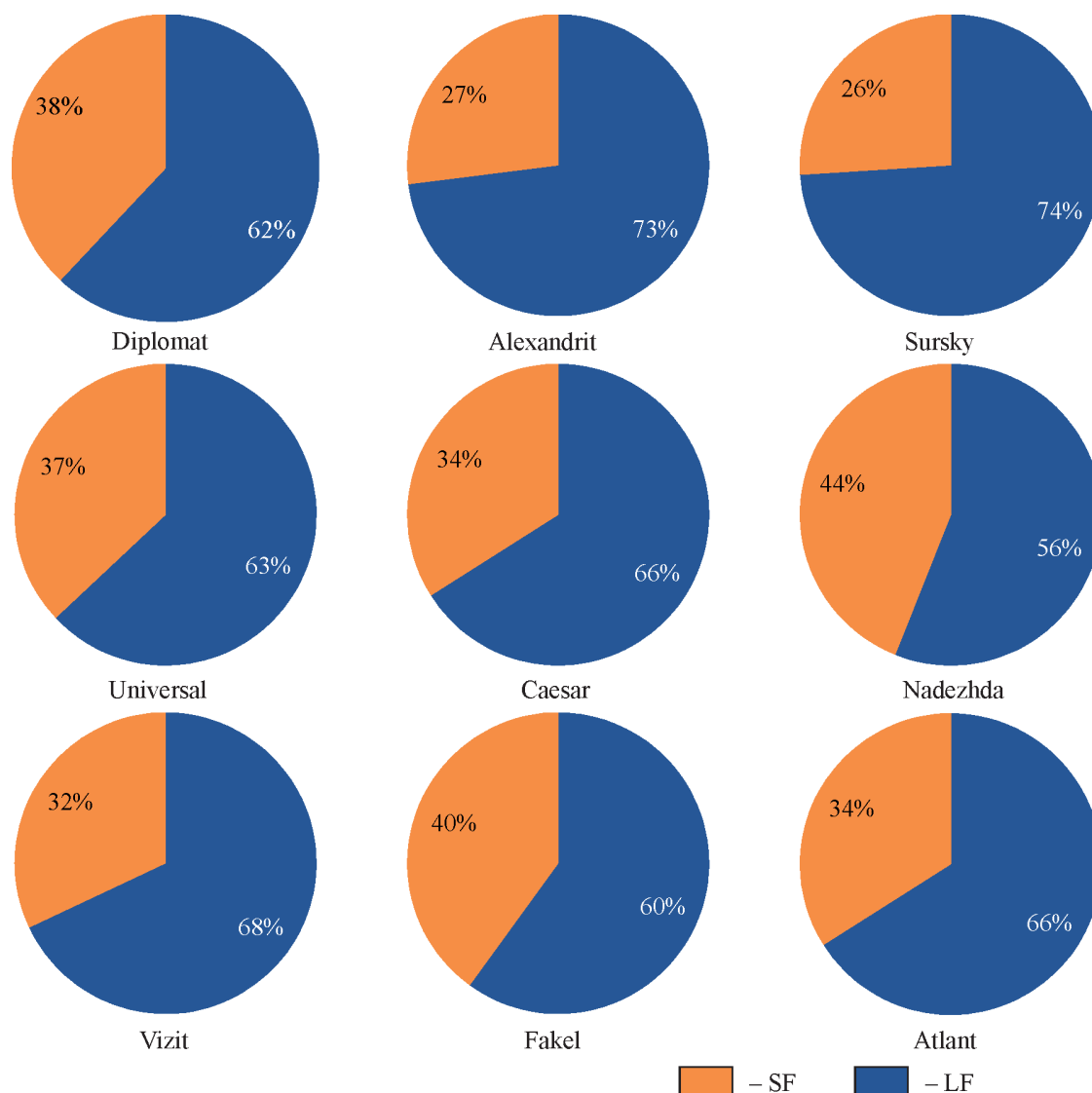
3. Despite the relatively low yield of maximum long fiber percentages obtained from flax straw processing under industrial conditions, which varies between 25.5 and 48.1% across flax varieties, varieties with an optimal ratio of long to short fiber percentages were identified.

The following varieties were considered the best by this criterion: Surskiy, for which the long fiber percentage, taking into account its fiber count, is 74%; Alexandrit and Vizit, with long fiber percentages of 73 and 68%.

4. Processing of high-quality flax straw of the flax varieties Surskiy, Alexandrit, and Vizit, rated at a number not lower than 1.75, under production conditions can ensure the maximum degree of realization of their biological potential in relation to the yield and quality of flax fiber, and, accordingly, the complex criterion for the efficiency of flax production of long fiber percentages.

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**Рис. 2.** Соотношение удельного веса процентнономеров длинного и короткого волокна при максимальной степени реализации биологического потенциала сортов льна-долгунца (ДВ – длинное волокно, КВ – короткое волокно), %

**Fig. 2.** The ratio of the specific gravity of long and short fiber percentages at the maximum degree of realization of the biological potential of fiber flax varieties (LF - long fiber, SF - short fiber), %

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## Характеристика сорных растений семейства Гречишные (Polygonaceae) юга Приморского края

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В статье представлены сведения о видовом составе сорных растений семейства Гречишные (Polygonaceae), стабильно произрастающих на территории юга Приморского края и доминирующих в агроценозах. Цель исследования – провести анализ растений семейства Гречишные как компонента сорной растительности юга Приморского края в зависимости от типа местообитания. Полевые исследования проходили с использованием традиционного маршрутно-рекогносцировочного метода в 2018–2023 гг. в городских и сельских поселениях и на территории Государственного природного заповедника «Уссурийский» им. В.Л. Комарова. В процессе работы проанализированы литературные данные и информация из интернет-ресурсов, исследованы гербарные образцы. Проведены фенологические наблюдения и фотографирование объектов из мест произрастания. Обнаружен 31 вид растений семейства Гречишные, являющихся фоновыми для природной или адвентивной флоры исследуемого региона, 27 видов выявлено на территории заповедника, 12 занесены в список сорных на территории Приморского края. Многие из обнаруженных растений могут применяться в качестве кормовой базы в животноводстве и пчеловодстве, а также могут быть задействованы в технологических процессах и в быту для различных целей. В настоящее время такие виды, как *Acetosa pratensis*, *Cephalophilon nepalense*, *Chylocalyx perfoliatus*, *Fagopyrum tataricum*, *Fallopia convolvulus*, *Polygonum aviculare*, *Persicaria hydropiper*, *P. bungeana*, *P. longiseta*, *P. viscosa*, *P. viscofera*, *Rumex crispus*, отмечены в большинстве административно-территориальных районов региона и активно расселяются по антропогенно трансформированному участку. Предлагаем внести в список сорных растений Приморского края *Acetosa pratensis*, *Cephalophilon nepalense*, *Persicaria longiseta*, *P. viscosa*.

**Ключевые слова:** Гречишные, сорные растения, местообитания, агроценозы, Уссурийский заповедник, Приморский край

## Characteristics of weeds of the Buckwheat family (Polygonaceae) in the south of the Primorsky Territory

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Information is provided on the species composition of weeds of the Buckwheat family (Polygonaceae) stably growing in the south of the Primorsky Territory and dominating in agrocenoses. The purpose of the study is to analyze plants of the Buckwheat family as a component of weed vegetation in the south of the Primorsky Territory depending on the type of the habitat. Field research was carried out using the traditional route reconnaissance method in 2018–2023 in urban and rural settlements and on the territory of the V.L. Komarov Ussurisky Nature Reserve. During the course of the work, literature data and information from Internet resources were analyzed, and herbarium samples were studied. Phenological observations and photographs of the objects from their habitats were taken. 31 species

of the Buckwheat family were discovered, which are the background for the natural or adventive flora of the region under study; 27 species were found on the territory of the Ussurisky Nature Reserve, 12 were included in the list of the weeds in the Primorsky Territory. Many of the plants discovered can be used as feed in animal husbandry and beekeeping, as well as in technological processes and in everyday life for various purposes. Currently, the following species: *Acetosa pratensis*, *Cephalophilon nepalense*, *Chylocalyx perfoliatus*, *Fagopyrum tataricum*, *Fallopia convolvulus*, *Polygonum aviculare*, *Persicaria hydropiper*, *P. bungeana*, *P. longiseta*, *P. viscosa*, *P. viscofera*, *Rumex crispus* are recorded in most administrative-territorial regions of the region and are actively spreading across anthropogenically transformed areas. We propose to add the following species to the list of the weeds in the Primorsky Territory: *Acetosa pratensis*, *Cephalophilon nepalense*, *Persicaria longiseta*, *P. viscosa*.

**Keywords:** Buckwheat family, weeds, habitats, agrocenoses, Ussurisky Nature Reserve, Primorsky Territory

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**Conflict of interest**

The authors declare no conflict of interest.

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## INTRODUCTION

Weeds in agricultural crops have traditionally been the subject of phytosanitary monitoring. However, due to the trend toward greening agriculture, a comprehensive approach to this problem is currently being applied. Within this approach, secondary habitats with disturbed natural cover include agrocenoses, ruderal habitats, fallow lands, and pastures within a specific agricultural landscape [1, 2]. Plant communities are not isolated, but gradually transition from one to another. This necessitates monitoring weeds not only in fields, but also in ruderal habitats within agroecosystems, as well as in residential areas and along transport routes [3–5].

It is known that the taxonomic composition and abundance of weeds vary in different areas and depend on both environmental factors and crop cultivation technologies, the volume of use of chemical pesticides, the area of disturbed territories, abandoned lands and uncultivated lands, which are sources of the spread of harmful and alien species [6–9]. To date, results of the studies of the flora of weeds in the south of the Russian Far East have been published and summarized, the most aggressive of which are quarantine objects<sup>1–4</sup>. The penetration of a significant number of such species into specially protected natural areas is the cause for great concern [10, 11].

<sup>1</sup>Buch T.G., Kachura N.N., Shvydkaya V.D., Andreeva E.R. Weeds of the Primorsky Territory and measures to combat them. Vladivostok: Far Eastern Book Publishing House, 1981, 254 p.

<sup>2</sup>Kozhevnikov A.E., Kozhevnikova Z.V., Kwak M., Lee B.Y. Illustrated flora of the Primorsky Territory (Russian Far East). Incheon: Nat. Inst. Biol. Res., 2019, 1124 p.

<sup>3</sup>Inogradova Yu.K., Antonova L.A., Darman G.F., Devyatova E.A., Kotenko O.V., Kudryavtseva E.P., Lesik (Aistova) E.V., Marchuk E.A., Nikolin E.G., Prokopenko S.V., Rubtsova T.A., Khoreva M.G., Chernyagina O.A., Chubar E.A., Sheiko V.V., Krestov P.V. Black Book of the Flora of the Far East: Invasive Plant Species in the Ecosystems of the Far Eastern Federal District. Moscow, 2021, 510 p.

<sup>4</sup>Fedina L.A. Additions to the flora of the Ussurisky Nature Reserve (Primorsky Territory) over ten years (2007–2016) // Komarovskiy Readings, 2017, N 65, pp. 55–60.

The purpose of the study is to analyze plants of the buckwheat family (Polygonaceae) as a component of weed vegetation in the south of the Primorsky Territory depending on the type of the habitat.

## MATERIAL AND METHODS

Field research was conducted from 2018 to 2023 in the Primorsky Territory, in urban and rural settlements, and in the V.L. Komarov Ussuri State Nature Reserve. The study utilized a route survey method, analyzed literature and online information, and examined herbarium specimens. Vascular plant identification was based on survey reports<sup>5</sup>.

Various types of habitats were surveyed: 1 – shrub thickets; 2 – forest clearings; 3 – forest paths; 4 – mesophytic meadows; 5 – ditches, boundaries, inter-row spaces, field imperfec-

tions; 6 – vegetable garden plots; 7 – roadsides of field roads; 8 – damp habitats (river valleys, wet ditches, swampy areas); 9 – lawns, flower beds; 10 – house territories; 11 – garbage collection containers, landfills; 12 – roadsides of highways; 13 – ditches; 14 – slopes, pebbles.

## RESULTS AND DISCUSSION

Currently, 97 species of plants from the Polygonaceae family are known to grow in the Primorsky Territory (see footnote 2). We discovered 31 species of Polygonaceae, which are common to the natural or adventitious flora of the study region (see the table).

According to our data, the favorite habitats of plants from the Polygonaceae family are ditches, boundaries, row spacings, field imperfections, forest paths and roadsides (up to 15-19 species were recorded), as well as vegetable plots and

Характеристика видов растений семейства Гречишные (Polygonaceae), произрастающих на территории исследуемых местообитаний  
Characteristics of the plant species of the Polygonaceae family growing on the territory of the studied habitats

Species	Habitat type														Other
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
* <i>Acetosa pratensis</i> Mill. (Sour dock) (s, p)	-	+	-	+	+	-	+	-	-	-	-	-	-	-	Ko, M, E
* <i>Acetosella vulgaris</i> (Koch) Fourr. (Common field sorrel) (s, p)	+	+	+	-	-	-	+	-	-	-	-	-	-	-	M, E, T, P
* <i>Bistorta pacifica</i> (V. Petrov ex Kom.) Kom. (Pasific snakeweed) (s, p)	-	+	+	+	-	-	+	-	-	-	-	-	-	-	O, F, Ko, M, H, E, T
* <i>Cephalophilon nepalense</i> (Meissn.) Tzvel. (Nepal smartweed) (s, a-b)	-	-	-	-	-	+	-	+	-	+	-	-	-	+	O, H
* <i>Chylocalyx perfoliatus</i> (L.) Hassk. ex Miq. (Hylocalyx perfoliate) (s, a-b)	+	-	-	-	-	-	-	+	-	-	-	+	+	-	O
* <i>Fagopyrum tataricum</i> (L.) Gaertn. (Tatar buckwheat) (s, a-b)	+	-	-	-	-	+	-	-	-	-	-	+	+	-	F, M, H, E
* <i>Fallopia convolvulus</i> (L.) A. Love (Black bindweed) (s, a-b)	+	-	+	-	+	-	+	+	-	-	-	-	-	-	F, M, E, T
* <i>F. dentato-alata</i> (Fr. Schmidt) Holub (Knotweed) (s, a-v)	+	+	+	-	-	-	-	-	-	-	-	-	-	+	O, F, E, T
* <i>F. dumetorum</i> (L.) Holub (Shrubby knotweed) (s, a-v)	+	+	+	-	-	-	+	-	-	-	-	-	-	-	O, F, E, T
* <i>F. pauciflora</i> (Maxim.) Kitag. (Pauciflorous knotweed) (s, a-v)	+	-	+	-	+	-	-	-	-	-	-	-	-	+	O, F, E, T
* <i>Persicaria bungeana</i> (Turcz.) Nakai ex Mori (Bunge persicaria) (s, a-b)	-	-	-	+	+	+	+	-	+	+	+	+	-	-	O, F, E, T
* <i>P. hydropiper</i> (L.) Spach (Biting knotweed) (s, a-b)	-	-	+	-	+	-	-	+	-	-	-	-	+	-	M, H, E, T

<sup>5</sup>Vascular plants of the Soviet Far East / ed. S.S. Kharkevich. L.: Nauka, 1989, vol. 4, 378 p.

end of the table

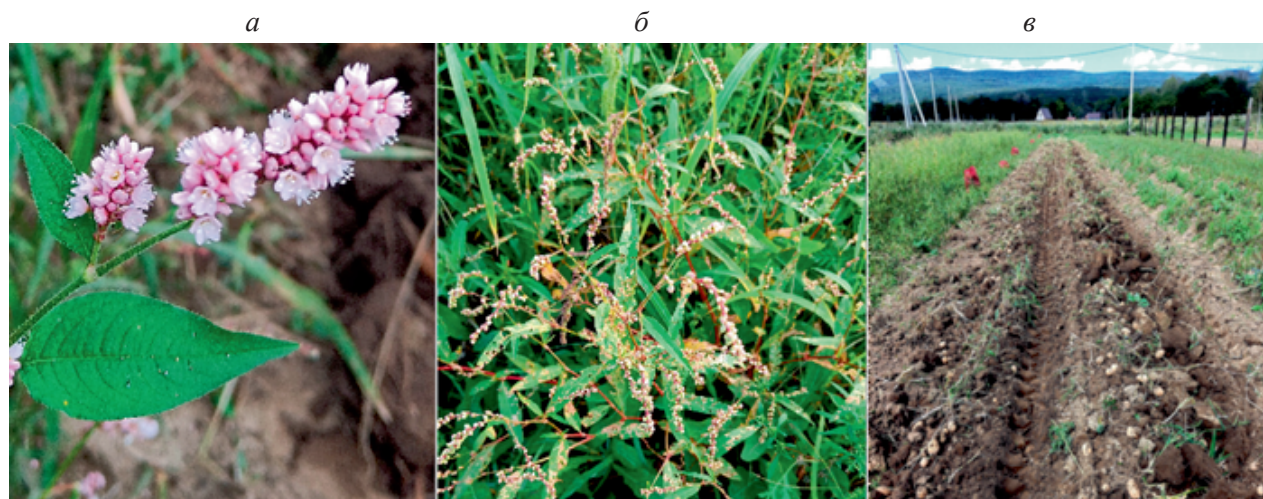
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
* <i>P. lapathifolia</i> (L.) S.F. Gray (Pale smartweed) (s, a-b)	-	-	+	-	+	+	+	-	-	-	-	-	-	-	M, H, E
<i>P. longiseta</i> (De Bruyn) Kitag. (Long-bristle knotweed) (s, a-b)	-	-	-	-	+	+	+	-	+	+	+	-	-	-	M, H, E
* <i>P. maculosa</i> S.F. Gray (Spotted knotweed) (s, a-b)	-	-	-	-	+	+	-	-	-	+	+	-	-	-	O, M, H, E, T, P
* <i>P. orientalis</i> (L.) Spach (Eastern knotgrass) (s, a-b)	-	-	-	+	+	+	-	-	+	-	-	-	-	-	M, H, E
* <i>P. yokusaiana</i> (Makino) Nakai ( <i>Persicaria yokusaiana</i> ) (s, a-b)	-	-	+	-	+	-	+	+	-	-	-	-	+	-	M, H, E
* <i>P. viscofera</i> (Makino) H. Gross ex Nakai ( <i>Persicaria viscofera</i> ) (s, a-b)	-	-	-	-	+	+	-	-	-	+	-	-	+	-	O, F
<i>P. viscosa</i> (Buch.-Ham. ex D. Don) H. Gross ex Nakai ( <i>Persicaria viscosa</i> ) (s, a-b)	-	-	-	+	+	+	-	-	-	+	+	+	-	-	O, F
* <i>Polygonum aviculare</i> L. (Knotgrass) (s, a-b)	-	-	+	-	-	+	+	-	-	+	-	-	-	-	F, Ko, M, T
* <i>P. calcatum</i> Lindm. (Trampled knotgrass) (s, a-b)	-	-	+	-	+	+	+	-	-	+	-	-	-	-	F, M, E
* <i>P. neglectum</i> Bess. (Unsighted knotgrass) (s, a-b)	-	-	+	-	-	-	-	+	-	-	-	-	-	-	F, M, E
* <i>Rumex crispus</i> L. (Curly sorrel) (s, p)	+	+	+	+	+	-	-	-	-	-	+	-	-	-	Ko, M, E
* <i>R. longifolius</i> DC. (Long-lived sorrel) (s, p)	-	-	-	+	-	-	+	+	-	-	-	-	-	-	Ko, M, E
* <i>R. maritimus</i> L. (Marine sorrel) (s, a-b)	-	-	+	+	-	-	+	+	-	-	-	-	-	-	F, M, E
* <i>R. patientia</i> L. (Spinach sorrel) (s, p)	-	-	-	+	-	-	+	-	-	-	-	-	-	-	F, M, E
* <i>Truellum dissitiflorum</i> (Hemsley) Tzvel. (Sparsiflorous prickly stalk) (s, a-b)	-	-	-	-	+	-	-	+	-	-	-	-	+	-	O, F, M
* <i>T. hastatosagittatum</i> (Makino) Sojak (Spearhead - sagittate prickly stalk) (s, a-b)	-	-	-	-	+	-	-	+	-	-	-	-	+	-	O, F, M
<i>T. sagittatum</i> (L.) Sojak (Sagittifolious prickly stalk) (s, a-b)	-	-	-	-	+	-	-	+	-	-	-	-	+	-	O, F, M
* <i>T. sieboldii</i> (Meissn.) Sojak (Siebold prickly stalk) (s, a-b)	-	-	-	-	+	-	-	+	-	-	-	-	+	-	O, F, M
* <i>T. thunbergii</i> (Siebold. et Zucc.) Sojak (Thunberg prickly stalk) (s, a-b)	+	+	+	-	+	-	+	+	-	-	-	-	-	-	O, F, M
Total	9	7	15	9	19	11	15	13	3	8	5	4	9	3	

Note. O – ornamental; F – forage; Ko – used in cosmetology or perfumery; M – medicinal; H – honey plant; E – edible; T – technical; P – poisonous; s – reproduce by seeds. Life cycle: p – perennial grass; a-b – annual or biennial grass; a-v – annual summer-green herbaceous vine (annual vine). “\*” – plants listed as weeds in the Primorsky Territory; “●” – plants growing in the Ussurisky State Nature Reserve on the territory of the Ussurisky urban district.

wetlands (up to 11-13 species). Habitats with the lowest diversity of weed species (up to 3-4) are highway shoulders, gravel beds, lawns and flowerbeds. Of the species we studied, 27 were found on the territory of the Ussurisky Nature Reserve, 12 are listed as weeds in the Primorsky Territory. Many of these plants can be used as forage in animal husbandry and beekeeping, can be involved in technological processes and in everyday life

for various purposes [12] (Figs. 1, 2, photo M. Maslov).

Members of the Polygonaceae family are characterized by the formation of numerous seeds. Each plant of this family can produce over 1,000 seeds during the growing season, most of which remain viable in the soil for up to four years. For example, a single *P. hydropiper* plant produces up to 2,000 viable seeds per season (see



**Рис. 1.** Растения семейства Гречишные в агроценозах Приморского края:

*a* – *P. orientalis*; *б* – *P. bungeana*; *в* – междурядья на картофельном поле, заселенные этими видами растений (Уссурийский городской округ, с. Каменушка)

**Fig. 1.** Plants of the Buckwheat family in agrocenoses of the Primorsky Territory:

*a* – *P. orientalis*; *б* – *P. bungeana*; *в* – row spacing in a potato field populated by these plant species (Ussuriysk urban district, Kamenushka village)



**Рис. 2.** Огородный участок, заселенный *P. longisetata* (Уссурийский городской округ, с. Каймановка)

**Fig. 2.** A garden plot inhabited by *P. longisetata* (Ussuriysk urban district, Kaymanovka village)

footnote 1). An example of its rapid expansion is *C. nepalense*, which was first discovered in 2008 in the Ussurisky Nature Reserve, located in the Ussuri Urban District (see footnote 4). In 2023, *C. nepalense* was observed in large numbers in vegetable gardens in the same urban district.

Of the species listed in the table, most belong to the group of annual weeds (annual and biennial herbs, annual summer-green herbaceous vines); sour dock, field sorrel and Pacific grass plantage are perennial weeds.

A generalization of the phenological characteristics of the species showed that flowering in 20 of them occurs from July to September (fruiting – from August to September – October): *Cephalophilon nepalense*, *Fallopia convolvulus*, *F. pauciflora*, *Persicaria bungeana*, *P. hydropiper*, *P. lapathifolia*, *P. longisetata*, *P. maculosa*, *P. orientalis*, *P. yokusaiana*, *P. viscofera*, *P. viscosa*, *Polygonum aviculare*, *P. calcatum*, *P. neglectum*, *Rumex crispus*, *R. patientia*, *Truellum dissitiflorum*, *T. sieboldii*, *T. thunbergii*. Flowering of 11 species is recorded from June-July to August (fruiting – from July to September): *Acetosa pratensis*, *Acetosella vulgaris*, *Bistorta pacifica*, *Chylocalyx perfoliatus*, *Fagopyrum tataricum*, *F. dentato-alata*, *F. dumetorum*, *Rumex longifolius*, *R. maritimus*, *Truellum hastatosagittatum*, *T. sagittatum*. In recent years, there has been a significant increase in the duration of flowering in most of the plant species of this family that we studied.

## CONCLUSION

According to the data obtained, the following plant species from the Buckwheat family should be noted in the southern Primorsky Territory: *Acetosa pratensis*, *Cephalophilon nepalense*, *Chy-*

*localyx perfoliatus*, *Fagopyrum tataricum*, *Fallopia convolvulus*, *Polygonum aviculare*, *Persicaria hydropiper*, *P. bungeana*, *P. longiseta*, *P. viscosa*, *P. viscofera*, *Rumex crispus*, which we have noted in most of the administrative-territorial districts of the region and are actively dispersing across anthropogenically transformed areas (road shoulders, abandoned fields and meadows, construction quarries, etc.), are found in city parks, squares and in residential areas. Most of them grow in agricultural crop plantings. Such species as *Fallopia pauciflora*, *Persicaria lapathifolia*, *P. maculosa*, *P. orientalis*, *P. yokusaiana*, *P. calcatum*, *Truellum dissitiflorum*, *T. hastatosagittatum*, *T. sagittatum*, *T. sieboldii*, *T. thunbergii* do not grow abundantly in agrocenoses. *Rumex longifolius* is found as a weed primarily along paths and trails. It should be noted that none of the Polygonaceae family species are currently included in the "Black Book of the Flora of the Far East." We propose adding the following species to the list of weeds in the Primorsky Territory: *Acetosa pratensis*, *Cephalophilon nepalense*, *Persicaria longiseta*, *P. viscosa*.

## ЗАКЛЮЧЕНИЕ

Согласно полученным данным, на территории юга Приморского края следует обратить внимание на следующие виды растений из семейства Гречишные: *Acetosa pratensis*, *Cephalophilon nepalense*, *Chylocalyx perfoliatus*, *Fagopyrum tataricum*, *Fallopia convolvulus*, *Polygonum aviculare*, *Persicaria hydropiper*, *P. bungeana*, *P. longiseta*, *P. viscosa*, *P. viscofera*, *Rumex crispus*, которые отмечены нами в большинстве административно-территориальных районов региона и активно расселяются по антропогенно трансформированным участкам (обочинам автомобильных дорог, заброшенным полям и лугам, строительным карьерам и т.д.), встречаются в городских парках, скверах и на придомовых территориях. Большинство из них произрастают в посадках сельскохозяйственных культур. Такие виды, как *Fallopia pauciflora*, *Persicaria lapathifolia*, *P. maculosa*, *P. orientalis*, *P. yokusaiana*, *P. calcatum*, *Truellum dissitiflorum*,

*T. hastatosagittatum*, *T. sagittatum*, *T. sieboldii*, *T. thunbergii*, в агроценозах произрастают не обильно. *Rumex longifolius* встречается как сорное растение в основном вдоль троп и дорожек. Следует отметить, что ни один из видов растений семейства Polygonaceae до настоящего времени не включен в «Черную книгу флоры Дальнего Востока». Предлагаем внести в список сорных растений Приморского края следующие виды: *Acetosa pratensis*, *Cephalophilon nepalense*, *Persicaria longiseta*, *P. viscosa*.

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## Биологическая эффективность биорациональных инсектицидов в интеграции с энтомофагом *Habrobracon hebetor* (Say, 1836) против восточного кукурузного мотылька *Ostrinia furnacalis* (Guenee, 1854)

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В статье представлены результаты полевого изучения эффективности энтомофага *Habrobracon hebetor* (Say, 1836) и биорациональных инсектицидов: БиоКилл, КЭ (10 г/л) и Проклэйм, ВРГ (50 г/кг). Опыты проведены в Приморском крае в 2022, 2023 гг. Объект исследования – восточный кукурузный мотылек. Схема опыта включает семь вариантов: контроль (без обработки и выпуска энтомофага), обработку инсектицидами с одно- и двукратным выпуском паразитоидов. Повторность трехкратная. Площадь делянки 28 м<sup>2</sup>. Эффективность определяли по поврежденности растений (в баллах) по методике И.Д. Шапиро. Цель работы – изучить биологическую эффективность *Habrobracon hebetor* (Say, 1836) в интеграции с инсектицидами против восточного кукурузного мотылька. В ходе исследований выявлен высокий процент поврежденности початка и ножки початка, слом стебля и метелки кукурузным мотыльком в контрольном варианте – 10,0 и 15,0%; 36,7 и 16,8% соответственно. Определен наименьший балл повреждения в вариантах Проклэйм, ВРГ + двукратный выпуск энтомофага – 0,2 и БиоКилл, КЭ + однократный выпуск паразитоида – 0,3. Высокую биологическую эффективность против вредителя (93,0%) наблюдали при использовании биоинсектицида Проклэйм, ВРГ с двукратным выпуском габробракана. Наибольшей прибавкой зерна с початка (21 г) по отношению к контролю характеризуется вариант с применением Проклэйм, ВРГ – 0,2 кг/га + двукратный выпуск энтомофага.

**Ключевые слова:** кукуруза, *Ostrinia furnacalis* Guenee, *Habrobracon hebetor* Say, биорациональные инсектициды, биоинсектициды

## Biological effectiveness of biorational insecticides in combination with the entomophagous *Habrobracon hebetor* (Say, 1836) against the Asian corn borer *Ostrinia furnacalis* (Guenee, 1854)

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The paper presents the results of a field study on the effectiveness of the entomophagous insect *Habrobracon hebetor* (Say, 1836) and bio-rational insecticides BioKill, EC (10 g/l) and Proclaim, WSG (50 g/kg). The experiments were conducted in the Primorsky Territory in 2022-2023. The Asian corn borer was the research object. The design of the experiment included seven variants: the control (without any treatment and the use of the entomophagous insect) and treatments with insecticides and single and double release of the parasitoids. The experiment was carried out with three repetitions. The area of the experimental field plot was 28 m<sup>2</sup>. The effectiveness was determined depending on the degree of the damage caused to plants (point score) according to the methodology of I.D. Shapiro. The research goal was to study the biological efficacy of *Habrobracon hebetor* (Say, 1836) in combination with the insecticides against the Asian corn borer. During the research, a high percentage of damage to the cob and cob stalk, as well as breakage of the stem and tassel by the corn borer, was identified in the control variant – 10 and 15%, 36.7 and 16.8%, respectively. The lowest degree of damage was characteristic of the variants with the use of Proclaim, WSG + the double release of the entomophagous insect – 0.2 points and with the use of Biokill, EC + the single release of the parasitoid – 0.3 points.

The use of bio-insecticide Proclaim, WSG, in combination with the double release of *Habrobracon hebetor* (Say, 1836) showed high biological efficacy. The highest gain in grain yield per ear (21 g) in comparison to the control was found in the variant with the use of Proclaim, WSG (0.2 kg/ha), and the double release of the entomophagous insect.

**Keywords:** corn, *Ostrinia furnacalis* Guenee, *Habrobracon hebetor* Say, biorational insecticides, bioinsecticides

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**Конфликт интересов**

Авторы заявляют об отсутствии конфликта интересов.

**Conflict of interest**

The authors declare no conflict of interest.

## INTRODUCTION

Corn (*Zea mays*) occupies one of the leading places among agricultural crops in the Far Eastern region. Its uniqueness lies in its high yield and versatile uses [1–4].

One of the limiting factors for obtaining a high-quality corn crop is damage to crops by diseases and pests [5–7]. The Asian corn borer *Ostrinia furnacalis* (Guenee, 1854) (Lepidoptera: Crambidae) causes significant damage to corn in the Primorsky Territory. *O. furnacalis* is an internal stem pest of corn that has serious economic significance in many countries around the world [8–10].

Meteorological conditions (high temperatures and abundant precipitation) in Primorye during the growth and development of corn contribute to the rapid reproduction and spread of *O. furnacalis*. Virtually the entire plant suffers from damage caused by this pest [11, 12]. In addition to direct damage to productivity, the corn borer also causes significant indirect harm, as damage to the integrity of the plant's covering tissues contributes to the infection of corn by pathogens [13].

Corn cultivation is impossible without the use of pesticides. The products designed to destroy insect pests provide invaluable assistance in the comprehensive fight against them, reducing the

damage caused and preventing the development of dangerous diseases in crops. However, traditional chemical insecticides have a number of disadvantages: they increase pesticide exposure and cause mass deaths of not only harmful but also beneficial insect species. In addition, *O. furnacalis* larvae (the harmful phase) penetrate plants closer to the third instar and lead a hidden lifestyle, thus becoming invulnerable to pesticides. In this regard, the use of integrated plant protection methods is relevant.

*Habrobracon hebetor* (Say, 1836) (Hymenoptera: Braconidae) is of considerable interest as a bioagent and is already being used to control various pests both in Russia and abroad [14, 15].

The purpose of the research is to evaluate the biological effectiveness of *H. hebetor* in combination with biorational insecticides against *O. furnacalis* in the southern Far East.

## MATERIAL AND METHODS

Experimental work was carried out in the Primorsky Territory in the area with one generation of corn borers in the fields of the corn breeding and primary seed production laboratory of the Federal Scientific Center of Agricultural Biotechnology of the Far East named after A.K. Chaiki in 2022 and 2023.

The material for the study was the Slavyanka corn variety.

The study used biorational insecticides Bio-Kill, EC (abamectin, 10 g/l), Proclaim, WSG (emamectin benzoate, 50 g/kg) and laboratory populations of *H. hebetor* parasitoids (see Fig. 1) from the collection of the Department of Biological Plant Protection Methods of the Far Eastern Research Institute of Plant Protection as a mother culture.

The plants were sprayed with bioinsecticides during the panicle emergence period. The first release of *Gabrobracus* was carried out 14 days after treatment with the preparations, and the second release was carried out 10 days after the first release of the entomophagous insect. Test tubes with *H. hebetor* imagoes were delivered from the laboratory to the field in the morning hours in sunny weather at three points in each experimental variant and opened.

For timely treatment of corn with pesticides, the crops were inspected for egg clusters and pest egg counts. To this end, the plants were inspected once every 10 days from mid-June (late June), noting the number of eggs and egg clusters. Counts were taken on 25 plants in each plot.

The plot area in this variant is 28 m<sup>2</sup>. The trial is repeated three times. The corn variety is



**Рис. 1.** *Habrobracon hebetor* Say, 1836 (оригинал)  
**Fig. 1.** *Habrobracon hebetor* S. (original)

Slavyanka. The seeding rate is 75,000 seeds/ha. The plots are systematically placed. Sowing is on May 11. Harvesting is done manually at full maturity, followed by threshing with a thresher. Plants were treated with foliar spraying agents using an OB-14 Turbo knapsack sprayer. The working fluid consumption rate is 300 l/ha.

Biological efficiency was determined based on plant damage (in points) using the formula

$$B = \frac{A - B}{A} \times 100\%,$$

where A – damage to plants in control; B – damage to plants in the experimental variant.

The experiments with the preparations were carried out in accordance with the field experiment methodology of B.A. Dospekhov<sup>1</sup> and the methodological guidelines of VIZR<sup>2,3</sup>. Damage was assessed in points before harvesting according to the method of I.D. Shapiro<sup>4</sup>. Statistical processing was carried out using the Excel program.

Experiment options:

1. Control (without treatment and release of *H. hebetor*).
2. Single release of the entomophage *H. hebetor* (2000 individuals/ha; 34 individuals per plot).
3. Double release of the entomophage *H. hebetor* (1000 individuals/ha; 17 individuals per plot for one release).
4. Treatment with Proclaim, WSG (50 g/l) – 0,2 kg/ha.
5. Treatment with Proclaim, WSG (50 g/l) – 0,2 kg/ha + a single release of the entomophage *H. hebetor* (2000 individuals/ha; 34 individuals per plot).
6. Treatment with Proclaim, WSG (50 g/l) – 0,2 kg/ha + a double release of the entomophage

<sup>1</sup>Dospekhov B.A. Methodology of field experiment (with the basics of statistical processing of research results) / Stereopit. ed. reprint from the 5th edition, supplemented and revised. Moscow: Alliance, 2014, 351 p.

<sup>2</sup>Guidelines for registration testing of insecticides, acaricides, molluscicides, and rodenticides in agriculture. St. Petersburg, 2009, 321 p.

<sup>3</sup>Guidelines for testing biological products for plant protection against pests, diseases, and weeds. Moscow: Kolos, 1973, 41 p.

<sup>4</sup>Shapiro I.D. Harmfulness of the stem borer on corn crops in the Krasnodar Territory // Bulletin of the All-Russian Institute of Plant Protection, 1979, N 46, pp. 45–49.

*H. hebetor* (1000 individuals/ha; 17 individuals per plot for each release).

7. Treatment with Biokill, EC (10 g/l) – 0,4 l/ha.

8. Treatment with Biokill, EC (10 g/l) – 0,4 l/ha + a single release of the entomophage *H. hebetor* (2000 individuals/ha; 34 individuals per plot).

9. Treatment with Biokill, EC (10 g/l) – 0,4 l/ha + a double release of the entomophage *H. hebetor* (1000 individuals/ha; 17 individuals per plot for each release).

## RESULTS AND DISCUSSION

As a result of the conducted research, data on the damage to corn plants was obtained, and the biological and economic effectiveness of the use of biorational insecticides and entomophages against Asian corn borer was revealed.

A high percentage of damage to the cob and peduncle, stem and panicle breakage by *O. furnacalis* caterpillars (see Fig. 2) was detected in the control variant – 10 and 15%, 36.7 and 16.8%, respectively (see Table 1). The minimum number of caterpillars per plant (0.03 individuals) compared to the control (2.0 individuals) was noted in the Proclaim, WSG (0.2 kg/ha) + a double release of the entomophage variant (see Fig. 3). The lowest stem breakage was observed in the variants using the Proclaim, WSG bioinsecticide – 0.3%.

The shorter the stem tunnel length, the more effective the product is against the pest cater-

pillars. All products in the experiment demonstrated superiority in this regard (0.80–1.97 cm) compared to the control.

The lowest damage score to corn was observed in the Proclaim, WSG + a double release of the entomophage variants – 0.2 and Biokill, EC + a single release of the parasitoid – 0.3 (see Table 1). High biological effectiveness against the pest (93.0%) was observed when using the Proclaim, WSG bioinsecticide with a double release of *Habrobracon* (see Table 2).

Grain weight, depending on the variant, ranged from 70.5 to 91.5 g (see Table 3). The Proclaim variant, WSG + a double entomophage release, stands out in this respect, exceeding the control by 21.0 g.

Based on the results of examining the plants for the presence of egg-laying sites, it can be noted that the corn borer begins to lay offspring on corn plants from mid-June, but reaches its maximum (according to methodological recommendations) in most cases closer to mid-July, where the maximum number of eggs on one plant is 5, which is 2.5 times higher than the initial number (see Table 4).

The eggs are flat and round, and females lay them in clusters of 2 to 200 eggs per clutch (averaging 30–40) in a tiled pattern. They are most often located on the underside of corn leaves near the midrib. Egg development duration is 3–9 days (see Fig. 4).

It should be noted that the economic thresh-



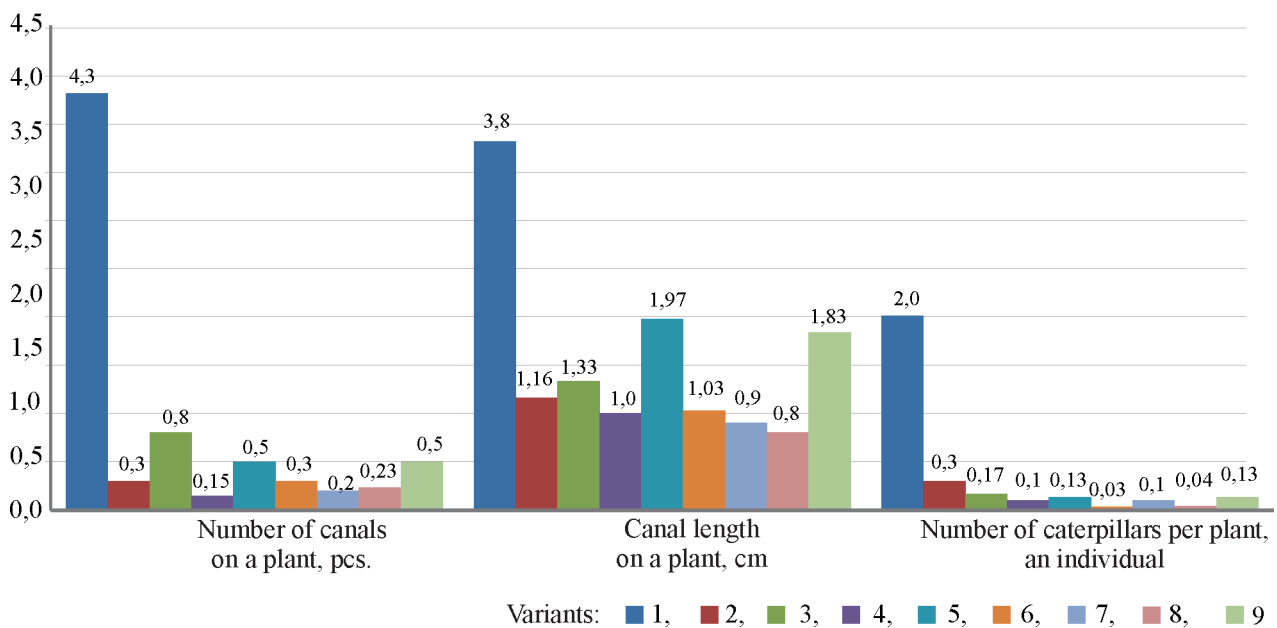
**Рис. 2.** Гусеница *O. furnacalis* G.: (а) и поврежденный стебель кукурузы (б) (оригинал)  
**Fig. 2.** Caterpillar of *O. furnacalis* G.: (a) and a damaged corn stalk (б) (original)

**Табл. 1.** Показатели поврежденности кукурузы вредителем при совместном применении биоинсектицидов и *H. hebetor* (среднее за 2022, 2023 гг.)

**Table 1.** Parameters of the damage caused by the pest to corn plants after the use of the bioinsecticides and *H. hebetor* (average for 2022, 2023)

Option	Damage, %				Damage score
	Panicle fracture	Spike stalk	Spike	Stem fracture	
1. Control (without treatment)	16,8 ± 3,6	15 ± 2,8	10 ± 1,6	36,7 ± 2,5	2,3 ± 0,19
2. Single release of the entomophage	6,7 ± 0,6	10 ± 1,3	0,00	3,4 ± 0,7	0,8 ± 0,13
3. Double release of the entomophage	0,00	6,7 ± 0,6	0,00	13,3 ± 0,6	0,8 ± 0,03
4. Proclaim, WSG – 0,2 kg/ha	0,00	8,0	0,00	9,5 ± 0,6	0,7 ± 0,13
5. Proclaim, WSG – 0,2 kg/ha + single release of the entomophage	0,00	0,00	0,00	0,3 ± 0,07	0,5 ± 0,06
6. Proclaim, WSG – 0,2 kg/ha + double release of the entomophage	0,00	0,00	0,00	0,3 ± 0,03	0,2 ± 0,03
7. Biokill, EC – 0,4 l/ha	0,00	7,3 ± 0,6	7,2 ± 0,9	2,4 ± 0,6	0,71 ± 0,07
8. Biokill, EC – 0,4 l/ha + single release of the entomophage	10,4 ± 0,4	0,00	0,00	2,4 ± 0,23	0,3 ± 0,16
9. Biokill, EC – 0,4 l/ha + double release of the entomophage	11,7 ± 0,4	0,00	0,00	0,9 ± 0,13	0,4 ± 0,06

Note. The value «±», indicated in the table is the difference error.



**Рис. 3.** Влияние биологических средств защиты на заселенность *O. furnacalis* и поврежденность кукурузы (среднее за 2022, 2023 гг.)

**Fig. 3.** Influence of the biological plant protection products on the population size of *O. furnacalis* and the damage caused to corn plants (average for 2022, 2023)

**Табл. 2.** Эффективность применения биологических средств защиты кукурузы против *O. furnacalis* (среднее за 2022, 2023 гг.)

**Table 2.** Efficacy of the biological plant protection products against *O. furnacalis* (average for 2022, 2023)

Option	Biological effectiveness, %
1. Control (without treatment)	–
2. Single release of the entomophage	64,0
3. Double release of the entomophage	64,0
4. Proclaim, WSG – 0,2 kg/ha	70,0
5. Proclaim, WSG – 0,2 kg/ha + single release of the entomophage	80,0
6. Proclaim, WSG – 0,2 kg/ha + double release of the entomophage	93,0
7. Biokill, EC – 0,4 l/ha	67,0
8. Biokill, EC – 0,4 l/ha + single release of the entomophage	77,0
9. Biokill, EC – 0,4 l/ha + double release of the entomophage	71,0
LSD <sub>05</sub>	7,4

**Табл. 3.** Влияние биопрепаратов и энтомофага *H. hebetor* на хозяйственно ценные признаки кукурузы (среднее за 2022, 2023 гг.)

**Table 3.** Influence of the bioproducts and the entomophagous insect *H. hebetor* on the economically important traits of corn (average for 2022, 2023)

Option	Grain weight from one cob, g	Corn cob length, cm	Corn cob weight, g
1. Control (without treatment)	70,5	14,1	100,3
2. Single release of the entomophage	81,4	14,5	112,0
3. Double release of the entomophage	87,0	12,6	100,5
4. Proclaim, WSG – 0,2 kg/ha	81,0	13,1	99,5
5. Proclaim, WSG – 0,2 kg/ha + single release of the entomophage	85,7	14,0	89,7
6. Proclaim, WSG – 0,2 kg/ha + double release of the entomophage	91,5	13,7	110,5
7. Biokill, EC – 0,4 l/ha	82,0	14,1	110
8. Biokill, EC – 0,4 l/ha + single release of the entomophage	81,8	13,8	86,4
9. Biokill, EC – 0,4 l/ha + double release of the entomophage	73,8	13,05	123,1
LSD <sub>05</sub>	6,4	0,7	7,2

**Табл. 4.** Результаты обследования кукурузы на наличие яйцекладок восточного кукурузного мотылька, 2022, 2023 гг.

**Table 4.** Results of the corn monitoring for egg masses of the Asian corn borer, 2022, 2023

Option	Number of egg clutches on 25 plants, pcs.	Number of eggs in the clutch, pcs.	Number of eggs per plant, pcs.
1	2	3	4
<i>First monitoring (II–III ten-day periods of June)</i>			
1. Control (without treatment)	0,00	0,00	0,00
2. Single release of the entomophage	0,00	0,00	0,00

end of table 4

1	2	3	4
3. Double release of the entomophage	0,00	0,00	0,00
4. Proclaim, WSG – 0,2 kg/ha	1 ± 0,00	40 ± 1,36	1,6
5. Proclaim, WSG – 0,2 kg/ha + single release of the entomophage	0,00	0,00	0,00
6. Proclaim, WSG – 0,2 kg/ha + double release of the entomophage	0,00	0,00	0,00
7. Biokill, EC – 0,4 l/ha	0,00	0,00	0,00
8. Biokill, EC – 0,4 l/ha + single release of the entomophage	0,00	0,00	0,00
9. Biokill, EC – 0,4 l/ha + double release of the entomophage	0,00	0,00	0,00

*Second monitoring (III ten-day period of June – I ten-day period of July)*

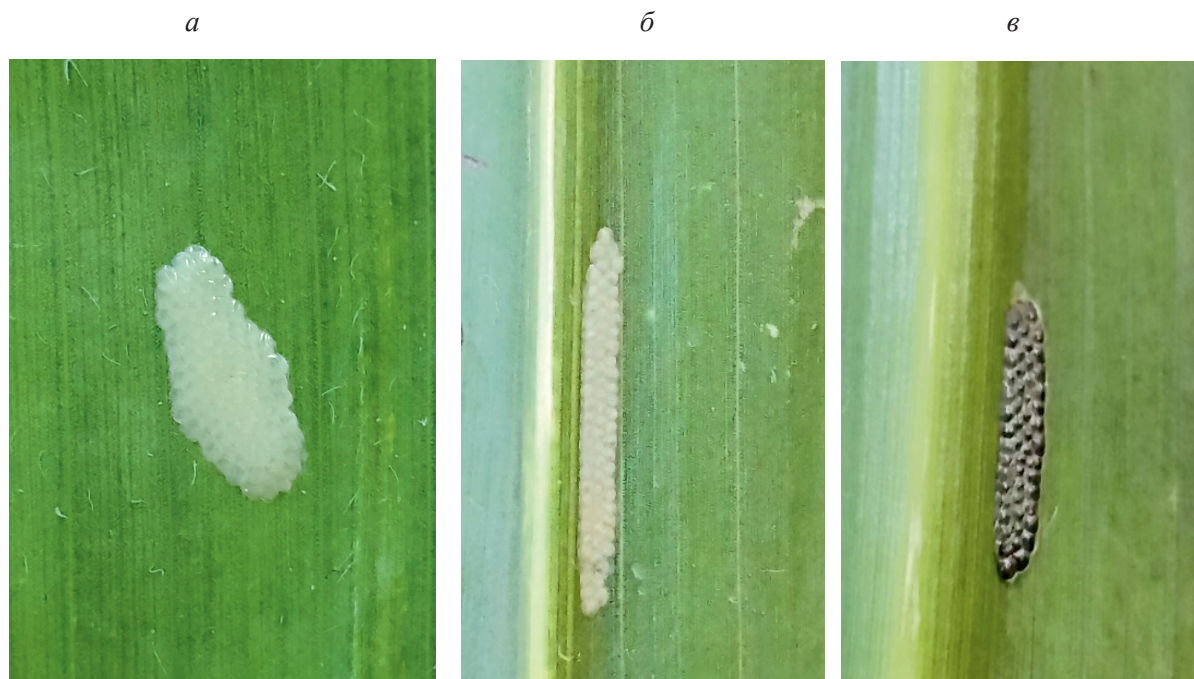
1. Control (without treatment)	1 ± 0,70	0,00	0,00
2. Single release of the entomophage	0,00	0,00	0,00
3. Double release of the entomophage	0,00	0,00	0,00
4. Proclaim, WSG – 0,2 kg/ha	1 ± 0,70	38 ± 5,4	1,52
5. Proclaim, WSG – 0,2 kg/ha + single release of the entomophage	0,00	0,00	0,00
6. Proclaim, WSG – 0,2 kg/ha + double release of the entomophage	1 ± 0,00	9 ± 1,3	0,36
7. Biokill, EC – 0,4 l/ha	0,00	0,00	0,00
8. Biokill, EC – 0,4 l/ha + single release of the entomophage	1,00 ± 0,00	60 ± 5,2	2,4
9. Biokill, EC – 0,4 l/ha + double release of the entomophage	0,00	0,00	0,00

*Third monitoring (II ten-day period of July)*

1. Control (without treatment)	2 ± 0,0	114 ± 4,7	4,56
2. Single release of the entomophage	0,7 ± 0,4	11 ± 0,7	0,44
3. Double release of the entomophage	0,7 ± 0,4	16,3 ± 2,4	0,66
4. Proclaim, WSG – 0,2 kg/ha	1 ± 0,0	63 ± 2,0	2,52
5. Proclaim, WSG – 0,2 kg/ha + single release of the entomophage	3,3 ± 0,7	61,3 ± 4,7	2,46
6. Proclaim, WSG – 0,2 kg/ha + double release of the entomophage	3,0 ± 0,7	83,0 ± 1,0	0,32
7. Biokill, EC – 0,4 l/ha	3,3 ± 0,34	126,0 ± 17,0	5,0
8. Biokill, EC – 0,4 l/ha + single release of the entomophage	1 ± 0,7	79,0 ± 4,0	3,16
9. Biokill, EC – 0,4 l/ha + double release of the entomophage	1 ± 0,0	54,3 ± 4,2	2,16

Note. The value "±" given in the table is the difference error.

<sup>5</sup>Govorov D.N., Zhirov A.D., Shabelnikova A.A., Nikulin A.N. et al. Review of the phytosanitary condition of agricultural crops in the Russian Federation in 2022 and forecast of the development of harmful objects in 2023 // Ministry of Agriculture, 2023.



**Рис. 4.** Яйцекладки *O. furnacalis* на нижней стороне листа, яйца светлые (а, б) – яйцекладка недавно отложена; темные (в) – яйцекладка перед отрождением гусениц (оригинал)

**Fig. 4.** Egg masses of *O. furnacalis* at the lower side of a leaf: light eggs (a, б) – the eggs were laid recently; dark eggs (в) – caterpillars are ready to hatch from the eggs (original)

old of harmfulness (ETH) of the corn borer differs depending on the intended use of corn: 1.0–2.0 egg layings/100 plants – when grown for grain and 2.0–4.0 egg layings/100 plants – for green mass<sup>5</sup>.

## CONCLUSION

The research revealed:

– the use of all the drugs used in integration with entomophages leads to a reduction in damage to corn plants by pests;

– the minimum damage score for *Zea mays* is shown by the options Proclaim, WSG + a double release of entomophage – 0.2 and Biokill, EC + a single release of the parasitoid – 0.3;

– the greatest increase in grain per cob (21 g) in relation to the control is observed in the variant with the use of Proclaim, WSG – 0.2 kg/ha + a double release of the entomophage;

– the best biological effectiveness against *Ostrinia furnacalis* G. is demonstrated by the biological product Proclaim, WSG – 0.2 kg/ha with a double release of *H. hebetor*.

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## Сравнительный посев и преимущество фестулолиума перед основными злаковыми травами в лесостепи Западной Сибири

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В лесостепной зоне Западной Сибири доказана возможность использования фестулолиума на кормовые цели как в одновидовых посевах, так и в составе травосмесей с многолетними бобовыми травами. Исследования проводили в 2021–2023 гг. на научно-экспериментальном стационаре, расположенном в Новосибирской области. В полевом опыте представлены коострец безостый Рассвет, райграсс пастбищный ВИК 66, овсяница красная Максима 1, фестулолиум ВИК 90, эспарцет песчаный СибНИИК 30, клевер белый Ривендел. Установлено, что наибольшей зимостойкостью среди злаковых многолетних трав выделялись фестулолиум и овсяница красная (99%). При пастбищном использовании одновидовых посевов многолетних злаковых трав наибольшая урожайность сухой массы получена у коостреца безостого – 31,9 ц/га, при внесении минеральных удобрений  $N_{14}P_{60}K_{60}$  – 46,0 ц/га. Незначительно (на 8–12%) уступает ему фестулолиум, где сбор сухой массы составил 28,2 ц/га без внесения минеральных удобрений и 42,8 ц/га при их внесении. Наименьшая урожайность сухой массы получена на варианте с посевом райграсса пастбищного – 23,1 и 30,4 ц/га соответственно. В смешанных травостоях многолетних злаковых трав с бобовыми наибольшая урожайность сухой массы получена в смеси коострец безостый + эспарцет песчаный + фестулолиум – 35,7 ц/га, при внесении минеральных удобрений  $N_{14}P_{60}K_{60}$  – 47,2 ц/га. Внесение минеральных удобрений в травосмесях дало прибавку урожайности 33–35%. Среди многолетних злаковых трав наибольшее содержание переваримого протеина на 1 к. ед. было у фестулолиума – 116 г, наименьшее – у райграсса пастбищного – 107 г.

**Ключевые слова:** фестулолиум, многолетние травы, минеральное удобрение, урожайность, продуктивность, травосмесь, пастбище

## Comparative sowing and the advantage of festulolium over the main cereal grasses in the forest-steppe of Western Siberia

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In the forest-steppe zone of Western Siberia, the possibility of using festulolium for fodder purposes has been proven, both in single-species crops and in grass mixtures with perennial leguminous grasses. The research was conducted in 2021–2023 at a scientific and experimental station located in the Novosibirsk region. The field experiment includes the following species: awnless brome Rassvet, perennial ryegrass VIK 66, red fescue Maksima 1, festulolium VIK 90, Hungarian sainfoin SibNIIC 30, and white clover Rivendel. It has been established that festulolium and red fescue (99%) stood out as the most winter-hardy among perennial grasses. When using single-species perennial grass crops for grazing, the highest dry matter yield was obtained from awnless brome grass – 31.9 c/ha, with the application of  $N_{14}P_{60}K_{60}$  mineral fertilizers – 46.0 c/ha. Festulolium is slightly inferior (by 8–12%) to

it, with a dry matter yield of 28.2 c/ha without mineral fertilizers and 42.8 c/ha with mineral fertilizers. The lowest dry matter yield was obtained in the variant with perennial ryegrass sowing – 23.1 and 30.4 c/ha, respectively. In mixed stands of perennial grasses and legumes, the highest dry matter yield was obtained in a mixture of awnless brome, Hungarian sainfoin and festulolium – 35.7 c/ha, with the application of mineral fertilizers  $N_{14}P_{60}K_{60}$  – 47.2 c/ha. The application of mineral fertilizers in grass mixtures resulted in a 33–35% increase in yield. Among perennial grasses, festulolium had the highest digestible protein content per 1 feed unit (116 g), while perennial ryegrass had the lowest (107 g).

**Keywords:** festulolium, perennial grasses, mineral fertilizer, yield, productivity, grass mixture, pasture

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#### Conflict of interest

The authors declare no conflict of interest.

## INTRODUCTION

New species and varieties of forage crops are becoming increasingly important, boasting higher and more stable yields, high energy and protein content compared to traditional varieties. Intergeneric and interspecific hybrid varieties are of great importance for forage use, including festulolium (*Festulolium* F. Aschers. Et Graebn.), hybrids of *Lolium* sp. and *Festuca* sp. It has high energy and protein content, combining the high shoot formation capacity of ryegrass with the high winter hardiness of fescue grass<sup>1,2</sup> [1].

The use of festulolium in forage production in Western Siberia is of particular interest, as it is a new and promising crop for the region, but understudied. Its advantages over traditionally cultivated brome, fescue, and ryegrass include high winter hardiness, aftergrowth, and nutri-

tional value. Based on these combined characteristics, festulolium can meet the high demands of production while creating a high-quality forage base<sup>3</sup> (see footnote 2) [2].

Due to high tillering and the ability to produce numerous leafy shoots, hay made from such grass stands has a pleasant aroma and a green color, which improves animal consumption and milk production. A uniform supply of green material throughout the season allows for the preparation of various types of forage, as well as for grazing<sup>4-6</sup> [3–5].

When creating pastures, it's important to select the right crops to create a balanced grass stand, ensuring productive longevity, high yields, and crop aftergrowth after animal grazing, as well as resistance to trampling. Festulolium counteracts pasture soil compaction due to differences in root system architecture compared to ryegrass and fescue [6]. Positive results from its use in

<sup>1</sup>Zolotarev V.N., Perepravo N.I. Distinctive features of fescue-ryegrass hybrid varieties when grown for seeds // New and non-traditional plants and prospects for their use, 2016, N 12, pp. 314–317.

<sup>2</sup>Bezgodov A.V., Belyaev A.V., Ponomarev A.B. New species and varieties of perennial cereal grasses in the Middle Urals for haymaking and pasture use // Innovative technologies in science and education, 2016, N 4 (8), pp. 199–207.

<sup>3</sup>Platace R. Ligning and ash content correlations in grass biomass pellets / R. Platace, A. Adamovics // 14th International Multidisciplinary Scientific Geoconference: Albena, Bulgaria: Bulgarian Acad Sci., 2014, pp. 331–338.

<sup>4</sup>Mashyanov M.A., Ganicheva V.V. Dependence of herbage yield on the included species of meadow plants in the soil and climatic conditions of the Vologda region // Dairy Bulletin, 2012, N 1 (5), pp. 21–27.

<sup>5</sup>Ostrem L., Volden B., Steinshamn H. Festulolium fibre characteristics and digestibility as affected by maturity // Grass and forage science, 2015, vol. 70 (2), pp. 341–352.

<sup>6</sup>Sanderson M.A., Stout R., Brink G. Productivity, botanical composition, and nutritive value of commercial pasture mixtures // Agronomy journal, 2016, vol. 108 (1), pp. 93–100.

creating seeded pastures have been obtained in the European part of Russia and the Ural region [7–10].

The importance and relevance of such research in Western Siberia are noted in the work of N.I. Kashevarova [11]. The conducted research has proven the effectiveness of joint sowing of festulolium with perennial legumes such as alfalfa, sainfoin and clover to obtain high-quality forage in arable land [12, 13]. However, no one has addressed the issue of cultivating festulolium in a mixture with other grasses in hayfields and pastures in Siberia. Festulolium is a high-yielding, nutritious crop that is flexible to growing conditions and can not only expand the species composition of forage plants, but also significantly improve the forage base in the region in the long term. However, it is not widespread in Western Siberia.

## MATERIAL AND METHODS

The research was conducted from 2021 to 2023 at the experimental research station of the Siberian Research Institute of Fodder Crops of the Siberian Federal Scientific Center of Agro-BioTechnologies (SFSCA) of the Russian Academy of Sciences. The experimental field is located in the forest-steppe of the Ob region, which is part of the forest-steppe zone of the West Siberian region<sup>7</sup>.

The climate of the zone is sharply continental with relatively short summers and long, cold winters. The average annual precipitation is 392 mm, of which 254 mm (66%) falls in April–September, 181 mm in June–August, and 138 mm in November–March (17–20%). The probability of wet years ( $HTC > 1.4$ ) is 10–25%, and dry years ( $HTC < 0.6$ ) is 40–65%<sup>8</sup>.

The soil of the experimental plot is zonal – leached chernozem, medium-deep, medium-humus, medium-loamy, the humus content in the arable layer is 6.6%. According to Chirikov, the soil in the 0–20 cm layer is characterized by a high supply of mobile phosphorus (22 mg/100 g) and exchangeable potassium (21.4 mg/100 g). The reaction of the soil solution is slightly al-

kaline – 7.4. The sum of absorbed bases is 32.6 mmol (eq.) / 100 g, the soil density in the 0–20 and 20–40 cm layers is 1.16 and 1.22 g / cm<sup>3</sup>, respectively, the permanent wilting point is 10.2 and 8.0 mm. Groundwater was not detected to a depth of 5 m (see footnote 7).

Moisture availability during the 2021 growing season was insufficient ( $HTC$  May–September = 1.0), particularly in May ( $HTC = 0.56$ ) and July ( $HTC = 0.36$ ), with increased availability in June ( $HTC = 1.49$ ) and September ( $HTC = 1.44$ ). Air temperatures in May and August were 3.5 and 1.7°C above normal, respectively.

During the 2022 growing season, precipitation totaled 130 mm ( $HTC = 0.6$ ), consistent with arid conditions. Precipitation was distributed unevenly: 2.5 mm fell in May (7% of the norm), 59 mm in June (107%), 29 mm in July (47%), and 23 mm in August (34%). The total temperature above 10°C from May to August was 2090°C. During the summer months, air temperatures were at the long-term average, with only May being 4.3°C higher.

Growing season conditions in 2023 were atypical due to uneven precipitation. From May to September, 250.5 mm of precipitation fell ( $HTC = 0.99$ ), and the sum of temperatures above 10°C was 2502°C. In May, 5.5 mm of precipitation fell (14.8% of the long-term average), while the average daily air temperature was 2.3°C above normal. Precipitation in June was 47% of normal, or 26.1 mm, with temperatures 1.9°C above normal. In July, 62.3 mm of precipitation fell (102% of normal). Productive moisture reserves in the one-meter soil layer on July 7 were assessed as very poor.

Thus, the agroclimatic potential of the forest-steppe zone of Western Siberia is characterized by increased instability. It largely depends on the amount of precipitation, the uniformity of its distribution, and the temperature regime during the growing season, which are among the most important factors limiting the yield and its quality.

*Experiment 1. The influence of mineral fertilizers on the yield of perennial cereal grasses*

<sup>7</sup>Soil and Climatic Atlas of the Novosibirsk Region. Novosibirsk: Nauka, 1978, 121 p.

<sup>8</sup>Agroclimatic resources of the Novosibirsk region. Moscow: Gidrometeoizdat, 1971, 155 p.

Factor A – cultures, kg/ha: awnless brome – 20; perennial ryegrass – 15; red fescue – 15; festulolium – 18.

Factor B – fertilizers: without fertilizers; application of  $N_{14}P_{60}K_{60}$ .

*Experiment 2. The influence of the composition of the grass mixture and mineral fertilizers on the yield of perennial grasses*

Factor A – mixed grass crops, kg/ha: awnless brome (7) + white clover (3) + perennial ryegrass (5); awnless brome (7) + white clover (3) + red fescue (5); awnless brome (7) + white clover (3) + festulolium (6); awnless brome (7) + Hungarian sainfoin (30) + festulolium (6); awnless brome (7) + Hungarian sainfoin (30) + perennial ryegrass (5).

Factor B – fertilizers: without fertilizers; application of  $N_{14}P_{60}K_{60}$ .

Seeding was carried out using autumn plowing. Prior to seeding, the soil was cultivated with a KPS-4.2 soil cultivator, followed by rolling with a ZKKSh-6 star-wheeled roller. Perennial grasses were seeded in the second ten-day period of July 2022 using a SN-16 seeder to a depth of 2–3 cm. Coverless seeding was used. As weeds grew, they were mown with a rotary mower.

The field experiment included awnless brome Rassvet, perennial ryegrass VIK 66, red fescue Maxima 1, festulolium VIK 90, Hungarian sainfoin SibNIK 30, white clover Rivendel.

On half of the plots, mineral fertilizer was applied at a dose of  $N_{14}P_{60}K_{60}$  annually in the spring before the growth of perennial grasses, followed by harrowing with BZTS-1.0.

**RESULTS AND DISCUSSION**

A comparative analysis of the yields of the main grasses used for forage in the forest-steppe of Western Siberia revealed that festulolium yielded the highest green and dry matter yields—32.0 and 5.5 t/ha, respectively (see Table 1). Compared to its parental forms (ryegrass and fescue), the yield increased by 12.5–28.0% in green matter and 2.4–5.0% in dry matter.

The research results demonstrated the potential of festulolium for forage production in the forest-steppe conditions of Western Siberia. Festulolium yields were 45% higher (10.0 t/ha) than

those of awnless brome grass, the most common perennial grass in the forest-steppe zone of Western Siberia.

The highest germination rates were obtained for perennial ryegrass (754 shoots/m<sup>2</sup>), while the lowest were shown by festulolium (502 shoots/m<sup>2</sup>). The perennial grass plants had high winter hardiness – 97–99% (see Table 2).

A simulated grazing study of perennial grass stands using mowing showed that the highest dry matter yield, totaling 31.9 c/ha, was obtained with awnless brome grass after four cuttings. Other grasses significantly reduced their yields: festulolium by 12% (28.2 c/ha), red fescue by 13% (27.8 c/ha), and perennial ryegrass by 28% (23.1 c/ha) (see Table 3).

Application of mineral fertilizers at a dose of  $N_{14}P_{60}K_{60}$  increased grass yields by an average of 44% (to 30.4–46.0 centners of dry matter/ha), with the highest yields observed in awnless brome grass and festulolium. Dry matter yields in perennial ryegrass and red fescue significantly decreased by 12–34%.

The main dry matter yield was obtained during the second and third grazing from July 17 to September 2, which amounted to 67% of the total yield in the variants without applying fertilizers, and with fertilizer application – 61%.

The high yield of festulolium and the feasibility of its cultivation in Siberia suggest the feasibility of its cultivation in a mixture with

**Табл. 1.** Урожайность многолетних злаковых трав, скошенных в фазе колошение (2021 г.), т/га

**Table 1.** Yield of perennial grasses mown in the earing phase (2021), t/ha

Culture	Green mass yield	Dry matter, %	Collection of absolutely dry matter
Awnless brome	22,0	19,5	4,29
Timothy grass	24,0	17,4	4,18
Common ryegrass	28,0	19,2	5,37
Festulolium	32,0	17,2	5,50
Meadow fescue grass	23,0	22,8	5,24
LSD <sub>05</sub>	3,1		

legumes for forage. In the mixtures consisting of two cereals and one legume, the highest dry matter yield over four grazing runs was achieved without fertilizer in the combination of awnless brome + sandy sainfoin + festulolium – 35.7 c/ha. The application of mineral fertilizers at a

dose of  $N_{14}P_{60}K_{60}$  increased the yield by 32% – to 47.2 c/ha (see Table 4, the figure).

The awnless brome + white clover + festulolium variant showed slightly lower yields. The total dry matter yield after four grazings was 33.1 c/ha, while with the addition of mineral fertilizers at a dose of  $N_{14}P_{60}K_{60}$  it was 44.6 c/ha. The lowest total dry matter yield after four grazings was obtained in the awnless brome + white clover + perennial ryegrass variant – 30.3 c/ha, while with the addition of mineral fertilizers at a dose of  $N_{14}P_{60}K_{60}$  it was 40.7 c/ha. The addition of mineral fertilizers at a dose of  $N_{14}P_{60}K_{60}$  resulted in a 33–35% yield increase in the experimental variants.

Biochemical analysis of the dry mass of perennial cereal grasses showed that the crude protein content in the feed was 8.61–10.26%, the yield of feed units was 2.16–3.27 thousand, crude protein was 2.9–4.4 centners, digestible protein was 2.32–3.52 centners, and digestible

**Табл. 2.** Густота травостоя многолетних злаковых трав и зимостойкость (2022–2023 гг.), шт./м<sup>2</sup>  
**Table 2.** Herbage density of perennial grasses and winter hardiness (2022–2023), pcs/m<sup>2</sup>

Culture	Autumn	Spring	Winter hardiness, %
Awnless brome	482	469	97
Common ryegrass	754	741	98
Red fescue grass	522	516	99
Festulolium	502	496	99
LSD <sub>05</sub>	62,4	61,7	

**Табл. 3.** Урожайность сухой массы многолетних злаковых трав в зависимости от внесения удобрений (среднее за 2023–2024 гг.), ц/га

**Table 3.** Yield of dry weight of perennial grasses depending on fertilizer application (average for 2023–2024), c/ha

Culture	Bleeding				The sum for four bleedings
	first (30.05.24)	second (17.07.24)	third (02.09.24)	fourth (16.10.24)	
<i>Without fertilizers</i>					
Awnless brome	6,5	10,2	10,9	4,3	31,9
Common ryegrass	3,9	7,6	8,2	3,4	23,1
Red fescue grass	5,5	9,1	9,6	3,6	27,8
Festulolium	5,5	9,0	9,9	3,8	28,2
Average	5,4	9,0	9,7	3,8	27,8
LSD <sub>05</sub>	0,5	0,9	0,9	0,4	2,6
<i>Application of <math>N_{14}P_{60}K_{60}</math></i>					
Awnless brome	8,3	13,1	14,5	5,7	46,0
Common ryegrass	5,5	9,4	10,7	4,5	30,4
Red fescue grass	6,9	11,4	12,7	4,9	40,3
Festulolium	7,7	12,1	13,1	5,3	42,8
Average	7,1	11,5	12,8	5,1	39,9
LSD <sub>05</sub>	0,7	1,1	1,2	0,5	4,1

protein per 1 feed unit was 107–116 g (see Table 5).

Among perennial cereal grasses, the highest provision of 1 fodder unit of digestible protein was found in festulolium and red fescue (up to 116 g), the lowest – in perennial ryegrass and awnless brome grass (up to 108 g).

Thus, festulolium crops, slightly inferior to awnless brome in terms of dry matter yield, surpass it in terms of digestible protein content per 1 fodder unit and can be used to create cereal-legume grass stands in pastures.

### CONCLUSIONS

1. In the forest-steppe zone of Western Siberia, the potential for using festulolium for forage has been proven, both in single-species crops and in the mixtures with perennial legumes. Festulolium and red fescue have demonstrated the highest winter hardiness of perennial grasses – 99%.

2. In a single-species perennial grass crop, awnless brome grass achieved the highest dry matter yield over four grazing sessions: 31.9 c/ha. The application of mineral fertilizers at a dose of  $N_{14}P_{60}K_{60}$  increased the yield by 44% (to 46.0 c/ha).

3. The highest dry matter yield in the three-component mixture was obtained with awnless brome + Hungarian sainfoin + festulolium – 36.2 c/ha. With the addition of  $N_{14}P_{60}K_{60}$ , the dry matter yield increased by 12% to 40.4 c/ha.

4. The application of mineral fertilizers at a dose of  $N_{14}P_{60}K_{60}$  resulted in an increase in the yield of cereal-legume grass mixtures by 33–35%.

5. The highest supply of 1 fodder unit of digestible protein was found in festulolium and red fescue (up to 116 g), the lowest – in perennial ryegrass and awnless brome (up to 108 g).

**Табл. 4.** Урожайность сухой массы травосмесей многолетних трав (среднее за 2023–2024 гг.), ц/га  
**Table 4.** Yield of dry mass of perennial grass mixtures (average for 2023-2024), c/ha

Option	Bleeding				The sum for four bleedings
	first (30.05.24)	second (17.07.24)	third (02.09.24)	fourth (16.10.24)	
<i>Without fertilizers</i>					
Awnless brome + white clover + common ryegrass	6,0	9,2	10,9	4,3	30,3
Awnless brome + white clover + red fescue grass	6,3	9,5	11,3	4,6	31,6
Awnless brome + white clover + festulolium	6,6	10,0	11,6	5,0	33,1
Awnless brome + Hungarian sainfoin + festulolium	7,4	11,3	11,9	5,2	35,7
Awnless brome + Hungarian sainfoin + common ryegrass	6,9	10,2	10,8	4,7	32,6
LSD <sub>05</sub>	0,6	1,0	1,2	0,5	3,2
<i>Application of <math>N_{14}P_{60}K_{60}</math></i>					
Awnless brome + white clover + common ryegrass	8,2	12,2	14,9	5,4	40,7
Awnless brome + white clover + red fescue grass	8,5	12,5	15,4	5,8	42,2
Awnless brome + white clover + festulolium	8,8	13,4	16,0	6,4	44,6
Awnless brome + Hungarian sainfoin + festulolium	9,9	14,8	16,0	6,5	47,2
Awnless brome + Hungarian sainfoin + common ryegrass	9,2	13,6	15,1	5,8	43,7
LSD <sub>05</sub>	0,9	1,3	1,6	0,6	4,4

**Табл. 5.** Питательность и продуктивность травостоев многолетних злаковых трав при внесении минеральных удобрений N<sub>14</sub>P<sub>60</sub>K<sub>60</sub> (2024 г.)

**Table 5.** Nutritional value and productivity of perennial grasses when applying mineral fertilizers N<sub>14</sub>P<sub>60</sub>K<sub>60</sub> (2024)

Option	Content		Yield from 1 ha			Digestible protein per 1 k.u., g
	crude protein, %	feed units	feed units, thous.	crude protein, c	digestible protein, c	
Awnless brome	9,53	0,71	3,27	4,4	3,52	108
Common ryegrass	9,64	0,71	2,16	2,9	2,32	107
Red fescue grass	10,26	0,71	2,86	4,1	3,28	115
Festulolium	10,22	0,71	3,04	4,4	3,52	116
LSD <sub>05</sub>			0,3	0,3	0,3	



Травосмесь кострец безостый + эспарцет песчаный + фестулолиум

Grass mixture: awnless brome + Hungarian sainfoin + festulolium

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## Влияние ламинарии на обмен веществ и энергии у молодняка лошадей якутской породы

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Представлен анализ эффекта добавления ламинарии в рацион молодняка лошадей якутской породы на обмен веществ и энергии. Показано, что молодняк опытной группы, получавший ламинарию в рационе, демонстрировал более высокое использование кальция и фосфора с увеличением их содержания в организме на 3,98 и 1,64% соответственно. Это указывает на улучшенное усвоение основных питательных веществ. Отмечено, что хотя количество валовой энергии, потребленной молодняками опытной и контрольной групп, было сравнительно равно, обменная валовая энергия у молодняка опытной группы была выше на 1,16%, что свидетельствует о более эффективном использовании энергии в организме. Молодняк контрольной группы уступал аналогам опытной группы по величине коэффициента переваримости сырой клетчатки на 1,8%, переваримости сухого вещества – на 1,4%, органического вещества – на 1,9% и БЭВ – на 5,5% ( $P \geq 0,95$ ). Также отмечена динамика живой массы. В начале эксперимента живая масса молодняка в обеих группах была примерно одинакова, но к концу эксперимента животные опытной группы продемонстрировали более интенсивный рост, увеличившись на 5,20 кг по сравнению с 3,67 кг у контрольной группы. Результаты исследований свидетельствуют о прямом влиянии добавки ламинарии на интенсивность роста и обмен веществ у молодняка лошадей. Добавление ламинарии в рацион способствует более эффективному использованию кальция и фосфора, лучшему усвоению питательных веществ, повышению обменной энергии и интенсивному росту животных. Эти факторы могут иметь важное значение при планировании кормления и ухода за молодняком лошадей для достижения оптимальных показателей роста и развития.

**Ключевые слова:** физиологический опыт, переваримость питательных веществ кормов, ламинария, лошади, якутская порода

## The effect of kelp on metabolism and energy exchange in young horses of the Yakutian breed

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The analysis of the effect of adding kelp to the diet of young horses of the Yakutian breed on metabolism and energy is presented. It was shown that young animals in the experimental group that received laminaria in their diet demonstrated higher utilization of calcium and phosphorus, with an increase in their content in the body by 3.98% and 1.64%, respectively. This indicates an improved absorption of essential nutrients. It was noted that although the amount of gross energy consumed by the young animals in the experimental and control groups was relatively equal, the gross energy metabo-

lism in the young animals in the experimental group was 1.16% higher, which indicates more efficient use of energy in the body. The young animals in the control group were inferior to their counterparts in the experimental group in terms of the digestibility coefficient of crude fiber (by 1.8%), dry matter (by 1.4%), organic matter (by 1.9%), and nitrogen-free extractive substances (by 5.5%) ( $P \geq 0.95$ ). The dynamics of live weight was also marked. At the beginning of the experiment, live weight of young animals in both groups was approximately the same, but by the end of the experiment, animals in the experimental group showed more intensive growth, increasing by 5.20 kg compared to 3.67 kg in the control group. The results of the studies indicate a direct effect of kelp supplementation on the growth rate and metabolism of young horses. Adding kelp to the diet promotes more efficient use of calcium and phosphorus, improves nutrient absorption, increases metabolic energy, and promotes intensive animal growth. These factors can be important when planning the feeding and care of young horses to achieve optimal growth and development.

**Keywords:** physiological experience, digestibility of feed nutrients, luminaria, horses, Yakutian breed

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Авторы заявляют об отсутствии конфликта интересов.

#### Conflict of interest

The authors declare no conflict of interest.

## INTRODUCTION

The first studies into the energy needs of Yakut horses, the mineral content of pasture plants, and the blood of horses were made by A.F. Abramov (1978). His findings showed that in winter, the Yakut horses' bodies experience a deficiency of many macro- and microelements.

In our research, we conducted a series of experiments to study metabolism in young horses. Eight experiments on the digestibility and balance of nitrogen, calcium, and phosphorus were conducted on the same horses, aged from 9 months to 3.5 years. Also, changes in the biochemical composition and natural resistance parameters of the blood of young horses aged 3 to 24 months, collecting blood samples monthly until 12 months of age and then at 19 and 24 months were analyzed.

Previously, our ancestors (Sakha) sold adult animals to collective farms before slaughter for meat. However, in the republic's horse breeding industry, based on the principle of "feed conservation," a decision was made to sell foals (at 6 months of age) and cull adult horses for meat

production, which led to a decrease in meat production per horse.

In this regard, we propose to continue our research to improve the methods of keeping and feeding young horses up to 1.5 years of age.

One of the key areas of further research is the analysis of the nutritional value of locally grown feeds in the region and the development of optimal feeding schemes based on this data. This will optimize feeding processes and improve the production efficiency of horse breeding (N.D. Alekseev (1979, 2006), N.P. Stepanov (2006), A.F. Abramov (1993)).

In addition, we will study the influence of various environmental factors, climate, and genetic characteristics of horses on their nutrient requirements. This will help develop personalized approaches to feeding animals based on their specific living conditions.

A.F. Abramov (1993) notes in his research that Yakut horses are significantly deficient in macro- and micronutrients, citing data from studies of horses from other regions. However, the nutritional needs of the Yakutian breed horses have not been adequately studied.

It is important to note that many researchers are studying the effectiveness of using both traditional and non-traditional feed additives in horse diets [1–5].

J. Montgomery et al. [6] fed hay enriched with selenium in their studies. The horses fed hay enriched with selenium had higher plasma selenium concentrations than the horses receiving a trace element complex containing selenium or the horses not receiving additional selenium ( $P < 0.0001$ ). The mean plasma selenium concentrations were within the reference range considered sufficient ( $>0.14$  mg/kg) for these horses.

Foreign authors also note that supplementation with synthetic vitamins does not have a significant effect on their concentration in the blood serum of horses kept on pasture<sup>1</sup>.

The study comparing the bioavailability of various organic micro- and macronutrients in cattle, sheep, and horses found that these compounds were quite effective in increasing serum levels of these elements<sup>2</sup>.

In the study by A.A. Slinkin et al. [7] on the feeding of Bashkir horses, it is also noted that in order to achieve high productivity of horses, the diet must be balanced in accordance with established feeding standards.

This indicates that organic feed additives enriched with various micro- and macroelements have greater bioavailability than vitamin-mineral complexes when used in feeding farm animals.

The studies mentioned above highlight the need not only to meet nutrient requirements but also to select optimal sources of these elements for maximum absorption by the animal's body. The development of feeding rations should consider not only quantitative but also qualitative aspects of feed composition.

Therefore, further research is needed to optimize the feeding ration for the Yakutian breed

horses. This includes analyzing the content of both macro- and microelements in the rations, studying the effect of various additives and mineral supplements on the blood microelement levels of the animals, and determining the requirements of Yakutian breed horses for these elements under various conditions [8, 9].

Additionally, it is necessary to conduct research to assess the digestibility and bioavailability of macro- and microelements from various feed sources, such as hay, grains, mineral supplements, etc. This will allow for the optimization of diet composition and ensure sufficient intake of the necessary elements to maintain health and improve the performance of horses.

This comprehensive study will help better understand which mineral elements are critical for the Yakutian horses.

It's also important to consider various horse-rearing conditions, such as climate, to help tailor feeding rations to the animals' specific needs and ensure optimal health and productivity.

Seaweed is widely used in the food industry in various countries, including Japan, China, and other regions. Although it has little nutritional value for humans, it has long been used as a feed supplement for livestock, especially during the winter. Seaweed can be considered an alternative to traditional feed sources.

Due to its unique biochemical composition, kelp has attracted attention as a potential animal feed supplement. It contains all the necessary trace elements in organic form, B vitamins, and essential amino acids. It is worth noting that kelp contains a significant amount of easily digestible iodine. These properties make it an attractive choice for improving the quality of animal feed. Iodine plays a vital role in the growth and development of young horses. Iodine deficiency in feed and water should be compensated for with special mineral supplements<sup>3</sup>.

<sup>1</sup>Saastamoinen M., Juusela J. Influence of dietary supplementation on serum vitamin A and D concentrations and their seasonal variation in horses // *Agricultural Science in Finland. Agricultural Research Centre of Finland, The Scientific Agricultural Society of Finland, The Finnish Society of Dairy Science*. 1992, N 1(5), pp. 477–482.

<sup>2</sup>Podoll K.L., Bernard J.B., Ullrey D.E., DeBar S.R., Ku P.K., Magee W.T. 1992. Dietary selenate versus selenite for cattle, sheep, and horses // *Journal of Animal Science*, N 70 (6), pp. 1965–1970. DOI: 10.2527/1992.7061965x.

<sup>3</sup>Babukhadia K.R., Sharvadze R.L., Elizaryev A.A. Use of Japanese Laminaria together with biologically active substances in feeding young chickens // *Problems of zootechnics, veterinary science and animal biology in the Far East: Collection of scientific papers* / Ed. V.A. Ryzhkov. Blagoveshchensk: Far Eastern State Agrarian University, 2015, Issue 22, pp. 39–48.

Professor Sauvageau's<sup>4</sup> noted in his monograph "Utilization of Marine Algae" that French horses successfully supplemented their diet with seaweed during the war. Initially, it was difficult to digest, but gradually became more digestible, likely due to the action of microorganisms.

Despite its potential benefits, the issue of nutrient absorption by animals using kelp remains poorly understood in the literature. Currently, there are no specific regulations for adding kelp to horse feed. Kelp can be added to concentrated feed or included in premix supplements to make it more readily available to horses.

The purpose of the study was to evaluate the effect of adding kelp to the diet of young Yakutian breed horses on metabolism and energy.

## MATERIAL AND METHODS

The scientific study was conducted from March to April in the Amginsky ulus (small innovative enterprise "EJYE" farm) in 2019. The experimental period lasted 21 days.

The study included a nutrient digestibility analysis using the methodology described by A.I. Ovsyannikov (1976). The subjects of the study were young 2.5-year-old Yakutian breed horses. Two groups were created for the experiment using the analog-pair method: a control group and an experimental group. The groups were formed based on age, origin, live weight, and body condition, with differences not exceeding 10%.

The animals were fed twice daily—morning and evening—and consumed the entire diet. The groups were housed in a stable pen throughout the experimental period. The control group consumed a basic diet consisting of 9.0 kg of hay and 3 kg of oats, while the experimental group, in addition to the basic diet, received 150 g of kelp for every 3 kg of oats per animal.

At the beginning and end of the experiment, the animals were weighed and their key morphometric parameters (height at the withers, oblique body length, and chest girth) were measured. At the end of the experiment, feed and fecal samples were collected for nutrient digestibility analysis. Sample collection and storage were carried out in accordance with established procedures<sup>5</sup>.

The needs of horses were calculated using the formulas proposed by A.N. Kosharov et al.<sup>6</sup>.

The requirement of horses for digestible protein to maintain life was calculated using the calculation methods developed by V.N. Kalashnikov, I.F. Draganov and V.G. Memedeikin (2010).

## RESULTS AND DISCUSSION

The chemical composition of the diets of young horses of the Yakutian breed aged 2.5 years in the winter-spring experiment is presented in Table 1.

A comparative analysis of the chemical composition of hay and a combination of oats with kelp revealed significant differences between them in the content of phosphorus (by 48%), calcium (by 15.35%), potassium (by 39%) and iodine (by 45.4%) ( $P \geq 0,95$ ).

Having analyzed the composition and volume of feed consumed, we calculated the amount of nutrients received by the animals studied per day (see Table 2).

From Table 2 it can be seen that the amount of dry organic matter, crude protein, crude fat and NFES consumed by animals in both groups was approximately the same.

Data obtained during a scientific and farming experiment indicate that the animals fed with the kelp feed supplement digested the greatest amount of nutrients from their diets. Moreover, young animals from the experimental groups outdid their counterparts from the control group

<sup>4</sup>Sauvageau C. The Use of Marine Algae Paris: Librairie Octave Doin, 1920, 394 p.

<sup>5</sup>Ovsyannikov A.I. Basics of experimental work in animal husbandry. Moscow: Kolos, 1976, pp. 281–293.

<sup>6</sup>Kosharov A.N. Theoretical justification and recommendations for the application of new feeding standards for horses / A.N. Kosharov, S.T. Ugadchikov, V.G. Memedeikin // Improving the selection of horse breeds: Collection of scientific papers. Moscow: VNIK, 1983, pp. 79–103.

in digesting dry matter by 178.3 g (2.22%), organic matter by 161.1 g (2.13%), protein by 19.2 g (1.09%), fat by 7.1 g (2.46%), and fiber by 146.3 g (6.65%) (see Table 3).

During the experiment, a comparatively high nutrient intake was observed in the experimental group of young horses, which resulted in higher digestibility coefficients of essential nu-

**Табл. 1.** Химический состав кормов  
**Table 1.** Chemical composition of feeds

Indicator	Chemical composition		
	hay	oat	oat + kelp
Water	4,58 ± 0,20	4,39 ± 0,13	11,97 ± 0,47
Crude protein	13,0 ± 0,78	20,43 ± 0,35	7,70 ± 0,91
Crude fat	1,62 ± 0,09	2,95 ± 0,22	1,50 ± 0,15
Crude fiber	41,70 ± 0,21	14,06 ± 0,11	10,60 ± 0,49
NFES	34,22 ± 1,26	51,94 ± 0,44	34,22 ± 1,26
Crude ash	4,98 ± 0,09	2,87 ± 0,05	6,61 ± 0,07
P, mg/100 g	200,4 ± 0,01	322,28 ± 9,42	345,28 ± 0,785*
Ca, mg/100 g	54,4 ± 0,04	60,8 ± 1,67	64,27 ± 0,663*
K, mg/100 g	216,1 ± 0,12	319,09 ± 14,66	354,88 ± 5,78*
Na, mg/100 g	21,0 ± 0,02	31,37 ± 1,046	33,92 ± 0,416
Mg, mg/100 g	–	106,14 ± 4,71	117,64 ± 1,86*
Fe, mg/kg	–	32,59 ± 1,98	37,45 ± 3,72
I, mcg /100 g	2,6 ± 0,03	3,612 ± 0,472	4,762 ± 0,186*

Note. Here and in Tables 3, 5, 7:  
\* $P \geq 0,95$ .

**Табл. 2.** Количество питательных веществ, потребленных молодняком в 2,5 года (в среднем на одно животное в сутки), г

**Table 2.** Amount of the nutrients consumed by 2.5-year-old youngstock (per animal per day), g

Indicator	Group	
	control	experimental
Dry matter	12259,6 ± 12,40	12265,0 ± 35,10
Organic matter	10829,6 ± 31,30	10746,7 ± 12,95
Crude protein	2318,4 ± 17,60	2344,2 ± 17,60
Crude fat	381,6 ± 7,10	399,1 ± 10,40
Crude fiber	4053,8 ± 88,70	4195,4 ± 22,70
NFES	4074,2 ± 92,30	3808,7 ± 52,70

trients. For example, the dry matter digestibility coefficient was  $65.5 \pm 0.08\%$ , which was 1.4% higher than in the control group, and the organic matter digestibility coefficient was  $70.1 \pm 0.20\%$ , exceeding the control group by 1.9%. It should be noted that the control group of young horses was inferior to the experimental group in terms of the crude fiber digestibility coefficient by 1.8% ( $P \geq 0.95$ ) and in terms of NFES by 5.5% ( $P \geq 0.95$ ).

The inclusion of kelp in the experimental group's diet had a positive effect on feed intake, digestibility, and nutrient availability. Similar data were obtained by Yu.A. Karmatskikh [10] in the studies examining the effect of bentonite on nutrient availability: a diet supplement-

ed with bentonite led to an increase in nutrient availability in mares and young Orlov Trotters.

Analysis of the calcium balance of young animals in the experimental group compared to the control group revealed more efficient utilization of both calcium and phosphorus in the body. The observed increase in calcium was 3.98%, and phosphorus was 1.64% compared to the control group. Furthermore, calcium absorption from feed intake exceeded that of the control group by 3.26%, and phosphorus absorption by 3.43%.

Employees of the All-Russian Research Institute of Horse Breeding of the Yakut Research Institute of Agriculture also noted that the introduction of feed additives, organic selenium,

**Табл. 3.** Коэффициенты переваримости основных питательных веществ рациона у молодняка в возрасте 2,5 года за период эксперимента, %

**Table 3.** Coefficients of digestibility of basic nutrients in the diet of 2.5-year-old youngstock over the experiment period, %

Indicator	Group	
	control	experimental
Dry matter	$64,1 \pm 0,06$	$65,5 \pm 0,08^*$
Organic matter	$68,2 \pm 0,17$	$70,1 \pm 0,20^*$
Crude protein	$75,0 \pm 0,08$	$74,8 \pm 0,20$
Crude fat	$73,6 \pm 0,32$	$72,1 \pm 0,50$
Crude fiber	$50,5 \pm 0,25$	$52,3 \pm 0,28^*$
NFES	$81,1 \pm 0,60$	$86,6 \pm 1,10^*$

**Табл. 4.** Использование кальция и фосфора в рационе молодняка лошадей якутской породы в возрасте 2,5 года за период эксперимента, г

**Table 4.** Utilization of calcium and phosphorus in the diet of 2.5-year-old youngstock of Yakutian Horse Breed over the experiment period, g

Indicator	Group	
	control	experimental
<i>Consumed in feed</i>		
Calcium	$64,19 \pm 2,50$	$67,26 \pm 1,13$
Phosphorus	$33,80 \pm 0,41$	$35,16 \pm 0,91$
<i>Excreted in feces</i>		
Calcium	$36,15 \pm 0,28$	$36,90 \pm 0,52$
Phosphorus	$23,0 \pm 0,01$	$23,04 \pm 0,35$
<i>Held in the body</i>		
Calcium	$26,89 \pm 1,28$	$30,37 \pm 1,57$
Phosphorus	$10,8 \pm 0,41$	$12,44 \pm 3,17$
<i>Used from the taken food, %</i>		
Calcium	41,89	45,15
Phosphorus	31,95	35,38

and mineral supplements based on local raw materials into the diets of mares and young animals contributes to a positive balance of nitrogen, calcium, and phosphorus and their greater deposition in the body [11–13].

The amount of gross energy consumed by young animals from both the experimental and control groups is relatively similar; however, the figures for young animals from the experimental group are only 0.3 MJ (0.14%) higher than those of the control group (see Table 5). Despite this, the metabolizable gross energy of young animals from the experimental group exceeds that of the control group by 1.16%. Differences in the expenditure of metabolizable energy for maintaining life between the groups were insignificant: in the experimental young animals it was  $35.5 \pm 0.41$  MJ, while in the control group it was  $35.4 \pm 0.32$  MJ.

Growth and development are interconnected processes that continuously interact with each other and manifest as a unity. Feeding is one of the key factors in the growth and development of an organism [14]. Feeding determines the development of an organism over time, as it represents the supply of substances that are converted into the body of animals. The composition of these substances, in addition to the structure of the diet, depends on their energy value and the quality of the nutrients included in it.

**Табл. 5.** Потребление и использование энергии молодняком лошадей якутской породы в возрасте 2,5 года в весеннем опыте, МДж

**Table 5.** Consumption and utilization of energy by 2.5-year-old youngstock of Yakutian Horse Breed in the spring experiment, MJ

Indicator	Group	
	experimental	control
Energy: gross digestible metabolizable	$214,3 \pm 1,12$	$214,6 \pm 2,14$
Including life support	$35,5 \pm 0,41$	$35,4 \pm 0,32$
Super-sustaining energy	$91,04 \pm 0,77$	$90,26 \pm 0,47^*$
Gross energy exchange, %	59,04	60,2

In winter, the growth of young Yakut sheep significantly slows as their body's energy is directed toward thermoregulation, which can lead to a decrease in live weight. Different feeding levels for growing animals have a significant impact on their growth and development. At the end of the winter-spring season, measurements of the animals' key parameters were taken before and after the kelp feeding experiment.

The study revealed a direct influence of feeding factors on the growth rate of the experimental young animals, which is clearly shown in Table 6. At the beginning of the experiment, the live weight of the young animals in the control and experimental groups was almost the same and amounted to  $298.08 \pm 5.86$  and  $299.67 \pm 2.35$  kg, respectively. By the end of the experiment, the live weight of animals in the control group increased by 3.67 kg and amounted to  $302.48 \pm 4.23$  kg, while in the experimental group, the live weight of young animals increased by 5.20 kg and amounted to  $304.87 \pm 2.85$  kg.

It is known that a deficiency of feed and individual nutrients in the diet can lead to slower growth and development of animals.

The conducted studies show that the young animals in the experimental group, which received a daily supplement of kelp to their main diet, demonstrated higher chest girth measurements by the end of the experimental period. The chest girth of the young animals in the experimental group was  $164.75 \pm 0.82$  cm, while that of the young animals in the control group was  $162.75 \pm 0.04$  cm. The difference in chest

**Табл. 6.** Живая масса молодняка лошадей якутской породы в возрасте 2,5 года за период опыта ( $n = 6$ )

**Table 6.** Live weight of 2.5-year-old youngstock of Yakutian Horse Breed over the experiment period ( $n = 6$ )

Live weight, kg	Group	
	control	experimental
Start of the experiment	$298,08 \pm 5,86$	$299,67 \pm 2,35$
End of the experiment	$302,48 \pm 4,23$	$304,87 \pm 2,85$

**Табл. 7.** Промеры молодняка якутской породы в возрасте 2,5 года за период опыта ( $n = 6$ )  
**Table 7.** Measurements of Yakutian Horse Breed youngstock at the age of 2.5 years old over the experiment period ( $n = 6$ )

Indicator	Group			
	control		experimental	
	Start of the experiment	End of the experiment	Start of the experiment	End of the experiment
HW, cm	132,98 ± 0,42	133,42 ± 1,22	133,08 ± 0,96	135,42 ± 0,86
OBL, cm	135,83 ± 1,16	137,58 ± 1,11	137,50 ± 1,08	139,0 ± 1,09
ChG, cm	160,08 ± 1,17	162,75 ± 0,04	160,98 ± 0,09	164,75 ± 0,82*

girth between the groups was 1.21%, with a significant difference ( $P \geq 0,95$ ).

Had the study continued for another month, the difference in body volume and weight would likely have been more significant. This indicates the potential long-term effects of kelp on the growth and development of young fish.

## CONCLUSION

Feeding young 2.5-year-old Yakutian breed horses hay and oats supplemented with kelp during the winter and spring can contribute to achieving relatively good animal productivity during the most challenging season of the year. This is confirmed by live weight gain data for the young animals in the experimental group.

The use of kelp in equine nutrition not only showed potential positive results in the study but also has potential practical applications in equine breeding. Further research could deepen our understanding of the mechanisms by which kelp affects equine metabolic processes and physiology, which, in turn, could lead to the development of more effective feeding methods and improved horse performance.

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Наряду с тракторами китайского производства на российский рынок стали поступать различные сельскохозяйственные машины из Китая. Проведен анализ технико-экономических показателей плугов китайского, российского производства и плугов ведущих западных брендов. Во время исследований использованы расчетный, расчетно-конструктивный, экономико-математический методы, а также методы сравнения, измерения, описания. Определены эксплуатационные свойства и оптимальный состав пахотных агрегатов в составе с тракторами различных производителей и тяговых классов с плугами китайского производства Optitech. На основании теоретических расчетов, проведенного тест-драйва сделан вывод о возможности эффективного использования трактора RSM-2375 с плугом Optitech PL 850 On land. Материалами для исследования послужили инструкции по эксплуатации плугов Optitech PL 850 различного исполнения с различными вариантами ширины захвата одного корпуса, а также инструкция по эксплуатации трактора RSM-2375. Сравнительный анализ эксплуатационных свойств пахотного агрегата при работе «вне борозды» и «в борозде» при определенном варианте балластирования провели во время тест-драйва с последующим сравнением с теоретическими исследованиями. Определены оптимальные составы пахотных агрегатов в составе с тракторами различных производителей и тяговых классов, подготовлены рекомендации по комплектованию агрегатов с плугами с различным количеством корпусов и различной шириной захвата одного корпуса. Перед тест-драйвом проведены теоретические расчеты по определению оптимальных эксплуатационных свойств трактора RSM-2375 при различных вариантах балластирования. Осуществлен сравнительный анализ пахотного агрегата при проведении тест-драйва и вариантами балластирования, произведены теоретические расчеты. Сельскохозяйственная техника китайского производства, в частности плуги, имеют все основания для использования в сельскохозяйственном производстве России.

**Ключевые слова:** эксплуатация, плуг, тяговое сопротивление, производительность, балластирование, тяговое усилие, эффективность

## Chinese agricultural machinery in Russian agriculture

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Along with Chinese-made tractors, various agricultural machines from China began to enter the Russian agricultural machinery market. Analysis of technical and economic indicators of Chinese and Russian plows and plows from leading Western brands has been made. During the research, computational, computational-constructive, economic-mathematical methods, as well as methods of comparison, measurement, and description were used. The operational properties and optimal composition of plowing units in combination with tractors from various manufacturers and traction classes with

Chinese-made Optitech plows have been determined. Based on theoretical calculations and test drives, it was concluded that the RSM-2375 tractor can be used effectively with the Optitech PL 850 On land plow. The materials used for the study were the operating instructions for Optitech PL 850 plows of various designs with different working widths for a single body, as well as the operating instructions for the RSM-2375 tractor. A comparative analysis of the operational properties of the plowing unit when working “outside the furrow” and “in the furrow” with a specific ballasting option was carried out during a test drive, followed by a comparison with theoretical studies. The optimal configurations of the plowing units have been determined for tractors of various manufacturers and traction classes, and recommendations have been prepared for assembling units with plows with different numbers of bodies and different working widths per body. Prior to the test drive, theoretical calculations were performed to determine the optimal operating characteristics of the RSM-2375 tractor under various ballasting conditions. A comparative analysis of the plowing unit was carried out during a test drive and with different ballasting options, and theoretical calculations were made. Chinese-made agricultural machinery, particularly plows, are well suited for use in Russian agricultural production.

**Keywords:** operation, plow, traction resistance, productivity, ballasting, traction force, efficiency

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**Conflict of interest**

The authors declare no conflict of interest.

## INTRODUCTION

Many scientists are working on the issues of efficient use of agricultural machinery in production, including foreign machinery. The main areas of research are substantiation of the objective necessity of agricultural cooperation between the People's Republic of China and the Russian Federation [1], changes in logistics chains in the formation of the machinery market [2–4], research into factors influencing the agricultural machinery market in Russia [5], problems of providing agricultural producers with machinery [6], and the efficiency of using agricultural machinery [7–13].

As a result of the departure of Western brands, a significant number of agricultural tractors from China have appeared on the market. In terms of engine power and traction properties, these are mainly tractors of traction classes 1.4; 2.0 and 3.0 tons; in 2024, tractors of traction class 4 tons will be presented. The first operating experience shows that Chinese-made tractors are not inferior, and in some cases surpass tractors of the Belarusian-Russian production in terms of operational properties, but are often inferior to them in terms of reliability.

Trailed, mounted, semi-mounted agricultural machines for soil cultivation have also begun to enter the Russian market of agricultural machinery from China: plows, disc harrows, grain and forage harvesters. Plows are being promoted to the Russian market especially actively.

The purpose of the study is to determine the optimal options for using Chinese-made plows.

The research objectives are to:

- carry out theoretical research to determine the optimal option for a unit with tractors of different traction classes;
- conduct a test drive to determine the main performance indicators of the plowing unit.

## MATERIAL AND METHODS

The study was conducted on the basis of technical and economic characteristics of agricultural tractors, plows using studies by the Russian, foreign authors and the author of this study. The following methods were used for the study: calculation, calculation and design, economic and mathematical, as well as methods of comparison, measurement, description.

## RESULTS AND DISCUSSION

To compare the technical and economic indicators of the ploughs, the characteristics of ploughs from Chinese, Russian and leading Western manufacturers are presented (see Table 1). The ploughs differ in operating weight and the required tractor engine power. For the Baichuan 1LFT-650Q and PPO-6 Dobrynya ploughs, the operating weight per 1 m of the plough working width is within the range of 1033–1160 kg, the designated tractor power per 1 m of the working width is within the range of 83.3–110 hp/m. The Jeegee 1LF-550, Jeegee 1LF-560, Long Feng Raptor 650 Optima, Lemken EurOpal 8, Lemken EurOpal 9 ploughs have an operating weight of 537–760 kg/m, and the designated tractor power is 66.7–100 hp/m. Chinese manufacturers also offer eight-body Jeegee 1LF-850 ploughs with a working width of one body from 33 to 50 cm (four positions), and their operating weight is 3600 kg.

Of particular interest are the Optitech (former AGCO-RM) ploughs with a number of bodies from 3 to 12 with a body width of 33 to 60 cm. The line of eight-body ploughs is represented by the Optitech PL 850 On land, Optitech PL 850, Optitech PL 850 L, Optitech PL 850 L On land brands, which differ in weight, body width, the ability to work both in the "furrow" and "out of the furrow" positions (PL 850 On land, PL 850 L On land) or only "in the furrow" (PL 850, PL 850 L). A special feature of these ploughs is that they can be used in versions with seven and eight bodies.

The Department of Service of Transport and Technological Machines and Equipment in the Agro-Industrial Complex of the Ural State Agrarian University has conducted theoretical studies on the formation of an optimal plowing unit from the presented ploughs in combination with various tractors. The hourly productivity and specific fuel consumption were taken as a basis.

**Табл. 1.** Основные характеристики плугов (число корпусов 6)<sup>1–6</sup>

**Table 1.** Main characteristics of the plows (the number of bodies is 6)<sup>1–6</sup>

Brand	Working width, cm		Operating weight, kg	Tractor capacity requirements, hp
	of the first body	of the plough		
Baichuan 1LFT-650Q	36/43/50	216–300	3450	300–330
Baichuan 1LFT-650Q	48/50/53	288–318	3690	310–350
Jeegee 1LF-550	33/38/44/50	198–300	1750	180–220
Jeegee 1LF-560	40/48/55/60	240–360	1960	180–240
Long Feng Raptor 650 Optima	35/40/45/50	210–300	2280	210–300
Lemken EurOpal 8	Steplessly variable 30–50	180–300	1610	up to 230
Lemken EurOpal 9	The same	180–300	1710	up to 250
PPO-6 Dobrynya	35/40/45/50	210–300	3098	150–250

<sup>1</sup>Plough BAICHUAN 1LFT-650. <https://agrosirius.ru/plug-agro-sirius-1lft-650?ysclid=m18lujzsq824117011> 18.09.2024.

<sup>2</sup>Mounted reversible plough Jeegee 1 LF-550. <https://jeegee.ru/plug-jeegeelk550/?ysclid=m18melbycz558592783> 18.09.2024.

<sup>3</sup>Mounted reversible plough Jeegee 1 LF-560. <https://jeegee.ru/plug-jeegee-lk560/> 18.09.2024.

<sup>4</sup>Mounted reversible plough Jeegee 1 LF-560. <https://jeegee.ru/plug-jeegee-lk560/> 18.09.2024.

<sup>5</sup>LONGFENG RAPTOR (mounted). [https://agro-nova.ru/catalog/navesnye/longfeng\\_raptor/?ysclid=m18mjpkc8w605268687](https://agro-nova.ru/catalog/navesnye/longfeng_raptor/?ysclid=m18mjpkc8w605268687) 18.09.2024.

<sup>6</sup>Semi-mounted reversible plough PPO-6 Dobrynya. <https://sel-teh.ru/oborotnyj-plug-ppo-6-dobrynya?ysclid=m1843id588644005658> 18.09.2024.

To calculate the traction resistance of PL 850 ploughs, the following initial data were adopted: plowing depth of 22 cm, specific soil resistance of 40 kN/m<sup>2</sup>, operating speed of the operation up to 12 km/h.

The traction resistance of the plough is determined by the formula

$$R_a = R_{IK} \times n + fm_3, \quad (1)$$

where  $R_{IK}$  – traction resistance, kN;  $n$  – number of bodies;  $f$  – rolling resistance coefficient of a plough;  $m_3$  – operating weight of a plough, kN.

The traction resistance of one body is determined by the formula

$$R_{IK} = abk, \quad (2)$$

where  $a$  – width of one body, m;  $b$  – processing depth, m;  $k$  – soil resistivity, kN/m<sup>2</sup>.

The Optitech PL 850 On land plough has a working width of 35/40/45/50 cm for one body, while the Optitech PL 850, Optitech PL 850 L, Optitech PL 850 L On land ploughs have a working width of 33/38/44/50 cm.

The working width and traction resistance of the plows with seven- and eight-body designs are presented in Table 2.

Using the data on traction resistance from Table 2, tractors with the appropriate traction force were selected, capable of effectively performing the technological operation of plowing in the corresponding gears, with a working speed that meets agrotechnical requirements and with a reserve of traction force (to overcome temporary resistance) on the hook. For all brands of ploughs and options for the width of capture of one plough body, calculations were made for hourly productivity, specific fuel consumption for units in the composition with the following tractors: Belarus 3522, K-525, K-730M, KAT-3004, K-739M, K-744R3, K-424, K-744R2.

The hourly productivity of the unit is calculated taking into account the plow's working width, working speed, coefficients taking into account the use of the working width, working speed, and working time of the shift. The specific fuel consumption is calculated taking into account its consumption during the main work,

**Табл. 2.** Ширина захвата, тяговые сопротивления плугов, кН

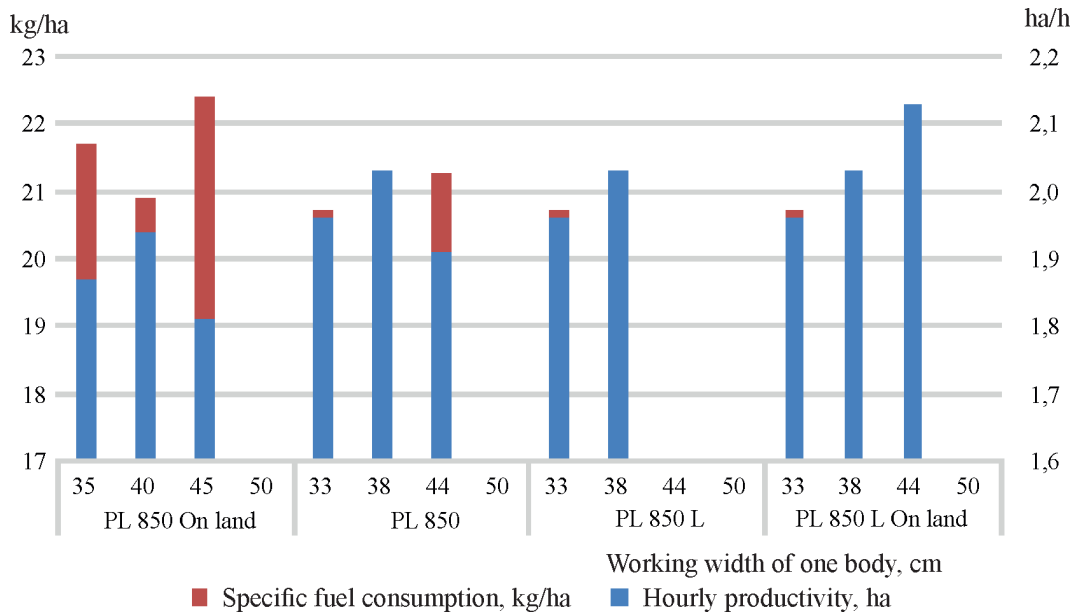
**Table 2.** Working width, traction resistance of the ploughs, kN

Plough brand	Body working width, cm	Seven bodies		Eight bodies	
		Plough working width, m	Tractive resistance	Plough working width, m	Tractive resistance
Optitech PL 850 On land	35	2,45	29,8	2,8	32,8
	40	2,8	32,8	3,2	36,4
	45	3,15	35,9	3,6	39,9
	50	3,5	39,0	4,0	43,4
Optitech PL 850	33	2,31	28,4	2,64	31,3
	38	2,66	31,5	3,04	34,8
	44	3,08	35,2	3,52	39,1
	50	3,5	38,9	4,0	43,3
Optitech PL 850 L	33	2,31	27,6	2,64	30,5
	38	2,66	30,7	3,04	34,0
	44	3,08	34,4	3,52	38,3
	50	3,5	38,1	4,0	42,5
Optitech PL 850 L On land	33	2,31	27,4	2,64	30,3
	38	2,66	30,4	3,04	33,8
	44	3,08	34,15	3,52	38,0
	50	3,5	37,9	4,0	42,3

turns, and idle crossings (data for calculations are taken from reference literature and operating instructions with data on specific fuel consumption per 1 effective hp/h).

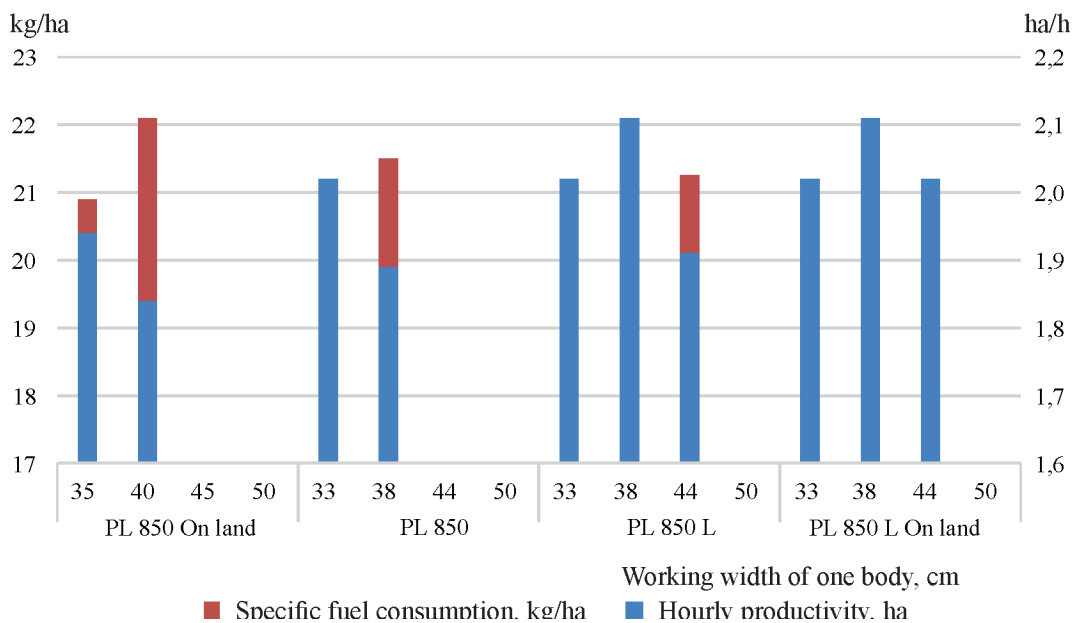
Fig. 1, 2 show the results of calculations to determine the hourly productivity and specific fuel consumption for plowing units consisting of

a Belarus 3522 tractor and seven- and eight-body ploughs. The highest productivity was recorded for the unit consisting of a Belarus 3522 with a seven-body plough PL 850 L On land with a working width of one body of 44 cm (2.13 ha/h), the specific fuel consumption was 19.1 kg/ha. The highest productivity was recorded for units



**Рис. 1.** Часовая производительность, удельный расход топлива агрегата в составе с трактором Беларус 3522 и семью корпусными плугами

**Fig. 1.** Hourly productivity, specific fuel consumption of the unit in combination with the Belarus 3522 tractor and 7-body ploughs



**Рис. 2.** Часовая производительность, удельный расход топлива агрегата в составе с трактором Беларус 3522 и восемью корпусными плугами

**Fig. 2.** Hourly productivity, specific fuel consumption of the unit in combination with the Belarus 3522 tractor and 8-body ploughs

with eight-body ploughs PL 850 L and PL 850 L On land with a working width of one body of 38 cm (2.11 ha/h), the specific fuel consumption was 19.2 kg/ha.

The K-424 tractor has maximum productivity in combination with seven-body ploughs PL 850 L and PL 850 L On land with a working width of one body of 33 cm (1.52 ha/h; 19.6 kg/ha).

The units in combination with the KAT-3004 tractor have maximum productivity with seven- and eight-body PL 850 L ploughs with a working width of one body of 33 cm (1.65 ha/h), specific fuel consumption is 17.7 kg/ha, as well as with the seven-body PL 850 L On land plough with a working width of one body of 33.38 cm (1.65 ha/h; 17.7 kg/ha).

The K-525 tractor has maximum productivity in combination with seven-body ploughs PL 850 L and PL 850 L On land with a single-body width of 33 cm (1.74 ha/h), specific fuel consumption is 17.8 kg/ha.

The K-730M has maximum productivity in combination with a seven-body plough PL 850 L On land with a single-body width of 50 cm (2.8 ha/h), with an eight-body plough PL 850 L On land with a single-body width of 44 cm (2.85 ha/h), specific fuel consumption is 16.6 kg/ha.

The K-739M tractor has maximum productivity when coupled with an eight-body PL 850 L On land plough with a working width of one body of 44 cm (3.11 ha/h; 16.5 kg/ha).

The unit in combination with the K-744P2 tractor has maximum productivity in combination with the PL 850 L On land seven-body plough with a single-body width of 50 cm (3.29 ha/h), specific fuel consumption is 13.1 kg/ha.

The K-744P3 has maximum productivity in combination with the eight-body plough PL 850 L On land with a single-body width of 50 cm (3.5 ha/h), specific fuel consumption is 13.7 kg/ha.

From the presented analysis, a preliminary conclusion can be made that it is most expedient to use this plough in the PL 850 L On land version with seven or eight bodies with a working width of one body of 44 or 50 cm, with tractors of traction class 5 and 6 (K-730M, K-739M,

K-744P2, K-744P3); hourly productivity - from 2.85 to 3.5 ha / h, specific fuel consumption from 13.1 to 16.6 kg / ha.

It is also possible to use tractors of the lower traction classes: Belarus 3522, K-525, KAT-3004 (Chinese-made tractor) with ploughs in the PL 850 L and PL 850 L On land versions, mainly with seven bodies, as well as with eight, but with a working width of one body of 33 cm. The efficiency of use will be 30% lower.

It is not advisable to use the K-424 tractor with ploughs of this brand, even in a seven-body version, with a working width of one body of 33 cm.

To check and clarify the operational data of Optitech ploughs, a test drive of the Optitech PL 850 On land plough was conducted in one of the agricultural organizations of the Sverdlovsk region with the participation of the representatives of Agrosnabtekhsevis OOO (Novosibirsk), B-Istokskoe RTPS JSC (Ekaterinburg), the Department of Service of Transport and Technological Machines and Equipment in the Agro-Industrial Complex of the Ural State Agrarian University.

The test drive was performed in a unit with the RSM-2375 tractor and the Optitech PL 850 On land plough (serial number 26967) with an eight-body design with a working width of one body of 38 cm (plough operation in the "out of furrow" and "in furrow" positions) (see Fig. 3). The RSM-2375 tractor on standard 710/70R38 tires with eight ballast weights of 30 kg on the front frame (240 kg) and 26 on the rear (780 kg), a total of 1020 kg, with the distribution of the operating weight by the three-point hitch assembly along the axles: front – 57%, rear – 43%. The technological operation was performed in gear II3 – 10.9 km / h.

To determine the operational properties of the unit consisting of “tractor RSM-2375 + plough OPTITECH PL 850 On land”, the following technical and economic indicators were used:

– plough PL 850 On land: operating weight 5500 kg, working width of one body 33/38/44/50 cm, number of bodies 7 + 1;

– RSM-2375 tractor: operating weight 12460 kg, up to 39 front ballast weights of 30 kg + bracket for securing 130 kg weights,



**Рис. 3.** Оборотный плуг OPTITECH PL 850 On land

**Fig. 3.** Reversible plough OPTITECH PL 850 On land

26 rear ballast weights of 30 kg + bracket for securing 110 kg weights (the operating instructions provide for 24 to 30 ballast weights of 30 kg as auxiliary rear weight, since the three-point hitch version does not provide for the installation of a rear set of weights) [14];

– when carrying out field work using a three-point hitch, the distribution of operating weight between the axles is permitted in the following ratio: 65% – front axle, 35% – rear.

To evaluate the operational properties of the RSM-2375+PL 850 On land unit, presented for a test drive to determine the optimal option for a plowing unit, the following options for tractor ballasting are proposed (see Table 3).

The results of calculations for determining the operating weight, power-weight ratio, and nominal traction force are presented in Table 4.

Table 4 shows that when using the factory set of ballast weights in a tractor with a three-point hitch, the tractor remains in the "energy" concept [14]. According to the operating instructions, the maximum efficiency of the tractor will

be achieved with an operating weight of 16,162 kg<sup>7</sup>. In this regard, the tractor can be additionally loaded with 1,512 kg of ballast weights. However, this is only possible for a tractor equipped with a PTO and a traction type hitch or by installing dual wheels.

Based on the data in Table 4, the traction forces were determined for various working gears with different ballasting options. The results for some options are presented in Table 5.

To determine the draft resistance of the plough, formulas (1), (2) were used. During the test drive, the PL 850 On land plough with a single body working width of 33/38/44/50 cm was used. During the test drive, the plough was adjusted to a single body working width of 38 cm, the operating weight – 5500 kg.

Traction resistance of one body –  $R_{1K} = 0,38 \times 0,22 \times 40 = 3,34$  кН, of the plough –  $R_a = 3,34 \times 8 + 0,15 \times 53,9 = 34,8$  кН.

To evaluate the operational properties for different options of using ballast weights, the following formulas were used.

<sup>7</sup>Buhler 2425, 2335, 2290, 2375, 2360 manual. [Digital resource]. URL: <https://manualsdump.com/en/manuals/buhler-2335model-2425model-2290model-2375model-2360model/97275/1>. Date of reference 23.09.2024.

**Табл. 3.** Варианты балластирования трактора

**Table 3.** Tractor ballasting options

Option	Front weights, kg			Rear weights, kg			Total, kg
	Mounting bracket	Front weights	Sum	Mounting bracket	Rear weights	Sum	
1	Without ballasting						
2	130	–	130	Without cargo			130
3	130	–	130	110	–	110	240
4	130	8 × 30	370	110	–	110	480
5	130	8 0 × 30	370	110	6 × 30	290	660
6	130	16 × 30	610	110	6 × 30	290	900
7	130	16 × 30	610	110	11 × 30	440	1050
8	130	24 × 30	850	110	11 × 30	440	1290
9	130	24 × 30	850	110	16 × 30	590	1440
10	130	32 × 30	1090	110	16 × 30	590	1680
11	130	32 × 30	1090	110	21 × 30	740	1830
12	130	39 × 30	1300	110	21 × 30	740	2040
13	130	39 × 30	1300	110	26 × 30	890	2190
14	130	8 × 30	370	110	26 × 30	890	1260

**Табл. 4.** Результаты расчетов показателей для трактора RSM-2375 в соответствии с вариантами балластирования

**Table 4.** Results of calculations of the indicators for the RSM-2375 tractor in accordance with ballasting options

Option	Front axle, kg		Rear axle, kg		Operating weight, kg	Energy saturation, kW/kN	Nominal traction force, kN
	value	%	value	%			
1	7102	57,0	5358	43,0	12460	2,26	47,9
2	7232	57,4	5358	42,6	12590	2,23	48,4
3	7232	57,0	5468	43,0	12700	2,21	49,2
4	7472	57,7	5468	42,3	12940	2,17	49,7
5	7472	56,9	5648	43,1	13120	2,14	50,4
6	7712	57,7	5648	42,3	13360	2,1	51,3
7	7712	57,1	5798	42,9	13510	2,08	51,9
8	7952	57,8	5798	42,2	13750	2,05	52,8
9	7952	57,2	5948	42,8	13900	2,02	53,4
10	8182	57,0	5948	43,0	14140	1,98	54,4
11	8182	58,0	6098	42,0	14290	1,96	54,9
12	8392	57,0	6098	43,0	14500	1,93	55,7
13	8392	58,0	6248	42,0	14650	1,91	56,3
14*	7472	54,0	6248	46,0	13720	2,05	52,7

\*Option No. 14 corresponds to the option of ballasting the tractor during a test drive.

**Табл. 5.** Тяговые усилия трактора RSM-2375 на различных передачах при различных вариантах догрузки

**Table 5.** Traction forces of the RSM-2375 tractor in different gears with different additional loading options

Range, operating speed, km/h		Tractive efforts in accordance with the option of additional loading with ballast weights, kN									
		Option								Field research	
		1		5		8		13			
1	2	1	2	1	2	1	2	1	2	1	2
II1 8,0		38,8		40,8		42,7		45,6		42,6	
II2 9,3		35,5		37,4		39,2		41,8		39,1	
II3 10,9		31,6		33,2		34,8		37,1		34,7	
II4 12,6	II4 7,9	27,4		28,8		30,2		32,2		30,1	
	III1 10,3		35,4		37,3		39,0		41,6		38,9
	III2 12,1		31,6		33,3		34,9		37,2		34,8
	III3 14,1		27,4		28,8		30,2		32,2		30,1

Note. 1 – without reduction gear; 2 – with reduction gear.

*Hourly productivity:*

$$W_q = eB_p V_p = e \xi_B \xi_V \tau B_a V_T \tag{3}$$

where  $e$  – coefficient taking into account the units of measurement of the speed of the unit;  $e = 0,1$ ;  $B_p$  – working width of the unit, m;  $B_p = \xi_B B_a$ , where  $\xi_B$  – coefficient of utilization of the capture width, taking into account the difference between the working capture width and the design one:

$\xi_B = \frac{B_p}{B_a}$ , when plowing  $\xi_B = 1,05$ ;  $V_p$  – workingspeed of the unit;  $V_p = \xi_V \times V_T$ , where  $\xi_V$  – speed utilization factor:  $\xi_V = \frac{V_p}{V_T}$ ,  $\xi_V = 0,83$  for tractors of classes 5 and 6 t;  $\tau$  – shift time utilization rate:  $\tau = \frac{T_p}{T_{CM}}$ , under good organization of work and normal operating conditions  $\tau = 0,7-0,8$ .

*Fuel consumption*

$$g_{\Gamma A} = \frac{G_{T.P} + G_{T.II} + G_{T.IIEP} + G_{T.XD}}{W_q} \tag{4}$$

where  $G_{T.P}$ ,  $G_{T.II}$ ,  $G_{T.IIEP}$ ,  $G_{T.XD}$  – average hourly fuel consumption during a shift (kg/h) during the main (clean) work, idling on turns, crossings and during idling of the engine (during stops of the unit with the engine running). Average hourly fuel consumption is taken from reference data

or by calculation through the specific fuel consumption per 1 hp and the degree of engine loading.

This study presents calculations for the options in Table 4.

*Option 1.* The technological process of plowing can be performed on the II1 gear without a reduction gear – 8 km/h, traction force 38.8 kN.  $W_q = 0,1 \times 1,05 \times 0,83 \times 0,75 \times 3,04 \times 8 = 1,59$  ha/h;

$$g_{\Gamma A} = \frac{37,7 \times 0,75 + 20,65 \times 0,25}{1,59} = \frac{28,3 + 5,16}{1,59} = 21 \text{ kg/ha.}$$

*Option 5.* The technological process of plowing can be performed on the II2 gear without a reduction gear – 9.3 km/h, traction force – 37.4 kN;

$W_q = 0,1 \times 1,05 \times 0,83 \times 0,75 \times 3,04 \times 9,3 = 1,85$  ha/h;

$$g_{\Gamma A} = \frac{39,7 \times 0,75 + 21,7 \times 0,25}{1,85} = \frac{29,8 + 5,42}{1,85} = 19 \text{ kg/ha.}$$

*Option 8.* The technological process of plowing can be performed on gear III1 with a reduction gear – 10.3 km/h, traction force – 37.4 kN.

$W_q = 0,1 \times 1,05 \times 0,83 \times 0,75 \times 3,04 \times 10,3 = 2,05$  ha/h;

$$g_{\Gamma A} = \frac{41,6 \times 0,75 + 22,7 \times 0,25}{2,05} =$$

$$= \frac{31,2 + 5,67}{2,05} = 18 \text{ kg/ha.}$$

*Option 13.* The technological process of plowing can be performed on gear III1 with a reduction gear – 10.3 km/h, traction force – 41.6 kN.

$$W_{\text{ч}} = 0,1 \times 1,05 \times 0,83 \times 0,75 \times 3,04 \times 10,3 = 2,05 \text{ ha/h;}$$

$$g_{\Gamma A} = \frac{44,3 \times 0,75 + 24,3 \times 0,25}{2,05} =$$

$$= \frac{33,2 + 6,05}{2,05} = 19,2 \text{ kg/ha.}$$

*Option 14.* The technological process of plowing can be performed on gear III1 with a reduction gear – 10.3 km/h, traction force – 38.9 kN.

$$W_{\text{ч}} = 0,1 \times 1,05 \times 0,83 \times 0,75 \times 3,04 \times 10,3 = 2,05 \text{ ha/h;}$$

$$g_{\Gamma A} = \frac{41,5 \times 0,75 + 22,08 \times 0,25}{2,05} =$$

$$= \frac{31,2 + 5,7}{2,05} = 18 \text{ kg/ha.}$$

The calculation results are presented in Table 6.

Using the index method, taking 1 additional load as the base option, the optimal option for operational properties will be determined (see Table 7).

It was found that the optimal option for using the machine-tractor unit was number 6, i.e. when using a bracket and 16 front weights, a rear bracket and 6 rear weights (total 900 kg), with weight distribution by axles: 7712 kg (57.7%) on the front axle and 5648 kg (42.3%) on the rear, the nominal traction force of the tractor is 51.3 kN.

**Табл. 6.** Производительность, расход топлива МТА при различных вариантах балластирования  
**Table 6.** Productivity, fuel consumption of the MTU with different ballasting options

Indicator	Ballasting option													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Hourly productivity, ha/h	1,59	1,59	1,59	1,59	1,85	2,05	2,05	2,05	2,05	2,05	2,05	2,05	2,05	2,05
Specific fuel consumption, kg/ha	21,0	21,3	21,4	21,8	19,0	17,5	17,7	18,0	18,2	18,5	18,7	19,0	19,2	18,0

**Табл. 7.** Сумма баллов при оценке различных вариантов балластирования на эксплуатационные свойства МТА

**Table 7.** Sum of the points when evaluating different ballasting options for the operational properties of the MTU

Option	Hourly productivity of MTU	Specific fuel consumption	Total points
1	1,0	1,0	2,0
2	1,0	0,99	1,99
3	1,0	0,98	1,98
4	1,0	0,96	1,96
5	1,16	1,1	2,26
<b>6</b>	<b>1,29</b>	<b>1,2</b>	<b>2,49</b>
7	1,29	1,19	2,48
<b>8</b>	<b>1,29</b>	<b>1,17</b>	<b>2,46</b>
9	1,29	1,15	2,44
10	1,29	1,13	2,42
11	1,29	1,12	2,41
12	1,29	1,1	2,39
13	1,29	1,09	2,38
<b>14</b>	<b>1,29</b>	<b>1,17</b>	<b>2,46</b>

During the test drive, the plowing unit worked “outside the furrow” and “in the furrow” (see Fig. 4, 5).

The actual operating speed of the unit when operating outside the furrow was 10 km/h, slip-

page was 8.3%, in the furrow it was 10.4 km/h, slippage was 4.6%.

Hourly productivity in the out-of-furrow position:

$$W_{\text{q}} = 0,1 \times 1,05 \times 0,75 \times 3,04 \times 10 = 2,39 \text{ ha/h.}$$



**Рис. 4.** Работа пахотного агрегата в положении «вне борозды»

**Fig. 4.** Operation of the plowing unit in the “out of furrow” position



**Рис. 5.** Работа пахотного агрегата в положении «в борозде»

**Fig. 5.** Operation of the plowing unit in the “in furrow” position

Hourly productivity in the in-furrow position:  
 $W_{\text{ч}} = 0,1 \times 1,05 \times 0,75 \times 3,04 \times 10,4 = 2,49$  ha/h.

Specific fuel consumption is 15.4 and 14.8 kg/ha, respectively.

## CONCLUSIONS

1. Along with tractors, foreign-made agricultural machinery, especially ploughs, is actively promoted on the Russian market. Chinese-made ploughs often copy each other or Western models, such as Lemken. The ploughs can be used in seven- and eight-body designs, which allows for a more efficient assembly of the plowing unit. The hourly productivity of the plowing units in combination with the Belarus 3522 tractor and the PL 850 On land seven-body plough with a single-body width of 0.4 m is 5.4% higher than that of the unit with an eight-body plough, 7.4% higher with the PL 850 plough with a single-body width of 0.38 m, and 5.4% higher with the PL 850 L On land plough with a single-body width of 0.44 m.

2. To change the operating mode "out of the furrow" to the "in the furrow" mode, there is no need to reconfigure the tractor hitch. It is enough to move the hydraulic cylinder of the plow hitch to the position corresponding to the modes, and adjust the position of the plow frame to match the position of the bodies of the traction line.

3. During theoretical studies to determine the operational properties of the RSM-2375 tractor in combination with the PL 850 On land plough with a working width of one body of 38 cm before the test drive, it was found that the operational properties are optimal with ballasting option 6. The unit with the tractor ballasting option during the test drive (option 8) of ballasting is inferior to the unit with option 6 due to increased fuel consumption associated with the increased weight of the tractor.

4. Tractor manufacturers claim that the maximum efficiency of the tractor will be achieved when using dual tires. The dual tire kit with a 710/70R38 tire (wide twin) weighs 1,280 kg, and installing dual tires will not change the balance between the axles. Using dual tires will increase the nominal traction force to 61.2 kN. The hourly productivity of the unit is 2.4 ha, and the

specific fuel consumption is 17.8 kg/ha. Using a tractor with dual tires without ballast weights is almost identical to option 8 and the option of ballasting the tractor during a test drive.

4. The calculations made confirm the tractor manufacturers' statement that the tractor's operation during field work is most efficient when working on dual tires.

5. During the test drive it was revealed that the plowing unit has the highest operational properties when the unit is operating in the "in furrow" position: hourly productivity is 4.2% higher, specific fuel consumption is 3.9% lower.

6. During the test drive, it was concluded that the PL 850 On Land plough in combination with the RSM-2375 tractor is capable of performing high-quality plowing in accordance with agro-technical requirements both when the unit is operating in the "outside the furrow" position and "in the furrow". The range of working gears and various ballasting options allow the plow to be used with different processing depths and body widths.

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## Методологический аспект проблемы развития резервных энергосберегающих систем вентиляции

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В статье рассмотрены специфика создания и основные предпосылки к внедрению резервных вентиляционных систем для типовых крупногабаритных птицеводческих цехов. Современное оборудование, используемое для обеспечения надлежащих микроклиматических условий в птицеводческих цехах, включая комбинированные вентиляционные системы тоннельного типа, полностью зависимо от электричества. В случае любой аварийной ситуации, связанной с электроснабжением, от удушья и перегрева погибает практически все поголовье. Особенно опасны летние высокотемпературные периоды, поскольку при остановке основной системы вентиляции воздухообмен с окружающей средой полностью прекращается в силу равенства значений температур внутри помещения и за его пределами. В публикации предлагается альтернативное решение: перемещение воздушной массы на основе принципа ее конвекционирования. Логика изложения материала делает возможным понимание как актуальности экономического аспекта прогнозируемого риска аварий и утраты рентабельности, так и достоверности проектирования функциональной структуры с созданием принципиальной схемы технического решения, исключающего подобные риски. Механизм создания векторных потоков, влияющих на формирование и релокацию температурных полей, а также на кратность воздухообмена внутри крупногабаритных технологических помещений, приводится не только в виде принципиальной схемы на основе ледогенераторов, но и как методологический алгоритм, положенный в план вычислительного эксперимента, целью которого является оценка функциональности и технологичности апробируемого проекта. Особенность предлагаемого подхода заключается в том, что при значительном расходе энергии не исключается возможность ее перераспределения для обеспечения работы системы охладительного контура с ледогенераторами. За счет «сэкономленной» электроэнергии резервная вентиляционная система, находясь в режиме «холодного» ожидания, потенциально готова запустить процесс конвекционного вентилирования птицеводческого цеха при отключении его от электросети на период проведения ремонтно-восстановительных работ.

**Ключевые слова:** птицеводческий цех, естественная вентиляция, охлаждающая установка, теплообмен

## Methodological aspect of the problem of development of backup energy-saving ventilation systems

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This publication examines the main prerequisites for the implementation and specifics of creating backup ventilation systems for typical large-scale poultry farms. The modern equipment used to provide microclimatic conditions, including combined tunnel-type ventilation systems, are completely dependent on electricity. In the event of any emergency related to the power supply of the poultry complex, almost the entire population of the serviced birds dies from suffocation and overheating. Summer high-temperature periods are especially dangerous, since when the main ventilation system stops, air exchange with the environment completely stops due to the equality of the temperatures inside and outside the premises. The publication proposes to consider an alternative: the movement of the air mass based on the principle of its convection. The logic of the presentation of the material in the publication makes it possible to understand both the relevance of the economic aspect of the predicted

risk of accidents and loss of profitability, and the reliability of the design of the functional structure with the creation of a basic diagram of the technical solution that eliminates such risks. The mechanism for creating vector flows that affect the formation and relocation of temperature fields, as well as the multiplicity of the air exchange inside large-sized technological premises, is presented not only in the form of a schematic diagram based on ice generators, but also formalized into a methodological algorithm included in the plan of a computational experiment, the purpose of which is to evaluate the functionality and manufacturability of the tested project. A feature of the proposed approach is that with significant energy consumption, the possibility of its redistribution to ensure the operation of the cooling circuit system with ice generators is not excluded. Due to the "saved" electricity, the backup ventilation system, being in the "cold" standby mode, is potentially ready to start the process of convection ventilation of the poultry shop when it is disconnected from the power grid for the period of repair and restoration work.

**Keywords:** poultry shop, natural ventilation, cooling unit, heat exchange

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#### **Конфликт интересов**

Авторы заявляют об отсутствии конфликта интересов.

#### **Conflict of interest**

The authors declare no conflict of interest.

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## **INTRODUCTION**

When analyzing the heat exchange process in a poultry house, it is important to note the significant influence of convection on the creation of a microclimatic environment within the process space, which allows us to consider the issues of modernizing ventilation systems from the point of view of expanding optional capabilities, but taking into account emergency situations. In this case, we are considering the removal of exhaust air from the interior of a poultry house during an emergency failure of the climate control system or a power outage in the poultry farm. In such circumstances, a reserved option for switching to natural ventilation becomes extremely necessary. Moreover, the performance and parametric characteristics of air flow, temperature stabilization, and the duration

of maintaining vital levels of these parameters, in relation to the maximum time required for repairs, must reliably exclude the possibility of mass mortality of birds during a crisis.

If the poultry house ventilation system fails due to low or subzero ambient temperatures, the minimum required air exchange in the process room can be ensured by promptly opening all existing process openings to the outside. Due to the temperature difference, fresh air will flow through roof vents, wall air vents, functional fan openings, and transport openings located in the room. It is possible, although technically extremely difficult, to carry out short-term repairs and maintenance work without evacuating the flock from the non-functional room.

The complexity of the issue of preserving poultry populations increases during the hot

season, when the temperature difference between the ambient environment and the internal temperature field is practically non-existent, and air exchange in the process room is possible only with the help of forced ventilation, as a result of which seasonal energy consumption increases by 300–400%. Moreover, the architectural and geometric design specifications of a poultry house typically do not provide for a reduction in thermal stress. Consequently, even a short-term ventilation system failure or power outage during periods of high temperatures will inevitably lead to overheating and exhaust air poisoning of virtually the entire flock.

The solution to this problem lies in a key physical phenomenon characteristic of heat and air exchange processes occurring in industrial and residential buildings where forced ventilation is unavailable or unfeasible. This involves the convective, oriented movement of air flows distributed within the temperature and gas-saturated fields of a confined space, and the need to install appropriate process equipment.

A typical poultry house, during periods of ventilation system failure, is precisely such a facility. While indoor air parameters are not standardized for semi-open and open poultry houses, the calculated indoor air temperature should be no more than 5°C above the average monthly outdoor temperature at 1:00 PM during the hottest month for closed process facilities during the hottest period of the year. In this case, the indoor air temperature should be no more than 34°C for chickens aged 1 to 10 days, no more than 31°C for other age groups of egg-laying poultry, and no more than 29°C for meat-producing poultry. The indoor air temperature may exceed these values only if the relevant requirements are included in the design specifications. The heat content of the indoor air in poultry buildings should not exceed 71 kJ/kg (17 kcal/kg) for chickens aged up to 50 days, and 67 kJ/kg (16 kcal/kg) for other age groups.

It should be noted that the design specifications include periods of emergency operation for ventilation and humidification systems. Furthermore, for areas with a design outdoor air temperature of 25°C or higher during the warm season at 1:00 p.m. during the hottest month, it is recommended to consider evaporative adiabatic cooling and humidification of the supply air. Furthermore, drinking water should be used to fill the spray chambers and humidifiers, as well as to fill the nozzles of local supplementary humidification systems [1, 2].

In principle, a schematic, functional, and technical solution for a natural-flow ventilation system for the facility under study is feasible. However, it would be necessary to further evaluate the feasibility of applied modeling within the framework of the basic design, the development of which is conceptually based on thermal physics, thermodynamics, and heat engineering. To this end, several questions must be addressed: how feasible is the recommended approach for natural-flow ventilation system projects? Is it feasible to use a fragmented process based on adiabatic cooling technology? How can a backup ventilation system be designed using the technological equipment already installed in the poultry house?

It is known that an adiabatic process is a thermodynamic process in a system without heat exchange with the environment. This means that it does not release heat into the surrounding space, but simultaneously reduces the temperature and humidifies the air mass. Therefore, adiabatic cooling systems are cooling technologies that utilize the principles of thermodynamics to reduce the temperature of air or water without the need for external heat transfer. In these systems, temperature reduction is achieved through gas expansion or water evaporation.

An adiabatic air humidification system, in turn, is designed as a climate control device or a group of interconnected devices used to increase

indoor humidity without altering the internal energy of the air. These systems typically inject water through nozzles after deep pre-treatment. These systems are commonly used to increase relative humidity in residential and commercial spaces.

The problem is that a major power failure disrupts both the ventilation equipment and the water supply. Therefore, it becomes crucial to quickly connect alternative energy sources to maintain the livestock's vital functions while climate control systems are being repaired or power to process facilities is interrupted.

There are many types of modern equipment for providing agricultural complexes with backup power sources: electric generators, backup mini-power plants, industrial gas generators, diesel generator sets, etc. Analysis of the electricity consumption spent on the ventilation system in a poultry farm showed that the minimum consumption was 2302 kW h (March), the maximum – 22,740 kW h (August). For example, to ensure the smooth operation of a poultry farm, eight DES 3000 diesel generator sets with a total capacity of 24,000 kW are required. The acquisition and maintenance of these units requires significant material costs (the total cost, including delivery and installation, ranges from 100,000 to 200,000 rubles per unit). Other disadvantages of using diesel generators include: emissions of nitrogen oxides, soot, and other pollutants; high noise levels; and dependence on diesel fuel, which can create certain difficulties in remote areas.

It's unlikely that engineering services at poultry farms will consider regenerative energy projects as a backup if the technical solution focuses on wave or tidal energy from seawater. The hydrothermal gradient and geothermal energy sources are also just a matter of rhetorical projections for the poultry industry—even in global electricity production, this approach only accounts for 0.5%. Installing solar panels

or wind turbines on poultry farms is impractical due to unstable natural and climatic conditions. Integrating alternative energy sources such as heat pumps into the poultry farm's technological system could be considered as an alternative.

The creation of backup ventilation capacity, a pressing issue in the poultry agro-industrial sector, necessitates a comprehensive analysis of the entire range of equipment currently in mass production. For example, the use of heat pumps and geothermal sources confirms the feasibility of generating the artificial cold necessary to create a temperature differential during convective airflows using geothermal energy.

This type of energy can be used in two ways. First, high-potential geothermal energy (over 100°C) can be converted into electricity for use in a vapor-compression or thermoelectric refrigeration system. Second, the heat from medium-potential geothermal fluid (over 60°C) can be used in heat-recovery absorption thermal transformers, whose equipment can generate artificial refrigeration in the summer. However, in neither case is it possible to activate ice-generation systems and initiate convective airflow during a power outage at the poultry farm. The reason is simple: both options require the same amount of electricity to generate artificial cold. Therefore, the working documentation does not provide for or include the schematic diagrams and technical solutions for geothermal heating units in the functional structure of these facilities.

In this regard, the search for solutions to the problem of livelihood support for productive livestock in poultry farms is proposed to be conducted in a "spatiotemporal" discrete manner, which can be interpreted as the advance development of technological prerequisites that do not affect the system process until a failure occurs. In the event of an emergency disruption to the process, the system process will be restored and maintained for the time required to carry

out repairs. As a result, the interpenetration or overlap of operational characteristics, which could lead to parametric transformation of process parameters and negatively impact the welfare of the birds, is eliminated. The principle of "early formation of process prerequisites" stems from the conditions for modeling the functional structure and the basic design of the technical solution for the backup ventilation system.

Condition one: the technological prerequisites are formed permanently—only during the operation of the primary climate control system under optimal operating conditions until it enters an emergency state. If the systems and mechanisms powered by the electrical grid are shut down, the formation of temperature fields and air flow vectors in the workshop ceases. At the same time, the accumulation of the potential activator of convective air exchange and convective heat exchange ceases; the climate control mode is transformed from forced ventilation (usually tunnel) to natural plenum air supply. In the event of a power failure during the particularly dangerous, high-temperature summer season, an alternative ventilation system will prevent mass bird mortality. However, to restore the air mass to a dynamic state, it is necessary to redistribute the facility's power consumption, taking into account the actuators and devices that control the process of generating the required operating parameters of the backup ventilation system.

This leads to the second condition: between the proposed functional structure of the backup ventilation system and the basic design of its technical solution, it is necessary to conduct a computational experiment, the factorization of which should be aggregated to optimize energy consumption for actuators and the level of their operational manufacturability. It is advisable to use a system synthesized from mathematical models of technological fragments of the production environment as the basis for the

methodological formalization of the computational experiment. In this case, the direction and intensity of convection currents affecting air exchange are of interest [1, 3].

## MATERIAL AND METHODS

A key feature of the technical implementation of a backup ventilation system for a poultry house is the presence of ice generators. Ice generators, whether they be refrigeration chambers, freezers, or any other type of freezing device capable of producing, retaining, and accumulating ice, act as activators of convection currents. The poultry house equipment design presents no technical difficulties. For the engineering department, installing two tubular refrigeration circuits around the perimeter of the process room will present no problems. However, activating an alternative air exchange mode as a process requires an analysis of the integrated system's functionality from a physics and thermodynamics perspective, i.e., formalizing cause-and-effect relationships at the methodological level.

It should be noted that thermal energy storage devices predominantly utilize phase-change substances (PCS) of the solid-liquid type. These are generally classified as organic, inorganic, and eutectic (eutectic solutions) [4]. Organic PCS include paraffins, fatty acids, and other compounds. In some cases, water is used as the storage medium in air conditioning and ventilation systems. It is characterized by high specific heat capacity and specific heat of freezing (melting ice) – 4.184 kJ/(kg·K) and 335 kJ/kg, respectively. When using ice made from water in the accumulators, the capacity of the tanks will be within acceptable dimensions and can be installed on the walls of the poultry house along the perimeter. Furthermore, melting ice produces water, which helps increase humidity in the poultry house, which is also necessary to

maintain the livestock during hot periods when the air conditioning system is turned off.

Next, let's consider the components and operation of a backup ventilation system intended for installation in poultry farms located in the areas with high summer temperatures. Typically, a standard poultry house design equipped with a forced-draft tunnel ventilation system includes openings for communication with the outside environment, through which fresh air is drawn in while tunnel fans remove accumulated biological gases (see Fig. 1). Such openings include: air valves (1) located along the entire length at the top of the load-bearing walls along the rows of cassettes with cages for keeping chickens (2); ventilation wells (3) located along the longitudinal axis on the roof of the workshop (as an option, it is permissible to use a model with an electric fan); technological openings (4) for the installation of tunnel fans (5) on one of the end walls of the workshop.

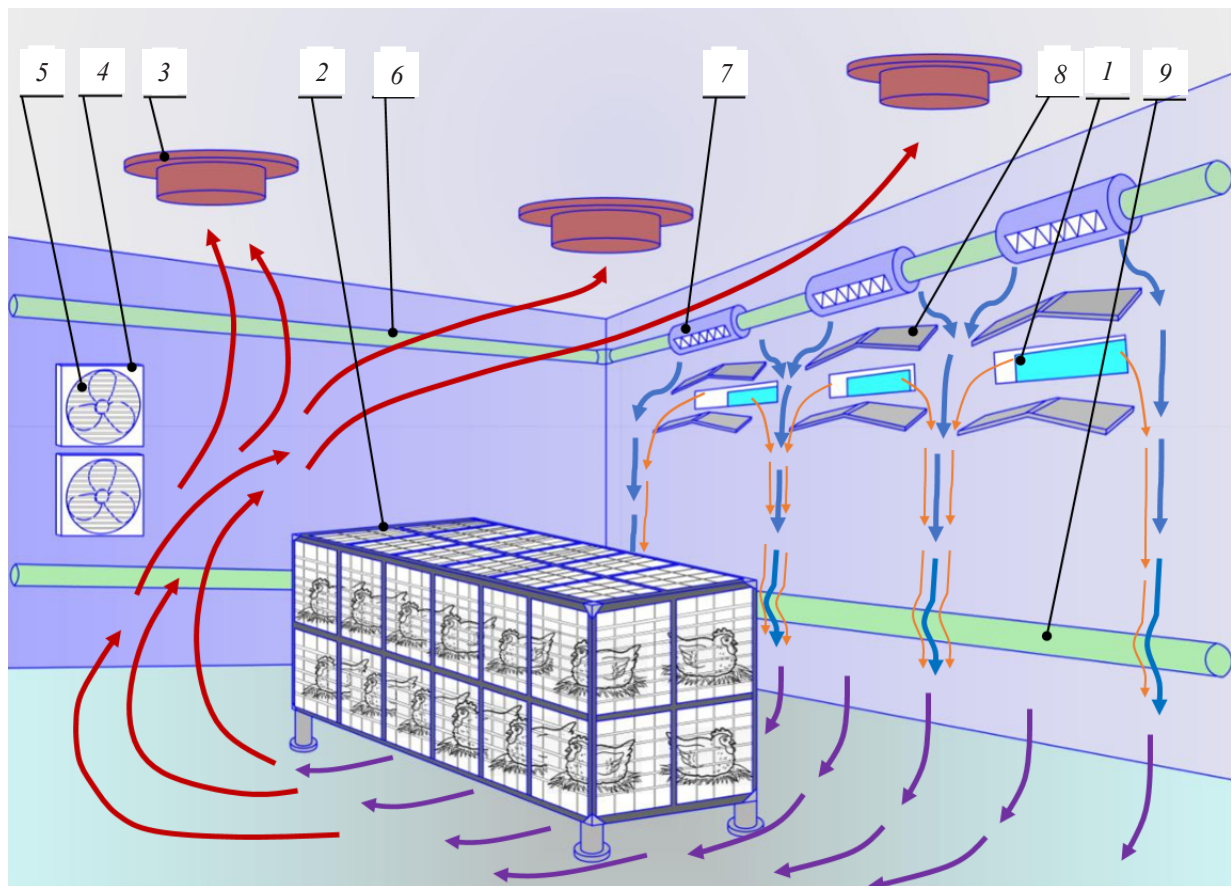
In the absence of electricity and identical temperature conditions inside and outside the workshop, air exchange within it virtually ceases. Air movement is activated immediately after a power outage using additional equipment with pre-set functional and pre-stabilized operating parameters allowing, through the use of all openings in the technological room, to form convection air flows and distribute them vectorially across the poultry placement sectors.

For this purpose, a pipeline (6) is installed around the entire perimeter of the workshop at a level above the air valves, channeling the refrigerant to the ice generators (7), installed directly above the air valves equipped with Delta plates (8). In addition, a lower circuit of the refrigeration pipeline (9) is installed along the perimeter. The distance from the floor to the mounting points of the lower circuit should not exceed the installation height above the floor of the lower tier of bird cages.

During operation of the main ventilation system, the piping cools and ice gradually forms in the ice generators. A power failure stops the forced removal of used air from the process room, and the process switches to convection air exchange. The wall-mounted air cascade, cooled by the ice generators, begins to move downward, flowing around the Delta plates and the air valve openings. This creates a vacuum in the interplate space and draws oxygen-rich air from the surrounding environment.

To prevent the mixing of hot and cold air from slowing the downward flow and causing its premature dissipation, the lower circuit of the refrigeration pipeline is designed according to the design, although without the installation of ice generators, it is more massive along its entire length. This ensures: firstly, stabilization of the temperature regime of the wall-mounted air mass cascade at the level of the convection differential; secondly, vectorial formation of the air circulation movement in the process room, taking into account the passage space under the lower tier of poultry cages. Thus, heavy gases (carbon dioxide, hydrogen sulfide, ammonia) are forced out by a cooled flow to the ventilation shafts and partially, due to the instability of their laminar flow, to the technological openings where tunnel fans are installed, which stopped functioning due to a power outage.

If we draw an analogy with the field of hydrodynamics, then the designed functional structure, as a result of a computational experiment, should confirm the possibility of realizing the so-called vertical turbulence, characteristic of the movement of water masses in river beds, or one of the elements of a whirlpool in the natural environment. The duration and intensity of air exchange in vertical turbulence mode depends on the volume of the process space and the capacity of the ice generators. This issue requires detailed analysis, including the design and technological parameters of the equipment



**Рис. 1.** Схема размещения охлаждающего контура с ледогенераторами  
**Fig. 1.** The layout of the cooling circuit with icemakers

providing backup (alternative) replacement for the forced ventilation system in the event of its failure<sup>1</sup> [1, 5].

If we abstract from the technological process in a poultry farm and consider it as a geometric space filled with geometric bodies – cages for keeping poultry, then hypothetically the convective formation of air flows in the specified room will have the surface of a distorted toroid or a toroid inscribed in a parallelepiped of the technological space for keeping poultry (see Fig. 2). In order to ensure full air exchange and optimize heat exchange processes in the room when calculating heat transfer coefficients, heat transfer, and air exchange rates, it is advisable to work with a closed-type toroid model, which is

a condition for the adequacy of the convection flow trajectory not only to the geometry of the process space, but also to the areas of the openings for communication with the environment.

Experience with laboratory and industrial testing throughout the history of scientific and technological progress demonstrates the complexity and significant expense of most research procedures when working with large-scale objects, especially when the transition to a technical solution involves the creation of rig-based simulation systems. Difficulties increase exponentially if the rig-based equipment testing plan involves the use of experimental groups of animals or birds. Moreover, the implementation of an innovative project may ultimately lose its cost-effectiveness

<sup>1</sup>Gadaborsheva T.B., Efremova G.S., Zakharyina A.Ya. Analysis of air mass movement in rooms with complex layouts // Internet Bulletin of the Volgograd State University of Architecture and Civil Engineering, 2015, N 1 (37), p. 1.

if the reliability of the basic design is not confirmed during the creation of a physical model of the technical solution (even with multiple corrections of the prototype after its reconstruction using a feedback system with the functional structure of the technological object).

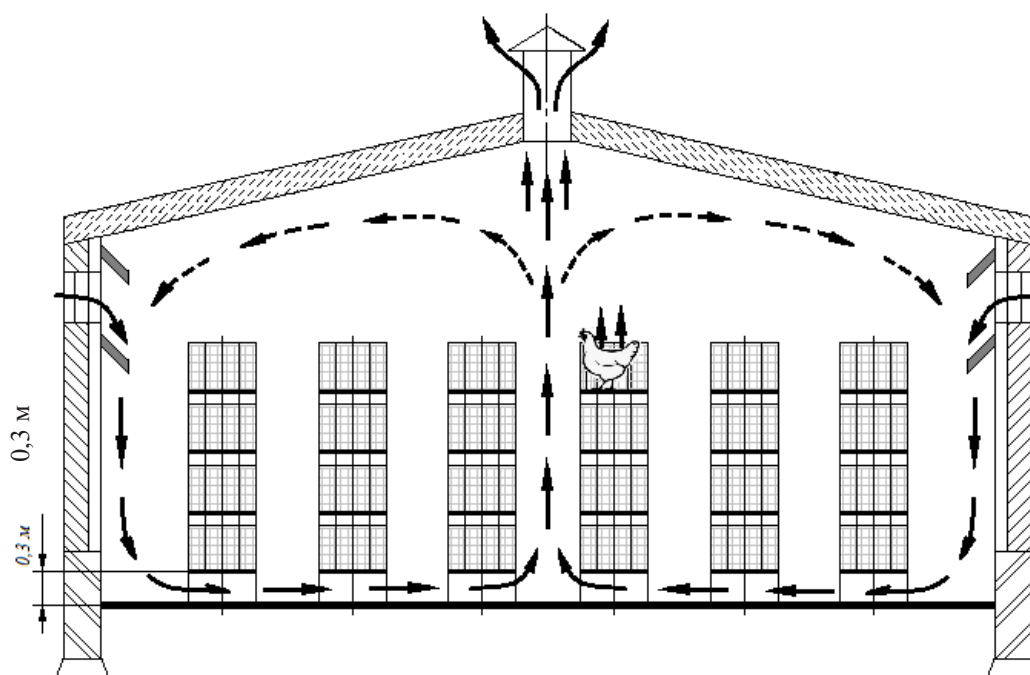
It should be noted here that large structural units not intended for expansion of the functional structure are subject to a categorical ban on unregulated use of supporting structures, due to the increased risk of their failure. For this reason, additional functionality is introduced to a technological facility only after conducting model studies: of the technological system, the set of technical facilities aggregated within it, and the economic system as an indicator of the profitability of innovative transformations [6, 7].

Within the framework of the topic under development, the fact of parametric integration within a single hydrodynamic process—convective air exchange—is particularly complex and, therefore, requires closer study. The transition from a functional structure to a reliable schematic diagram and, subsequently, to a technical

solution for a backup ventilation system is only possible through comprehensive optimization of the physical, technological, and functional parameters implementing its operating mode.

Only through computational experimentation can the costs of conducting research based on large-scale computational procedures be reduced – debugging and calibrating software models to simulate technological equipment is incomparably cheaper than “compiling” the instrument base in its natural implementation. But a computational experiment is, first of all, a targeted computer modeling for studying the behavior of complex systems and phenomena, which is based on a scientific research method focused on the properties of environments and physical and chemical quantities that characterize the possibility of implementation, as well as the state of the process at a technological facility.

As an example, we can cite the formalization of the natural inflow movement of air mass during the transition from the forced air exchange mode in a poultry house to air ex-



**Рис. 2.** Конвекционное формообразование воздушных потоков  
**Fig. 2.** Air flow convection shaping

change based on convection flows activated by a pre-generated ice mass.

Thus, the purpose of the research presented in this publication is to determine the ways and formalize the methodological foundations for optimizing the structure, as well as the operating mode of a backup ventilation system of the convection type in large-scale technological premises for containing biological objects [8–10].

Over time, air mixing within the poultry house will result in a relatively uniform temperature distribution ( $t_{int}$ , °C), allowing for the same  $t_{int}$  value to be used when calculating heat transfer across all surfaces (approximately 30 °C). An exception may be uneven temperature elevation due to excess heat from the birds and equipment when the house operates without a ventilation system in the event of an emergency shutdown. As a result of convective currents of warm air above the poultry cages, a layer of heated air (a "thermal cushion") quickly forms under the house roof.

During the hot season, the outside air temperature ( $t_{ext}$ ) is roughly comparable to the temperature inside the poultry house. The heat flow coming from the window openings of the production facility ( $Q_{ok}$ , W) is calculated using the formula

$$Q_{ok} = \alpha \cdot S_{ok} \cdot (t_{ext} - t_{int}),$$

where  $\alpha$  – air heat transfer coefficient, W/(m<sup>2</sup>·K);  $S_{ok}$  – surface area of window openings, m<sup>2</sup>.

If  $t_{ext} < t_{int}$ , then some of the heat flow will flow from the room to the outside. During the hottest period of the year, the opposite situation is possible: if  $t_{ext} > t_{int}$ , then the heat flow from the street will increase the thermal effect on the air in the workshop, and the temperature inside will begin to rise more rapidly.

When considering free convection in the surrounding environment, the mathematical model

will only take into account the unevenness of air density arising from temperature changes. Assuming that the air density, formed under the influence of pressure, is constant throughout the entire volume under study, the temperature field in the air should be considered two-dimensional and changing along the  $x$  and  $y$  axes.

The analytical expression for the two-dimensional temperature field of the medium  $t = t(x, y)$  is written as

$$t = 0,05(t_x - t_{int}) \left( \frac{y}{x} \left( \frac{1}{4} Gr_x \right)^{\frac{1}{4}} - 4,5 \right)^2 + t_{int},$$

where  $t_x$  – refrigeration unit temperature, °C;  $t_{int}$  – initial room air temperature, °C;  $Gr_x$  – local dimensionless Grashof criterion.

The Grashof number for air can be determined using the formula

$$Gr_x = \frac{g\beta(t_2 - t_1)}{l^3\rho^2},$$

where  $g$  – acceleration of gravity, m/s<sup>2</sup>;  $\beta$  – coefficient of volumetric expansion of the environment, K<sup>-1</sup>;  $t_1$  и  $t_2$  – temperature at different points, °C;  $l$  – determining size, m;  $\rho$  – dry air density, kg/m<sup>3</sup>.

It's logical that the pattern of changes in the temperature field of the environment makes it possible to analytically determine the temperature at any point in space. Thus, if the surface temperature of the refrigeration unit is  $t_x$ , then the excess temperature ( $\Delta t$ , °C) for a given heat exchange model in the room will be calculated based on the expression

$$\Delta t = t_x - t.$$

Calculation of excess temperature is necessary to determine the convective heat transfer coefficient and the amount of heat that can be removed from the room using a refrigeration unit.

Convective currents arise near the cooling unit (ice storage), causing heat exchange be-

tween these surfaces and the air. If the surface is cooled, the air around it also cools and descends, displacing the heated air, which has a lower density. In the zone where the flow begins, the boundary layer near the wall is laminar (see Fig. 3). Research has shown that the maximum airflow velocity is observed precisely in the laminar heat transfer regime. The transition from laminar to turbulent conditions occurs at some distance from the surface's origin ( $l_{кр}$ , m). At a room temperature of 30 °C, the distance  $l_{кр}$  can be found using the formula

$$l_{кр} \approx \frac{1,87}{\sqrt[3]{\Delta t}}$$

The average value of the convective heat transfer coefficient ( $\alpha_k$ , W/(m<sup>2</sup>·K)) within the entire region of the laminar heat transfer regime from 0 to  $l_{кр}$  at a room temperature of 30°C is determined from the expression

$$\alpha_k = 1,16 \sqrt[3]{\Delta t}$$

The required heat flow  $Q$  absorbed by the refrigeration unit from the surrounding air will be

$$Q = S \cdot \alpha_k \cdot \Delta t, \text{ Вт,}$$

where  $S$  – refrigeration unit area, m<sup>2</sup>.

In a descending cold flow, a boundary layer physically forms near the vertical surface of the process room walls, the thickness of which increases in the direction of flow. At the same time, the maximum velocity of the cooled air flow gradually decreases. At some distance from the lower boundary of the cooled surface, the flow regime becomes turbulent, and a further decrease in velocity is observed.

A study of the principle of air movement from the upper cooling level, where a cold

stream is generated by the ice generator, to the floor of the process room demonstrated the importance of the physical aspect of implementing a laminar flow regime for descending convective air streams. Only in this case will the speed of the cooled air flow not decrease, which is a prerequisite for the effective functioning of natural-forced ventilation<sup>2</sup> [11].

Technically, the laminar regime can be extended by creating additional cold concentrators along the trajectory of the descending convection air streams. An additional cooling element is installed below the poultry house walls, at a distance  $l_{кp1}$  from the first overhead ice generator, where the flow transitions to turbulent mode. Similarly, at a distance of  $l_{кp2}$  from the second ice generator, as well as  $l_{кpi}$  for the  $n$ -th cooling element (see Fig. 4). This arrangement of the cooling elements will allow maintaining a controlled temperature difference  $\Delta t_i$  ( $i = 1 \dots n$ ) in the air flow and maximally accelerate the vector movement of cold air currents to the floor of the poultry house.

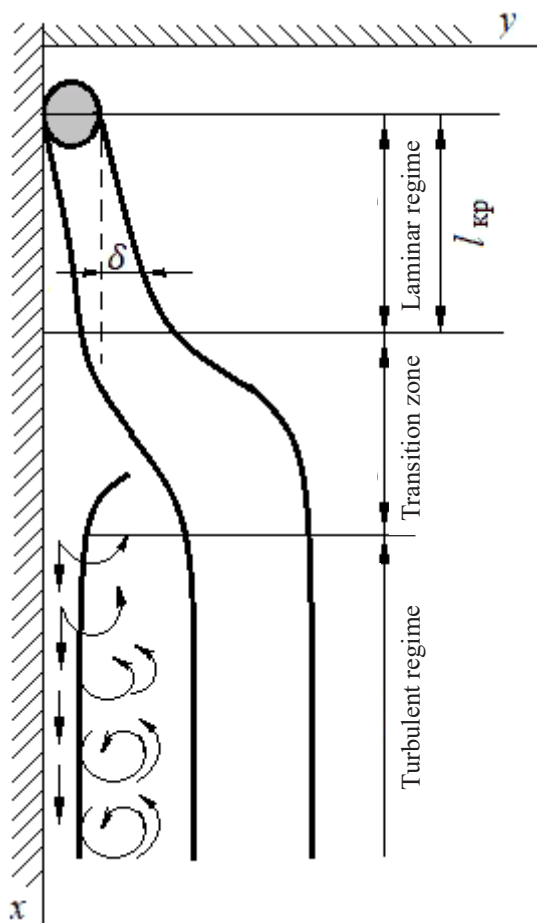
## RESULTS AND DISCUSSION

For the calculation and methodological testing, the characteristics of convective heat exchange on a freely located vertical cooling surface were adopted, taking into account the parameters of the cold-generating system for the premises of the poultry farm<sup>3</sup>.

The workshop room has the following dimensions: length 96 m, width 18 m, overhang height 4 m. At the initial moment,  $t_{int} = 30$  °C. During the hot period of the year, the average value is  $t_{ext} = 35$  °C. The temperature of the ice generator cooling elements is  $-15$  °C. The ice generator is a cylindrical body with a diameter

<sup>2</sup>Mitrofanov V.A. On the calculation of heat transfer from a non-uniformly heated flat wall into a stabilized turbulent flow of cooling liquid // Bulletin of the P.G. Demidov Yaroslavl State University. Series: Natural and technical sciences, 2015, N 3, pp. 57–63.

<sup>3</sup>Makarov S.S., Karpov A.I., Makarova E.V. Mathematical model of convective heat transfer of a coolant flow moving along the surface of a heated metal cylinder // Chemical Physics and Mesoscopy, 2016, vol. 18, N 1, pp. 32–40.



**Рис. 3.** Схема послойного распределения нисходящего потока воздуха при свободной конвекции  
**Fig. 3.** The scheme of layer-by-layer distribution of downward air flow at free convection

of 0.6 m, located at intervals along the entire length of the walls of the process room.

Estimated lateral surface area of the poultry house under study:

$$S = 2\pi rh = 2\pi \cdot 0,3 \cdot (96 + 18) \cdot 2 = 430 \text{ m}^2.$$

The total area of window openings in the poultry house:  $S_{\text{ок}} = (0,3 \times 0,5) \times 22 = 3,3 \text{ m}^2$ ; coefficient of convective heat transfer with window openings:  $\alpha_{\text{ок}} = 1,16 \approx 1,98 \text{ W}/(\text{m}^2 \cdot \text{K})$ ; heat flow entering the workshop from window openings:  $Q_{\text{ок}} = 3,3 \cdot 1,98 \cdot 5 = 32,72 \text{ W}$ .

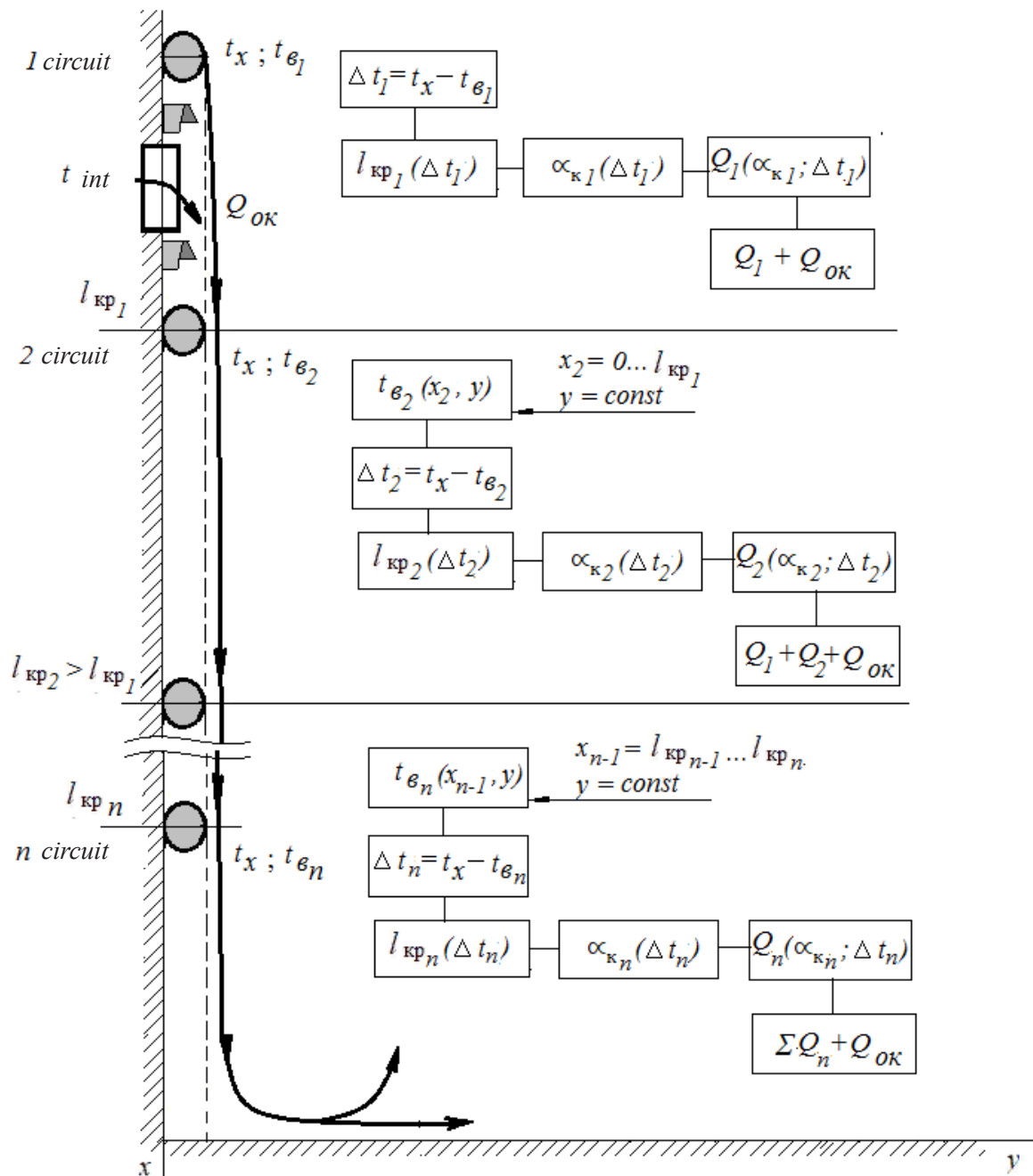
Thus, the presence of windows and other openings does not have a significant impact on

the thermal field inside the room due to their small size, but provides access to oxygen necessary to maintain the vital activity of the livestock.

The calculation of the amount of heat absorbed by each of the tiered circuits of the ice generators, as well as the total amount of heat absorbed by the entire system, is presented in the form of an algorithm in Fig. 5.

The primary ice generator circuit is located at the highest possible height under the ceiling of the poultry house, above the window openings where the hottest air accumulates. The heat capacity of the primary ice generator circuit ( $Q_1$ ) is 79.9 kW. Calculations showed that the heat capacity of the secondary ice generator circuit ( $Q_2$ ) is 29.4 kW, significantly lower than that of the primary circuit. This is due to the fact that the temperature inside the wall-mounted laminar layer drops significantly, slowing heat transfer. According to calculations, the third circuit of the ice generators absorbs even less heat:  $Q_3 = 8.1 \text{ K (W)}$ . In this case, the air temperature inside the laminar layer becomes negative ( $t_{\text{int}} = -7 \text{ }^\circ\text{C}$ ), the excess ambient air temperature decreases to 8 °C. Such temperature values are undesirable, since they can lead to hypothermia of the birds located in the rows of cages closest to the ice generators.

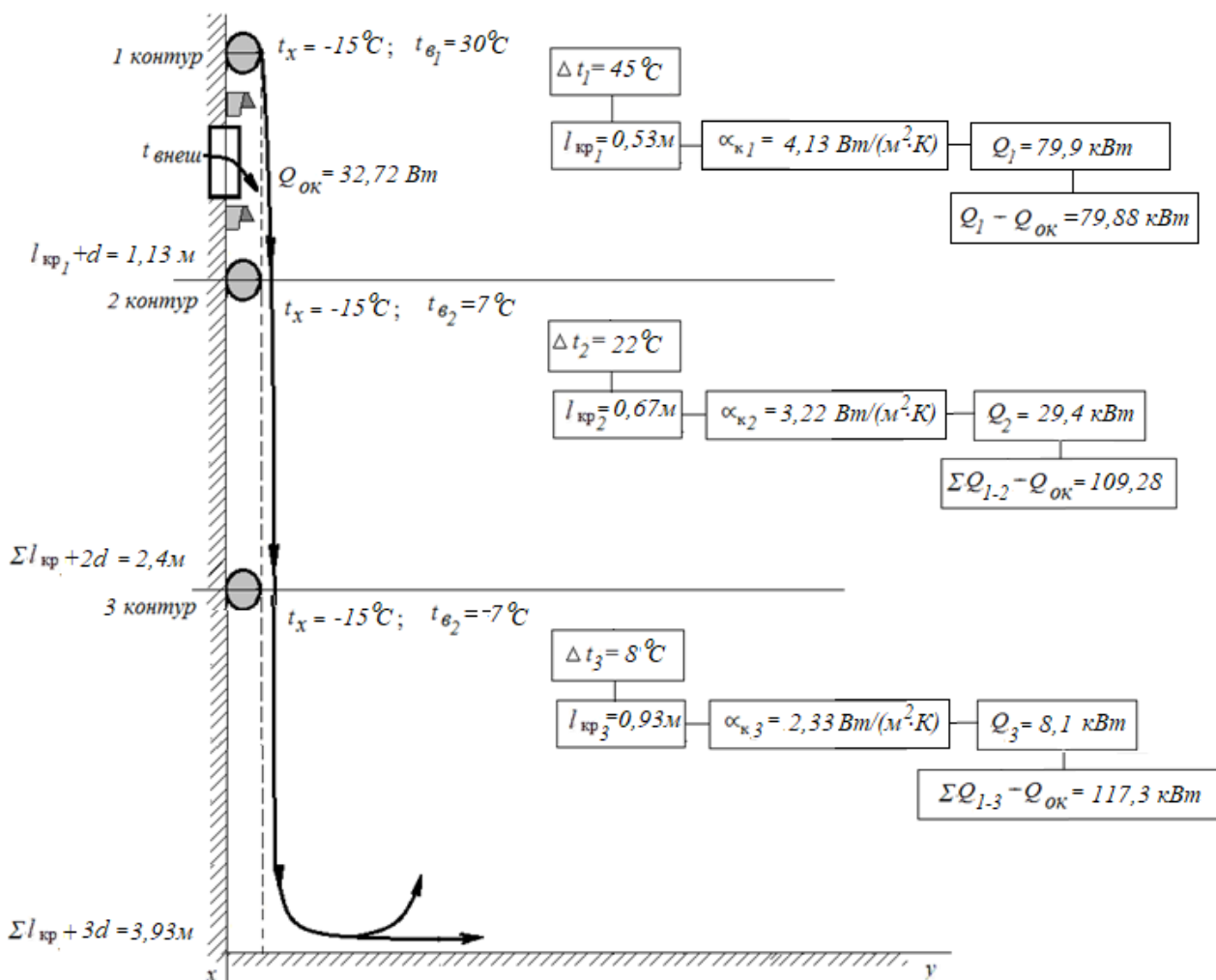
Based on sanitary and biological requirements and calculations, it can be concluded that the proposed air-cooling model for a poultry house requires two ice generator circuits located around the perimeter of the room. The first circuit directs the cooled air downwards (toward the floor), while the second circuit prolongs the laminar flow of the cooled air and forces the cooled air flow to continue its movement toward the floor, driven by the temperature and density differences between the air layers in the wall-mounted laminar flow. The cooled air mass continues its downward movement toward the workshop floor, then enters the subcage space, which is large enough to allow the accumulated



**Рис. 4.** Расчетно-функциональная схема параметрической модели конвекционного теплообмена  
**Fig. 4.** Computational and functional scheme of the parametric model for convection heat exchange

reserves of cooled air to pass to the next inter-cellular row. At the same time, the absorption of excess heat becomes more intense in the turbulent air mixing regime, which, according to calculations, begins at a distance of 1–2 meters from the wall on which the ice generators are located.

Research is currently planned to determine the parameters of turbulent air mass mixing with temperature differences between adjacent thermal fields inside a poultry farm. The development of a comprehensive algorithm for accounting for thermally active obstacles in the path of cooled air mass propagation—in this specific



**Рис. 5.** Алгоритмизованная структурно-функциональная схема элементов охлаждения конвекционных потоков для исследуемого помещения птицеводческого цеха

**Fig. 5.** Algorithmized structural and functional scheme of the cooling elements of convection flows for the studied poultry workshop premises

case, rows of cassettes containing chickens—is envisaged.

Further research is planned to focus on implementing the presented mathematical model in laboratory conditions. As a pilot project, a backup emergency air cooling system is planned for a poultry farm, using a dual-circuit ice generator system during periods of high ambient air temperature stress. The experiment will assess the risks associated with pre-preparing the backup system for an emergency, which, paradoxically, is associated with the normal operation of the main ventilation system. The longer the trouble-free period, the greater the risk of

ice generators freezing. To prevent this critical situation, ventilation systems should be controlled by a controller that streamlines the redistribution of power between the main ventilation system and the ice mass freezing system during trouble-free periods.

## CONCLUSION

The conducted studies have shown that the creation of emergency natural ventilation is possible, but with the mandatory implementation of the process of cold accumulation and further (in the event of transition to emergency mode) operation of the cooling system circuits

located along the perimeter of the poultry farm premises. As calculations have shown, to ensure convective movement of the air mass with the capture of oxygen-saturated air from the environment in the object under study, two levels of cooling circuits are sufficient to ensure the formation of laminar downward flows.

The proposed backup ventilation system involves creating a significant temperature differential within the room and, as a result, activating cold air circulation in planes oriented orthogonally to the walls of the process room. However, discussing the level of temperature and oxygen comfort without conducting research into the impact of thermally active barriers on the specifics of laminar flow transformation and temperature fields is extremely premature. Moreover, the study of trans-regime phenomena during the transition from laminar to turbulent flow in the cyclic completion phase requires special attention, since this is associated with the evacuation of exhaust air from the workshop and a natural decrease in the intensity of refrigeration devices during de-energization of the process facility.

An economic analysis of electricity costs showed that the annual electricity consumption during operation of the ventilation system of the poultry house is 127,988 kW h. The enterprise's costs for purchasing electricity at an electricity cost of 6.3 rubles/kW h amounted to 806,324 rubles.

The analysis shows that the highest energy consumption and costs occur during the warmer months, when tunnel ventilation is used. Moreover, with significant energy consumption, it is possible to redistribute it to support the operation of the cooling circuit system with ice generators. Due to the "saved" energy, the backup ventilation system, while in "cold" standby mode, is potentially ready to start convection ventilation of the poultry house during power outages during maintenance and repair work.

## СПИСОК ЛИТЕРАТУРЫ

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## Технология формового хлеба из обогащенной композитной пшенично-льняно-рыжиковой муки

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Получение продуктов переработки двух- или трехкомпонентных зерновых смесей на основе зерновых и масличных культур обеспечивает получение продуктов сбалансированного состава, присутствие в них в необходимых количествах нутрицевтиков, веществ, обладающих лечебно-профилактическими свойствами, которые могут быть использованы при производстве продуктов питания специального назначения. В качестве объектов исследования использовали композитную пшенично-льняно-рыжиковую муку в различных соотношениях: 95 : 5, 90 : 10, 85 : 15, 80 : 20. Содержание льняной и рыжиковой муки в композиции было в равной пропорции: 2,5 : 2,5; 5,0 : 5,0; 7,5 : 7,5 и 10,0 : 10,0. Разработана технология хлебобулочного изделия в виде формового хлеба из пшенично-льняно-рыжиковой муки различного соотношения. Определены физико-химические и органолептические показатели композитной пшенично-льняно-рыжиковой муки различного соотношения для выработки формового хлеба. Разработана рецептура хлебобулочного изделия в виде формового хлеба из композитной пшенично-льняно-рыжиковой муки различного соотношения. По результатам проведенных физико-химических анализов и органолептической оценки представленных образцов установлено, что наилучшими характеристиками обладает образец формового хлеба № 3, приготовленный из пшенично-льняно-рыжиковой муки с содержанием обогащающего льняно-рыжикового компонента 15%. Выявлено, что с увеличением количества льняно-рыжикового компонента композитной мучной смеси увеличивается содержание белков, жиров и незаменимых аминокислот в формовом хлебе, при этом количество углеводов в изделии уменьшается. Установлено, что с увеличением количества льняно-рыжикового компонента происходят увеличение биологической ценности и уменьшение энергетической ценности формового хлеба. При этом происходит обогащение готовых изделий белками, жирами, аминокислотами, хлеб имеет наиболее привлекательный товарный вид и хорошие органолептические показатели.

**Ключевые слова:** пшенично-льняно-рыжиковая мука, хлебобулочные изделия, формовой хлеб, показатели качества, обогащение

## Technology of tinned bread from enriched composite wheat-flax-camelina flour

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The production of processed products from two- or three-component grain mixtures based on grains and oilseeds ensures the production of products with a balanced composition, containing the necessary amounts of nutraceuticals, substances with therapeutic and prophylactic properties, which can be used in the production of special-purpose food products. Composite wheat-flax-camelina flour was used as the research object in various ratios: 95:5, 90:10, 85:15, 80:20. The content of flaxseed

and camelina flour in the composition was in equal proportions: 2,5 : 2,5; 5,0 : 5,0; 7,5 : 7,5 and 10,0 : 10,0. A technology has been developed for a bakery product in the form of tinned bread made from wheat, flax, and camelina flour in various proportions. The physical, chemical, and organoleptic properties of composite wheat-flax-camelina flour with different ratios for the production of tinned bread have been determined. A recipe for bakery products in the form of tinned bread made of composite wheat-flax-camelina flour of various ratios has been developed. Based on the results of physicochemical analyses and organoleptic evaluation of the presented samples, it has been established that sample of tinned bread No. 3, made of wheat-flax-camelina flour containing 15% of the enriching flax-camelina component, has the best characteristics. It has been revealed that with an increase in the amount of flax-camelina component in the composite flour mixture, the content of proteins, fats and essential amino acids in the tinned bread increases, while the amount of carbohydrates in the product decreases. It has been established that with an increase in the amount of flax-camelina component, the biological value increases and the energy value of the tinned bread decreases. The finished products are enriched with proteins, fats, amino acids, have the most attractive commercial appearance and good organoleptic properties.

**Keywords:** wheat-flax-camelina flour, bakery products, tinned bread, quality indicators, enrichment

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**Conflict of interest**

The authors declare no conflict of interest.

## INTRODUCTION

Flaxseed is a valuable food component, boasting not only high protein and fat content but also a unique macronutrient composition, primarily polyunsaturated fatty acids (PUFAs). Flaxseed protein complex, characterized by a high proportion of albumin-globulin fraction and essential amino acids, also boasts high nutritional and biological value [1–5]. The use of whole flaxseed in two-component grain mixtures is justified, since in this case the entire phytopotential of flax seeds is used, since it is known that the main source of PUFA is the germ and endosperm of flax seed, protein - the endosperm and germ, dietary fiber and lignans - the seed coat [6–10].

An analysis of literature data revealed that the use of flaxseed products in bakery and confectionery production is limited and primarily involves the use of flaxseed flour from flaxseed cake. This does not always have a positive im-

pact on the final product—bread—in terms of its technological quality indicators (volume yield, crumb porosity, etc.) [11–13].

False flax (*Camelina sativa* L.) belongs to the cruciferous family and is a valuable oilseed crop. Eight varieties of winter false flax and 12 varieties of spring false flax are included and approved for use in the State Register of the Russian Federation. In 2023, the gross yield of oil false flax oilseed was 105,900 centners. Currently, false flax seeds are primarily used to produce camelina oil, which contains up to 46% fat. Camelina oil is versatile, so it can be used for both industrial and food purposes. It is used in the cosmetics industry, metallurgy, and in the manufacture of paints and varnishes [13].

In terms of amino acid composition and protein biochemical value, camelina seeds, like flaxseed, surpass those of cereal crops (wheat, rye, and triticale), including the content of certain essential and limiting amino acids – lysine

and cystine. The well-balanced nature of camelina proteins in terms of key biochemical parameters and amino acid composition, as well as the high content of biologically valuable lysine (up to 5.3% of the total amino acid content), make camelina seed processing products a valuable raw material for food production [14].

The production of processed products from two- or three-component grain mixtures, such as those based on grains and oilseeds, will ensure balanced products containing the necessary amounts of nutraceuticals, substances with therapeutic and prophylactic properties, which can be used in the production of specialty foods. Developing new types of bakery products with increased nutritional value is a pressing challenge facing technologists. This challenge can be addressed by improving traditional and developing new technologies and recipes for bakery products.

The purpose of the work is to develop a technology for bakery products in the form of pan bread from enriched composite three-component wheat-flax-camelina flour of various ratios.

## MATERIAL AND METHODS

The following raw materials were used in the research: premium wheat flour "Makfa", flaxseed and camelina flour obtained as a result of laboratory grinding in a knife mill from flaxseed and camelina meal produced by OOO PC "Vkus Zdorovya", pressed baker's yeast "Lux Extra" OOO "Saf-Neva", edible salt "Extra", granulated sugar "Russkiy sakhar", eggs C1, butter "Traditionnoe", milk 3.2% "Domik v derevne", refined sunflower oil "Sloboda".

Composite wheat-flax-camelina flour in various ratios was used as the object of study: 95 : 5, 90 : 10, 85 : 15, 80 : 20. Moreover, the content of flaxseed and camelina flour in the composition was in equal proportions.: 2,5 : 2,5; 5,0 : 5,0; 7,5 : 7,5 и 10,0 : 10,0.

The acidity of the composite wheat-flaxseed-camelina flour was determined in accordance with GOST 27493–87 by titrating all ac-

id-reactive substances of the flour with a 0.1 N sodium hydroxide solution. Flour moisture content was determined using an accelerated method on a Sartorius MA100 device (Sartorius AG, Germany) in accordance with GOST 9404–88, flour water absorption capacity was determined on a Mixolab 2 device (Chopin Technologies, France), and the falling number was determined in accordance with GOST 27676–88 on a Falling Number device. Gluten content was determined by manual washing and weighing of raw gluten according to GOST 27839–2013, and gluten quality was determined on an GDI-1 device.

At the first stage of the research, the quality of the samples of composite wheat-flax-camelina flour of different ratios was determined (see Table 1).

With an increase in the flaxseed-camelina component in the composite flour mixture, quality indicators such as acidity and water absorption capacity of the flour increased, while the moisture content decreased. This is particularly noticeable in the increase in acidity when comparing the control premium wheat flour with wheat-flaxseed-camelina flour in the ratios of 85:15 and 80:20, which is 0.9 and 1.5 degrees higher, respectively. The decrease in gluten content with the addition of flaxseed-camelina flour is worth noting, while a significant improvement in gluten quality is noticeable with the highest flaxseed-camelina flour content in the mixture.

## RESULTS AND DISCUSSION

In the second stage of the research, a recipe was developed for a baked product made from wheat-flaxseed-camelina flour in varying ratios, in the form of pan bread. The baked goods were prepared from a control sample of premium-grade wheat flour and four samples of wheat-flaxseed-camelina flour in varying ratios (No. 1 – 95 : 5, No. 2 – 90 : 10, No. 3 – 85 : 15, No. 4 – 80 : 20).

Table 2 shows the ratio of wheat-flax-camelina flour for baking one portion of pan bread.

**Табл. 1.** Физико-химические показатели качества комбинированной пшенично-льняно-рыжиковой муки различного соотношения

**Table 1.** Physical and chemical quality indicators of composite wheat-flax-camelina flour with various ratios

Ratio of wheat and flaxseed and camelina flour, %	Humidity, %	Acidity, degrees.	Water absorption capacity, %	falling-number value, s	Gluten amount, %	Gluten quality, GDI
95 : 5	11,77	3,6	67	486	21,4	75
90 : 10	11,62	4,0	69	497	20,3	78
85 : 15	11,53	4,5	70	499	19,4	80
80 : 20	10,50	5,1	90	519	17,6	86

Table 3 presents the production recipe for a bakery product in the form of pan bread made from wheat-flax-camelina flour in various ratios.

Next, a laboratory baking trial was conducted and the quality of the finished baked goods in the form of pan bread to determine the optimal ratio of wheat, flaxseed, and camelina flour was evaluated. The technology for making pan bread from wheat, flaxseed, and camelina flour involves the following steps. The first step involves preparing a yeast slurry from pressed yeast and a salt solution. The second stage involves kneading the dough: flour, yeast slurry, salt solution, and the remaining water are added to the mixer, and the dough is kneaded for 3 minutes. The dough temperature after kneading is 30°C. In the third stage, the dough is placed in a proving cabinet for 170 minutes at 40°C

and 75–85% humidity. Two punchings are performed, 60 and 120 minutes after the start of fermentation. In the fourth stage, the dough is divided and shaped. The dough piece is then placed on a baking sheet and placed in a proving cabinet for a final proofing period of 30 minutes at 40°C and 75–85% humidity. Finally, the dough piece is baked in a convection oven with humidification at 220°C. The baking time for pan bread is 30 minutes. After baking, the sur-

**Табл. 2.** Соотношение комбинированной пшенично-льняно-рыжиковой муки различного соотношения для выпечки формового хлеба

**Table 2.** Ratio of composite wheat-flax-camelina flour of various ratios for baking tinned bread

Raw materials	Sample				
	control	No. 1	No. 2	No. 3	No. 4
Wheat flour premium grade, g	200	190	180	170	160
Flaxseed and camelina flour, g	–	10	20	30	40

**Табл. 3.** Рецепт формового хлеба из контрольной пшеничной муки высшего сорта и пшенично-льняно-рыжиковой муки различного соотношения на выход готового изделия массой 0,3 кг

**Table 3.** Recipe for tinned bread made from premium wheat flour and wheat-flax-camelina flour in various proportions, yielding a finished product weighing 0.3 kg

Raw materials	Quantity of ingredients, g				
	Sample				
	control	No. 1	No. 2	No. 3	No. 4
Wheat flour premium grade	200	190	180	170	160
Flaxseed and camelina flour	–	10	20	30	40
Pressed yeast	6				
Table salt	3				
Water	116				
Total	300				

face of the bread is moistened with water. The bread is then cooled at  $25 \pm 3^\circ\text{C}$ .

At the final stage of the laboratory baking trial, the quality indicators of pan bread made from control premium baking flour and composite wheat-flax-camelina flour of various ratios were determined.

The organoleptic and physicochemical quality indicators of the baked product in the form of pan bread were assessed no earlier than 4 hours after baking (see Table 4).

Based on organoleptic characteristics, pan bread made from wheat-flaxseed-camelina flour with a ratio of 95:5 and 90:10 received the highest scores. The control sample had an uneven surface with minor cracks. Sample No. 3, with a ratio of 85:15, had small cracks on the surface. Adding 20% flaxseed-camelina flour to the hearth bread recipe resulted in a pronounced bitter taste and a crumb structure with large pores. Therefore, adding more than 15% of hearth bread to the recipe is not recommended.

At the next stage of the research, the physicochemical quality indicators of pan bread made from control premium wheat baking flour

and wheat-flax-camelina flour in different ratios were determined (see Table 5).

Adding flaxseed-camelina flour to a pan bread recipe increases the moisture content of the finished product by 1.2–5.3%, decreases the porosity of the finished product by 1.67%, and increases the density by 1.1% with an addition of 10% or more, depending on the amount of flour added. Adding this flour to the recipe increases the acidity of the finished product by 20–43%, depending on the amount of flour added.

Fig. 1 shows the appearance of the samples of pan bread made from control premium wheat flour and wheat-flaxseed-camelina flour in different ratios.

Fig. 2 shows cross-sectional samples of tinned bread made from control premium wheat flour and wheat-flax-camelina flour in various ratios.

In the final stage of the study, the energy, nutritional, and biological value of baked goods in the form of pan breads made from control premium wheat flour and wheat-flaxseed-camelina flour in varying ratios were calculated. All calculations were conducted in accordance with

**Табл. 4.** Органолептические показатели формового хлеба из контрольной пшеничной муки высшего сорта и пшенично-льняно-рыжиковой муки различного соотношения

**Table 4.** Organoleptic indicators of tinned bread made from control wheat flour of the highest grade and wheat-flax-camelina flour of various ratios

Indicator	Sample				
	control	No. 1 (5%)	No. 2 (10%)	No. 3 (15%)	No. 4 (20%)
Taste and smell	5	5	5	5	4
Surface	5	5	5	5	4
View in the fracture	5	5	5	5	5
Structure	4	5	5	4	5
Shape	5	5	5	5	4
Color	4	5	5	5	5
Total	28	30	30	29	27

**Табл. 5.** Физико-химические показатели формового хлеба контрольного образца и пшенично-льняно-рыжиковой муки различного соотношения

**Table 5.** Physical and chemical indicators of tinned bread from the control sample and wheat-flax-camelina flour with various ratios

Indicator	Sample				
	control	No. 1 (5%)	No. 2 (10%)	No. 3 (15%)	No. 4 (20%)
Mass fraction of moisture, %	40,40	41,60	43,00	44,50	45,70
Acidity, degrees	1,60	2,00	2,40	2,60	2,80
Dimensional stability of hearth products (H : D)	3,73	3,35	3,54	3,55	3,54
Crumb porosity, %	81,12	79,45	82,23	81,58	81,77



**Рис. 1.** Внешний вид формового хлеба из контрольной пшеничной муки высшего сорта и пшенично-льняно-рыжиковой муки различного соотношения: 1 – контрольный образец; 2 – 5%; 3 – 10%; 4 – 15%; 5 – 20%

**Fig. 1.** Appearance of tinned bread made from control wheat flour of the highest grade and wheat-flax-camelina flour in various proportions: 1 – control sample; 2 – 5%; 3 – 10%; 4 – 15%; 5 – 20%

the guidelines of N.N. Tipsina and T.F. Varfolomeeva "Calculation of the nutritional value of bakery and confectionery products".

The nutritional value of pan bread was determined by comparing the chemical composition of 100 g of the finished product with a balanced diet formula, expressed as a percentage of the daily human requirement for essential nutrients and energy. Calculations were made of the energy, nutritional, and biological value of pan bread made from control premium wheat flour and wheat-flaxseed-camelina flour in varying ratios. The resulting calculation data for pan bread are presented in Tables 6 and 7.

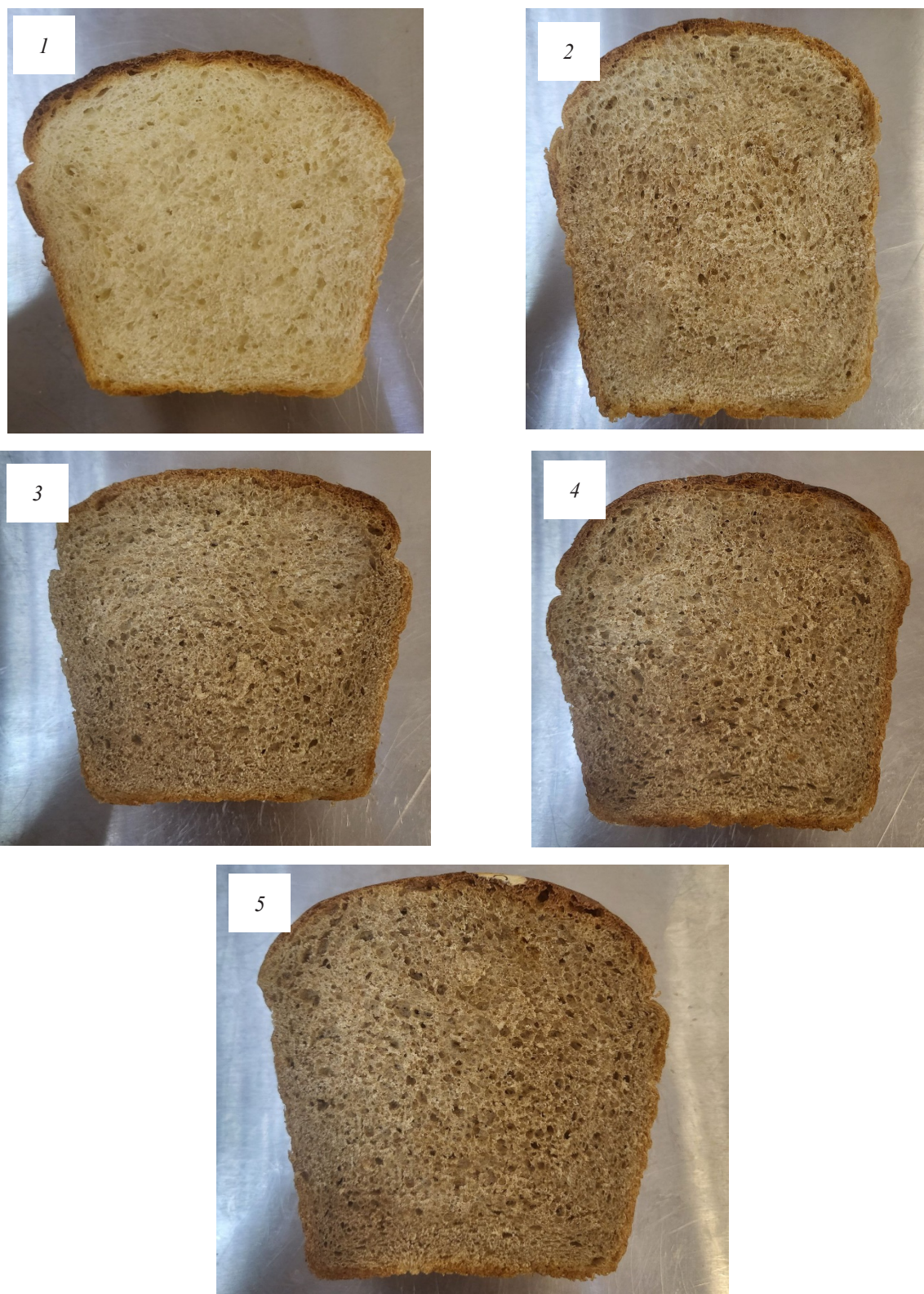
As the flaxseed-camelina component increases in the composite flour mixture, the protein, fat, and essential amino acid content of the pan bread increases, while the carbohydrate content decreases. It should also be noted that as the flaxseed-camelina component increases in the composite wheat-flax-camelina flour mixture, the energy value of the pan bread decreases.

## CONCLUSIONS

1. A technology for producing a tinned bread product from wheat-flaxseed-camelina flours of varying ratios has been developed. The physicochemical and organoleptic properties of composite wheat-flaxseed-camelina flours of varying ratios for the production of tinned bread have been determined.

2. A recipe for a tinned bread product made from composite wheat-flax-camelina flours of varying ratios has been developed. Based on the results of physicochemical analyses and organoleptic evaluation of the samples, it has been determined that tinned bread sample No. 3, made from wheat-flax-camelina flour with a 15% flax-camelina enriching component, exhibited the best characteristics.

3. With increasing amounts of the flaxseed-camelina component in the composite flour mixture, the protein, fat, and essential amino acid content of the pan bread increases, while the carbohydrate content decreases. It has



**Рис. 2.** Формовой хлеб в разрезе из контрольной пшеничной муки высшего сорта и пшенично-льняно-рыжиковой муки различного соотношения:  
1 – контрольный образец; 2 – 5%; 3 – 10%; 4 – 15%; 5 – 20%

**Fig. 2.** Cross-section of tinned bread made from control wheat flour of the highest grade and wheat-flax-camelina flour in various proportions:  
1 – control sample; 2 – 5%; 3 – 10%; 4 – 15%; 5 – 20%

**Табл. 6.** Расчетная пищевая и энергетическая ценность формового хлеба из контрольной пшеничной муки высшего сорта и пшенично-льняно-рыжиковой муки различного соотношения

**Table 6.** Estimated nutritional and energy value of tinned bread made from control wheat flour of the highest grade and wheat-flax-camelina flour in various proportions

Indicator	Contents per 100 g of product				
	Sample				
	control	No. 1 (5%)	No. 2 (10%)	No. 3 (15%)	No. 4 (20%)
Protein, g	8,78	9,44	10,11	10,78	11,44
Fat, g	1,69	2,05	2,41	2,77	3,13
Digestible carbohydrates, g	50,13	48,97	47,28	45,54	44,75
Dietary fiber, g	1,78	2,17	2,56	2,95	3,34
Ash content, %	1,57	1,96	2,36	2,75	3,14
Energy value, kcal	251,3	252,6	251,9	250,8	253,6

**Табл. 7.** Расчетная биологическая ценность формового хлеба из контрольной пшеничной муки высшего сорта и пшенично-льняно-рыжиковой муки различного соотношения

**Table 7.** Estimated biological value of tinned bread made from control wheat flour of the highest grade and wheat-flax-camelina flour of various ratios

Indicator, mg	Contents per 100 g of product				
	Sample				
	control	No. 1 (5%)	No. 2 (10%)	No. 3 (15%)	No. 4 (20%)
Isoleucine	4,66	4,67	4,75	4,79	4,83
Leucine	7,65	7,63	7,56	7,53	7,49
Lysine	2,67	2,82	3,27	3,55	3,77
Methionine + cystine	1,44	1,53	1,82	2,01	2,15
Phenylalanine + tyrosine	5,18	5,19	5,21	5,22	5,24
Threonine	2,94	3,02	3,27	3,42	3,55
Tryptophane	1,05	1,33	2,22	2,76	3,20
Valine	4,47	4,59	4,97	5,21	5,39

been found that with increasing amounts of the flaxseed-camelina component in the composite wheat-flax-camelina flour mixture, the biological value of the pan bread increases and the energy value decreases.

4. The most optimal sample was pan bread No. 3, made from wheat-flax-camelina flour with a 15% flax-camelina component. This enriches the finished product with proteins, fats, and amino acids, resulting in a more attractive presentation and good organoleptic properties.

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#### ИНФОРМАЦИЯ ОБ АВТОРАХ

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## Проблемы и пути управления эффективностью возделывания зерновых культур в Сибири

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Продовольственная безопасность Российской Федерации во многом определяется производством зерновых культур, в особенности пшеницы. Но дефицит финансовых и трудовых ресурсов, а также применение экстенсивных технологий не позволяют сельхозпроизводителям в полной мере реализовать достижения научно-технического прогресса. Требуется использование новых подходов к ведению сельского хозяйства и его машинно-техническому обеспечению, а также поиск инновационных решений, формируемых на основе принципа мультидисциплинарности. Однако техническая проблема обусловлена недостаточным развитием применяемых технических средств и отсутствием теории управления. Существующая отечественная техника способна реализовать лишь традиционные технологии без учета статистических характеристик свойств почвы. В этой связи главной целью данного исследования стало установление взаимосвязи параметров технологических процессов и технического оснащения с основными физико-механическими свойствами и состояниями почвы для реализации ресурсосберегающих технологий, обеспечивающих эффективность возделывания зерновых культур. В ходе исследования проведен анализ применяемых механико-технологических процессов возделывания зерновых культур, выявлены наиболее значимые факторы и показатели, влияющие на эффективность возделывания зерновых, предложены пути и способы управления эффективностью возделывания зерновых культур в Сибири. Также установлена причина высокой энергоемкости технологических процессов и обоснована конкурентоспособная величина урожайности зерновых культур. Сформированы рациональная структура рекомендуемых уровней интенсивности технологий и инновационные механико-технологические решения технологических процессов обработки почвы. Предложенные пути роста эффективности возделывания зерновых культур позволяют вскрыть резервы неиспользуемых ресурсов, стать основой для инновационных механико-технологических решений в рамках реализации ресурсосберегающих технологий в адаптивно-ландшафтном земледелии Сибири.

**Ключевые слова:** физические свойства почвы, процессы, зерновые культуры, урожайность, технологии, энергоемкость, деградация

## Problems and ways of managing the efficiency of grain cultivation in Siberia

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The food security of the Russian Federation is largely determined by the production of grain crops, and especially wheat. However, the shortage of financial and labor resources and the implementation of extensive technologies do not allow agricultural producers to realize the achievements of scientific and technological progress. New approaches to agriculture and its mechanical and technical support

are needed, as well as the search for innovative solutions based on the principle of multidisciplinary. However, the technical problem is caused by the incompleteness of the applied technical means and the lack of a control theory. The existing domestic technology is capable of implementing only traditional technologies without taking into account the statistical characteristics of soil properties. In this regard, the main objective of this study was to establish the relationship between the parameters of technological processes and technical equipment and the basic physical and mechanical properties and conditions of the soil for the implementation of resource-saving technologies that ensure the efficiency of grain crop cultivation. During the study, analysis of the mechanical and technological processes used in grain cultivation was conducted, the most significant factors and indicators affecting the efficiency of grain cultivation were identified, and ways and means of managing the efficiency of grain cultivation in Siberia were proposed. The reason for high energy consumption in technological processes was also established, and a competitive grain crop yield was justified. A rational structure of the recommended levels of technology intensity and innovative mechanical and technological solutions for soil cultivation processes were developed. The proposed ways to increase the efficiency of grain crop cultivation make it possible to tap into unused resources and become the basis for innovative mechanical and technological solutions within the framework of implementing resource-saving technologies in adaptive landscape farming in Siberia.

**Keywords:** physical properties of the soil, processes, grain crops, yield, technologies, energy intensity, degradation

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**Conflict of interest**

The authors declare no conflict of interest.

## INTRODUCTION

In Russia, grain production has historically been the leading subsector of agriculture and the core of the grain products subcomplex, with approximately 40% of agricultural production related to grain resources. As a kind of "donor" to agriculture, grain production remains the most prestigious and lucrative activity [1]. However, the predominant use of extensive technologies due to a shortage of financial and labor resources makes grain production not only extensive and energy-intensive, but also ecologically unbalanced. Thus, a 1% increase in grain crop efficiency requires the use of 2–3% of the consumed resources. The high energy intensity of grain production is due to the lack of consideration of the statistical characteristics of soil properties, leading to non-stationary processes requiring reserve energy and other capacities.

Intensification of production is identified as the primary factor in increasing crop yields and ensuring stable grain yields. Intensification of production is based on the principles of resource conservation. In crop production, resource conservation is considered within the framework of several approaches: economic, which involves reducing the cost of crop cultivation technology; energy, which involves reducing costs, expressed in energy units, used for all agricultural practices; and environmental and energy, which involves reducing the energy expended on crop cultivation, as well as on measures to preserve and improve soil fertility [2].

Currently, great hopes are placed on precision agriculture technologies (PAT). However, these technologies only take into account the nutrient content of the soil, not its physical properties [3]. The main component of the physical properties of soils is the particle size distribution of their solid phase. Its characteristics determine virtu-

ally all physical properties of the soil: porosity, bulk density, permeability, moisture capacity, air and hydrothermal regimes, etc. Therefore, the development of new technologies and equipment based on existing approaches does not provide adequate efficiency gains. New approaches to agricultural management and its mechanical and technological support are required [4]. New theoretical and methodological approaches and innovative solutions are needed, developed in complex systems using multidisciplinary [5]. However, the question of the formation of complexities is one of the key issues in science [6]. Therefore, it is impossible to create a generalized model; it is necessary to seek individual approaches and solutions for each specific case [7].

The most significant criteria for the effectiveness of agricultural practices are the economically justified yield and quality of the crop, while minimizing negative environmental impacts [8]. In this regard, the main task is to determine the optimal combination of technological advances with the preservation of the natural basis of production. This requires systematized theoretical knowledge and increased innovation in various technologies. The technical problem is caused by the insufficient development of the technical means used, and the lack of control theory does not provide the desired results when using the existing technical support within the PAT framework.

The purpose of the study is to establish the parameters of technological processes determined by the interrelations of the main properties and conditions of the soil with the working bodies of machine-technological equipment, ensuring the implementation of resource-saving technologies, the use of which in adaptive landscape farming allows to increase the efficiency of cultivation of grain crops.

The research objectives are:

1. to identify the main factors and indicators influencing the efficiency of grain crop cultivation as a result of the analysis of the efficiency of mechanical and technological processes.

2. to propose the main ways and means of managing the efficiency of grain crop cultivation in Siberia.

## MATERIAL AND METHODS

The methodology for developing agricultural technologies involves consistently overcoming factors limiting crop yield and product quality. For complex systems, including technologies and machine-tractor units, the hierarchy process analysis method is applied. The following principles underlie the methodology of the research: superposition; necessary diversity (Ashby's principle); block modularity; optimality.

## RESULTS AND DISCUSSION

Crop yield as an integral indicator of agriculture is regulated by technology, and agricultural technologies are developed in accordance with agro-ecological land types within agro-ecological groups. Land types are composed of elementary agro-landscape areas similar in terms of crop cultivation conditions.

The characteristics of arable lands in Siberia are presented in Table 1.

Table 2 presents data reflecting the level of production of grain and leguminous crops in the farms of all categories in the Siberian Federal District.

The structure of agricultural technologies, the elements of which are certain technological operations, their sequence, quantity, size and time of application, is not fully substantiated at this stage and represents a management problem even in precision farming technologies [9]. Moreover, the absence of a control theory in the PAT does not allow for the desired results to be achieved for the equipment used [10]. Achieving the desired growth rates of performance indicators at a particular enterprise is not always possible, which is due to the lack of consideration of the importance and significance of the problems being solved at all hierarchical levels, as well as the inability to manage these processes [11].

A comparative economic assessment of the effectiveness of innovative technical and technological solutions is carried out based on the dynamics of changes in fixed and variable costs. Three main postulates are applied to an optimal system: 1) functional unity, i.e., the coordinated

**Табл. 1.** Доля почв различного типа в составе пахотных земель по регионам Сибири, %  
**Table 1.** Proportion of different soil types in arable land composition by region in Siberia, %

Region	Sod-podzolic, turfy, gray forest, light gray	Dark gray, chernozemic forest steppe	Southern chernozems, chestnut	Saline
Republic of Altai	20	65	15	–
Republic of Tyva	–	10	87	–
Republic of Khakassia	6	25	69	–
Altai Territory	2	64	32	2
Krasnoyarsk Territory	15	76	7	–
Irkutsk Region	64	31	–	–
Kemerovo Region	16	84	–	–
Novosibirsk Region	5	74	7	14
Omsk Region	11	64	2	21
Tomsk Region	77	21	–	–

**Табл. 2.** Производство зерновых и зернобобовых культур в хозяйствах всех категорий  
по регионам Сибири

**Table 2.** Production of cereals and legumes in the farms of all categories by regions of Siberia

Region	Cultivated area, thous. ha			Yield, c/ha			Gross harvest, thous.tons		
	2015– 2019	2020– 2024	2020– 2024 in % to 2015– 2019	2015– 2019	2020– 2024	2020– 2024 in % to 2015– 2019	2015– 2019	2020– 2024	2020–2024 in % to 2015–2019
Republic of Altai	6,5	6,8	106,0	11,4	14,6	127,9	7,4	10,0	135,0
Republic of Tyva	10,5	14,8	141,0	10,6	10,1	95,4	11,1	14,9	134,4
Republic of Khakassia	87,5	87,5	100,0	13,4	17,5	130,0	117,5	152,7	130,0
Altai Territory	3486,8	3269,0	94,0	13,4	15,4	115,3	4669,5	5046,0	108,1
Krasnoyarsk Territory	1003,2	922,8	92,0	21,2	27,2	128,7	2122,2	2511,7	118,4
Irkutsk Region	422,3	395,0	94,0	18,2	21,0	115,7	767,5	830,8	108,2
Kemerovo Region	576,8	604,5	104,0	17,8	23,0	129,3	1025,7	1390,1	135,5
Novosibirsk Region	1499,8	1502,4	100,0	16,4	18,6	113,3	2458,5	2789,7	113,5
Omsk Region	2070,8	2040,2	98,5	15,7	14,9	94,7	3259,9	3042,1	93,3
Tomsk Region	179,8	166,9	92,8	18,3	22,6	123,7	328,6	377,5	114,9
Siberian Federal District	9343,9	9009,9	96,4	15,8	17,9	113,5	14768,	16165,4	109,5

functioning of the system's elements; 2) universal functionalism, associated with the hypothesis of the marginal utility of all growth factors; 3) functional necessity. Therefore, the coordination between crop productivity and the sustainability of the agroecosystem is achieved by the most effective technologies capable of managing the regimes of agricultural landscapes [9].

Moreover, the management of production processes (both at the enterprise level and at the level of micro-economic units) begins with the management of the technological structure of production. Without due attention to technological problems, management cannot be effective. Currently, there is no consensus on which issues should be considered a priority [12]. Each of the subjects of agricultural production management in the decision-making process is associated with the multifunctional nature of the interrelations of management objects. Scientists believe that rational land use is a comprehensive activity through which the use of land resources is organized, bringing the greatest benefit and economic advantage [13]. Therefore, preserving land resource potential and its efficient use is a crucial condition for ensuring food security and the internal and external sustainability of the Russian economy. Effective grain cultivation requires creating a value chain: soil properties, processes, yield, and profitability. The nature of soil use determines the desired level of profitability for grain crop cultivation [14].

Optimal soil properties are a function of a number of independent variables and a combination of soil properties. Moreover, each combination of physical, mechanical, and technological soil properties corresponds to its own optimal technological interventions, ensuring the greatest efficiency in terms of quality, energy consumption, and economic indicators. Changes in the physical, mechanical, and technological properties of processed materials influence the nature of the processing technology. However, even at the physiological level, there are still no substantiated standards for the impact of the diverse combination of plant life factors on

yield, its quality, and cost price. Grain production remains not only extensive and energy-intensive, but also ecologically unbalanced [15]. Therefore, zonal factors offer a significant potential for increasing the efficiency of agricultural production. However, Siberian chernozems, which produce the bulk of grain, have lost their ability to self-regulate. Their functional heterogeneity is perceived as a natural phenomenon. Furthermore, the calcium content of chernozems ensures their aggregates take on a nearly spherical shape, which reduces their hardness and strength by 10–15 times, making them less energy-intensive. These physical properties of chernozems are fundamental for the development of resource-saving technologies for grain crop cultivation in adaptive landscape agriculture in Siberia.

It has been established that soil combinations are ubiquitous in nature [16]. Moreover, the primary soil property is variability at all levels of its organization. The presence of soils in Western Siberia with physicochemical properties that increase or decrease the mobility of elements leads to the formation of biochemical provinces with excess or insufficient supply of chemical elements into the food chain. Emerging environmental challenges have made fundamental research into the natural and anthropogenic factors that determine the content and distribution of a wide range of chemical elements in soils, their availability to plants, and their ability to be released into water and the atmosphere essential. Agroecosystem productivity models provide the theoretical and practical basis for the development and implementation of scientifically sound agricultural systems. For this reason, modern research requires more precise analytical methods for determining chemical elements and their forms of occurrence in soils, and a deep understanding of the dialectical essence of the production process in agriculture and the associated features of resource use and reproduction should be the basis for the development of highly effective sustainable integrated agricultural systems [5].

Modern soil fertility is assessed using four

types of indicators: agrophysical, agrochemical, biological, and ecological. Crop rotation and tillage directly influence all productivity factors and perform a number of common functions. Fertilizers and plant protection directly influence only certain factors. However, their influence is indirectly manifested through the choice of crop rotation and tillage system [8]. The use of soil cultivation systems is determined by various soil, climatic, organizational, economic, socio-economic, and environmental conditions. The essence of soil cultivation is to alter the initial state of the soil environment and achieve specific soil conditions necessary for the cultivation of various crops.

The main methodological principles of theoretical justification of soil cultivation are:

1) minimization, up to and including the abandonment of treatment and the transition to a material impact on the soil;

2) a systematic approach to assessing the possibilities of quantitative dosage of mechanical tillage, taking into account the level of fertility, intensification and agricultural culture in each specific case;

3) zoning and consideration of soil and climatic conditions in accordance with the laws of agriculture;

4) differentiation of soil cultivation depending on its specific properties and characteristics (depth of the arable layer, structure of the genetic profile, agrochemical characteristics, biological processes);

5) discreteness, alternation in time of different methods of mechanical action on the soil, a combination of deep and intensive treatments with the gentle ones.

Experts believe that new technical and technological tools can increase the availability of previously unused natural resources and involve them in production [17]. However, innovative solutions that improve the efficiency of grain crop cultivation are formed in complex systems. Therefore, it is believed that the general task of resource conservation in agricultural technologies as complex systems is formed as a task in which the results of the previous level serve as

the initial data for subsequent levels [18]. In this regard, production technology is presented as a holistic sequence of management actions for agroecosystem biocenoses in zonal crop rotations of landscape agriculture. Selecting the optimal technology involves finding the best option that encompasses a full range of operations. The resulting technologies include: soil cultivation systems for climate zones and crops; fertilizer application systems, weed, pest, and disease control; chemical and forest reclamation systems; hydraulic engineering and irrigation systems; and a complex of machines and mechanisms [9]. Moreover, the quality of soil cultivation is an important factor, as mechanical tillage results in loosened soil. Tillage ensures the creation of an optimal arable layer with an optimal pore space structure. It contributes to the formation of aggregates of agronomically valuable size.

To find optimal mechanical and technological solutions, it is usually recommended to define the objective function as a measure of the effect. Three groups of parameters characterizing the effect of a technological object are distinguished: 1) those characterizing the scale of the technological process (e.g., productivity); 2) those characterizing the resource-saving management of the process; 3) those ensuring the required quality of the resulting product. However, there is no clarity in choosing the target function, and the needs for the industry's products are calculated based on the statistical relationship between the level of production needs and agricultural indicators (gross output or cost) [19]. Some authors propose using integral or logistic functions related to S-shaped curves in the context of forecasting the development processes of mechanical and technological solutions for obtaining a given product [20]. A more general analysis of the technological process of primary tillage is presented by us in [21].

Modern complexity theory is based on the laws of synergetics and represents a theory of the emergence of the aforementioned properties in the whole. It is argued that in biology, complexity is a consequence of the long-term

self-organization of physicochemical systems through continuous complication and acquisition of additional information. However, many mysteries remain that hinder the construction of a theory explaining the course of evolutionary processes at all levels of matter development [6]. Consequently, losses will occur. Thus, 1/3 of degradation occurs in agriculture [22].

The conducted analysis and research [23–26] made it possible to develop the main ways of managing the efficiency of grain crop cultivation in Siberian conditions.

## CONCLUSION

From a methodological point of view, the developed ways of growth and management of the efficiency of grain crop cultivation represent a whole that allows us to reveal previously unused resource reserves and propose a rational structure of innovative mechanical and technological solutions for the implementation of resource-saving technologies within the framework of adaptive landscape agriculture.

In the course of the conducted research, the following provisions were established that create a problematic situation:

– the diversity of soil properties and conditions, which determines the heterogeneity of the soil cover of Siberia, is its main characteristic that must be taken into account when designing technological processes and their technical support;

– domestic technology is only capable of implementing traditional and extensive technologies, making grain production energy- and material-intensive and ecologically unbalanced. The lack of control theory prevents the desired results from being achieved even with precision farming technologies;

– to ensure the stability of output indicators of the efficiency of grain crop cultivation, it is necessary to create complex technological and technical systems based on multidisciplinary;

– to evaluate the effectiveness of the application of technologies and their technical support,

an economically justified and ecologically balanced yield is required, the criterion for which is profit;

– the study of the profit functional at the extremum will allow us to obtain a yield function corresponding to optimal costs.

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## Клименок Иван Иванович



Сибирская сельскохозяйственная наука понесла тяжелую утрату. 17 июня 2025 г. на 76-м году жизни скончался доктор сельскохозяйственных наук, профессор, заслуженный ветеран СО РАН, бывший заместитель руководителя Сибирского научно-исследовательского и проектно-технологического института животноводства (СибНИПТИЖ СФНЦА РАН) Иван Иванович Клименок.

Иван Иванович родился 2 января 1950 г. в селе Яловка Красногорского района Брянской области в крестьянской семье.

В 1967 г. поступил в Витебский ветеринарный институт, в 1974 г. окончил зооинженерный факультет Новосибирского сельскохозяйственного института. Иван Иванович многие годы посвятил работе в СибНИПТИЖ: сначала был младшим, затем – старшим научным сотрудником, с 1994 г. – заведующим лабораторией разведения молочного скота, с 2000 г. – заместителем директора, потом – заместителем руководителя по научной работе.

После окончания аспирантуры в 1980 г. защитил кандидатскую диссертацию по обоснованию эффективных способов содержания телят в молочный период. Дальнейшие исследования посвящены выращиванию ремонтных телок черно-пестрой породы сибирского отродья, что позволило И.И. Клименку научно обосновать ресурсосберегающую технологию получения высокопродуктивных молочных животных и в 1994 г. защитить докторскую диссертацию.

Основная научно-исследовательская работа И.И. Клименка была направлена на интенсификацию молочного скотоводства в Сибири. Являясь ответственным исполнителем федеральной, руководителем и координатором региональных программ по совершенствованию черно-пестрого скота сибирского отродья и выведению его новых голштинизированных типов, он зарекомендовал себя как высококвалифицированный специалист и способный организатор.

Его многолетние исследования позволили установить широкий диапазон термонейтральной зоны у голштиinizированного черно-пестрого скота разного возраста, что послужило основой для разработки «Ресурсосберегающая технология производства молока в Сибири, обеспечивающая удой 7500 кг и более», отмеченной дипломом Россельхозакадемии «За лучшую завершённую разработку 2006 г.». Ее внедрение в ОАО «Большеникольское» Новосибирской области позволило повысить сохранность молодняка до 95% и более, в 2–3 раза сократить стоимость 1 скотоместа, повысить нагрузку на оператора машинного доения до 120 коров и раздоить первотелок до 6200 кг молока за лактацию. Приоритетность результатов исследований защищена авторским свидетельством СССР и пятью патентами на инвентарь, стойловое оборудование и молочную ферму.

Под руководством Ивана Ивановича изучены и научно обоснованы важнейшие элементы энергосберегающих технологий в молочном скотоводстве (целесообразная кровность голштин у черно-пестрых животных; оптимальные возраст (от 18 до 19 мес) и живая масса (от 380 до 400 кг) ремонтных телок при плодотворном осеменении), разработана методика оценки голштиinizированных коров по морфологическим и функциональным свойствам вымени и типу стрессоустойчивости, принципы определения качества молока, организации и технологии машинного доения коров. Данные материалы опубликованы в девяти методических рекомендациях и трех учебно-методических пособиях, рекомендованных к широкому внедрению и использованию в учебном процессе аграрных вузов Сибири и других регионов России.

И.И. Клименок – автор и основной исполнитель пяти селекционных достижений. Молочная продуктивность коров приобского, красноярского и прибайкальского типов черно-пестрой породы в хозяйствах-оригинаторах Сибири составляет от 5300 до 6500 кг, что на 680–1590 кг больше, чем у сверстниц, а у коров-рекордисток удой за лактацию превышает 12 000 кг молока жирностью от 3,6 до 4,4%. Живая масса коров андриановского типа герфордской породы достигает 550–600 кг, быков-производителей – 1000–1200 кг, молочность – 223 кг, среднесуточный прирост – 1286 г.

Результаты многолетней селекционно-племенной работы защищены пятью авторскими свидетельствами и пятью патентами, а ее углубленный анализ позволил не только запатентовать новый способ получения высокопродуктивных производителей сельскохозяйственных животных, но и создать новую породу молочного скота Сибирячка с удоем 7461 кг молока жирностью 3,8%, что на 1460 кг больше, чем у коров черно-пестрой породы.

И.И. Клименок подготовил 14 кандидатов сельскохозяйственных наук, являлся научным руководителем трех докторантов и соискателей. В соавторстве и самостоятельно им опубликовано более 210 научных работ, в том числе 11 книг, 9 рекомендаций, 3 учебно-методических пособия, а также 37 планов племенной работы с молочными стадами ведущих племенных заводов и репродукторов Западной Сибири. Он является автором раздела «Животноводство» в концепциях, рекомендациях и системах ведения АПК Северного Зауралья, Томской, Кемеровской, Новосибирской областей, республик Алтай, Бурятия и Тыва, а также раздела «Племенная работа» в «Справочнике сибирского животноводства», выдержавшего два издания.

Более 14 лет Иван Иванович работал в должности профессора кафедры ветеринарной генетики и биотехнологии Новосибирского государственного аграрного университета.

Исследования И.И. Клименка внесли существенный вклад в развитие теоретических основ молочного скотоводства, соответствуют мировому уровню, нашли широкое распространение в сельскохозяйственном производстве Сибири.

За разработку перспективных технологий в животноводстве и их активное внедрение в производство И.И. Клименок неоднократно награждался почетными грамотами Президиума и Сибирского регионального отделения Россельхозакадемии, Администрации Новосибирской области, получил звание «Заслуженный ветеран СО РАН», за особый вклад в развитие аграрной науки награжден медалью им. И.И. Синягина и медалью «40 лет СО Россельхозакадемии», отмечен благодарностью Президента Российской Федерации В.В. Путина.

Иван Иванович прожил яркую жизнь, всегда имел активную жизненную позицию, его отличали глубокая человечность, высокий профессионализм, жизнелюбие и оптимизм.

Ушел из жизни замечательный ученый, педагог, чей жизненный путь является примером честного и беззаветного служения Родине.

Светлая память об Иване Ивановиче навсегда останется в наших сердцах.

Выражаем соболезнования семье и близким в связи с тяжелой утратой.

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## ПРАВИЛА ДЛЯ АВТОРОВ

Правила для авторов составлены на основе этических принципов, общих для членов научного сообщества, и правил публикации в международных и отечественных научных периодических изданиях, а также в соответствии с требованиями ВАК для периодических изданий, включенных в Перечень российских рецензируемых научных журналов, в которых должны быть опубликованы основные научные результаты диссертаций на соискание ученой степени доктора и кандидата наук.

Журнал публикует оригинальные статьи по фундаментальным и прикладным проблемам по направлениям:

- общее земледелие и растениеводство;
- селекция, семеноводство и биотехнология растений;
- агрохимия, агропочвоведение, защита и карантин растений;
- кормопроизводство;
- инфекционные болезни и иммунология животных;
- частная зоотехния, кормление, технологии приготовления кормов и производства продукции животноводства;
- разведение, селекция, генетика и биотехнология животных;
- технологии, машины и оборудование для агропромышленного комплекса.

Статья, направляемая в редакцию, должна соответствовать тематическим разделам журнала «Сибирский вестник сельскохозяйственной науки»:

Наименование рубрики	Шифр и наименование научной специальности в соответствии с Номенклатурой научных специальностей, по которым присуждаются ученые степени
Земледелие и химизация	4.1.1. Общее земледелие и растениеводство (сельскохозяйственные науки) 4.1.3. Агрохимия, агропочвоведение, защита и карантин растений (сельскохозяйственные науки)
Растениеводство и селекция	4.1.1. Общее земледелие и растениеводство (сельскохозяйственные науки) 4.1.2. Селекция, семеноводство и биотехнология растений (сельскохозяйственные науки)
Защита растений	4.1.3. Агрохимия, агропочвоведение, защита и карантин растений (сельскохозяйственные науки)
Кормопроизводство	4.1.1. Общее земледелие и растениеводство (сельскохозяйственные науки) 4.1.2. Селекция, семеноводство и биотехнология растений (сельскохозяйственные науки) 4.1.3. Агрохимия, агропочвоведение, защита и карантин растений (сельскохозяйственные науки)
Зоотехния и ветеринария	4.2.3. Инфекционные болезни и иммунология животных (ветеринарные науки) 4.2.4. Частная зоотехния, кормление, технологии приготовления кормов и производства продукции животноводства (сельскохозяйственные науки) 4.2.5. Разведение, селекция, генетика и биотехнология животных (сельскохозяйственные науки)
Механизация, автоматизация, моделирование и информационное обеспечение	4.3.1. Технологии, машины и оборудование для агропромышленного комплекса (технические науки)
Проблемы. Суждения Научные связи Из истории сельскохозяйственной науки Краткие сообщения Из диссертационных работ	4.1.1. Общее земледелие и растениеводство (сельскохозяйственные науки) 4.1.2. Селекция, семеноводство и биотехнология растений (сельскохозяйственные науки) 4.1.3. Агрохимия, агропочвоведение, защита и карантин растений (сельскохозяйственные науки) 4.2.3. Инфекционные болезни и иммунология животных (ветеринарные науки) 4.2.4. Частная зоотехния, кормление, технологии приготовления кормов и производства продукции животноводства (сельскохозяйственные науки) 4.2.5. Разведение, селекция, генетика и биотехнология животных (сельскохозяйственные науки) 4.3.1. Технологии, машины и оборудование для агропромышленного комплекса (технические науки)

В журнале также публикуются обзоры, краткие сообщения, хроника, рецензии, книжные обозрения, материалы по истории сельскохозяйственной науки и деятельности учреждений и ученых.

Число публикаций одного автора в номере журнала не должно превышать двух, при этом вторая статья допустима лишь в соавторстве.

К рассмотрению принимаются материалы от различных категорий исследователей, аспирантов, докторантов, специалистов и экспертов в соответствующих областях знаний.

Все статьи рецензируются и имеют зарегистрированный в системе CrossRef индекс DOI.

При направлении статьи в редакцию журнала «Сибирский вестник сельскохозяйственной науки» рекомендуем руководствоваться следующими правилами.

## РЕКОМЕНДАЦИИ АВТОРУ ДО ПОДАЧИ СТАТЬИ

Представление статьи в журнал «Сибирский вестник сельскохозяйственной науки» подразумевает, что:

- статья ранее не была опубликована в другом журнале;
- статья не находится на рассмотрении в другом журнале;
- все соавторы согласны с публикацией текущей версии статьи.

Перед отправкой статьи на рассмотрение необходимо убедиться, что в файле (файлах) содержится вся необходимая информация на русском и английском языках, указаны источники информации, размещенной на рисунках и в таблицах, все ссылки оформлены корректно.

## ПОРЯДОК НАПРАВЛЕНИЯ РУКОПИСЕЙ СТАТЕЙ

1. Отправка статьи осуществляется через электронную редакцию на сайте журнала <https://sibvest.elpub.ru/jour/index>. После предварительной регистрации автора в правом верхнем углу страницы выбрать опцию «Отправить рукопись». Затем загрузить рукопись статьи (в формате \*.doc или \*.docx) и сопроводительные документы к ней. После завершения загрузки материалов обязательно выбрать опцию «Отправить письмо», в этом случае редакция автоматически будет уведомлена о получении новой рукописи.

Сопроводительные документы к рукописи статьи:

- скан-копия письма от организации с подтверждением авторства и разрешением на публикацию (образец на <http://sibvest.elpub.ru/>);
- скан-копия авторской справки по представленной форме (образец на <http://sibvest.elpub.ru/>), в которой должно быть выражено согласие на открытое опубликование статьи в печатном варианте журнала и его электронной копии в сети Интернет;
- скан-копия рукописи с подписями авторов. Автор, подписывая рукопись и направляя ее в редакцию, тем самым передает авторские права на издание этой статьи СФНЦА РАН;
- анкеты авторов на русском и английском языках (образец на <http://sibvest.elpub.ru/>);
- скан-копия справки из аспирантуры (для очных аспирантов).

2. Все поступающие в редакцию рукописи статей регистрируются через систему электронной редакции. В личном кабинете автора отражается текущий статус рукописи.

## ПОРЯДОК ОФОРМЛЕНИЯ СТАТЬИ

Текст рукописи оформляется шрифтом Times New Roman, кеглем 14 с интервалом 1,5, все поля 2,0 см, нумерация страниц внизу. Объем статьи не более 15 страниц (включая таблицы, иллюстрации и библиографию); статей, размещаемых в рубриках «Из диссертационных работ» и «Краткие сообщения», – не более 7 страниц.

**Структура оформления статьи:**

1. **УДК**
2. **Заголовок статьи на русском и английском языках (не более 70 знаков).**
3. **Фамилии и инициалы авторов, полное официальное название научного учреждения, в котором проведены исследования, на русском и английском языках.**

Если в подготовке статьи принимали участие авторы из разных учреждений, необходимо указать принадлежность каждого автора к конкретному учреждению с помощью надстрочного индекса.

4. **Реферат на русском и английском языках.** Объем реферата не менее 200–250 слов. Реферат является кратким и последовательным изложением материала статьи по основным разделам и должен отражать основное содержание, следовать логике изложения материала и описания результатов в статье с приведением конкретных данных. Не следует включать впервые введенные термины, аббревиатуры (за исключением общеизвестных), ссылки на литературу. В реферате не следует подчеркивать новизну, актуальность и личный вклад автора; место исследования необходимо указывать до области (края), не упоминать конкретные организации.

5. **Ключевые слова на русском и английском языках.** 5–7 слов по теме статьи. Желательно, чтобы ключевые слова дополняли реферат и название статьи.

6. **Информация о конфликте интересов либо его отсутствии.** Автор обязан уведомить редактора о реальном или потенциальном конфликте интересов, включив информацию о конфликте интересов в соответствующий раздел статьи. Если конфликта интересов нет, автор должен также сообщить об этом.

Пример формулировки: «Автор заявляет об отсутствии конфликта интересов».

7. **Благодарности на русском и английском языках.** В этом разделе указываются все источники финансирования исследования, а также благодарности людям, которые участвовали в работе над статьей, но не являются ее авторами.

8. **Основной текст статьи.** При изложении оригинальных экспериментальных данных рекомендуется использовать подзаголовки:

**ВВЕДЕНИЕ** (постановка проблемы, цели, задачи исследования)

**МАТЕРИАЛ И МЕТОДЫ** (условия, методы (методика) исследований, описание объекта, место и время проведения)

**РЕЗУЛЬТАТЫ И ОБСУЖДЕНИЕ**

**ЗАКЛЮЧЕНИЕ** или **ВЫВОДЫ**

**СПИСОК ЛИТЕРАТУРЫ.** Количество источников не менее 15. В список литературы включаются только рецензируемые источники: статьи из научных журналов и монографии. Самоцитирование не более 10% от общего количества. Библиографический список должен быть оформлен в виде общего списка в порядке упоминания в тексте, желательны ссылки на источники 2–3-летнего срока давности. Правила оформления списка литературы – в соответствии с ГОСТ Р 7.05–2008 (требования и правила составления библиографической ссылки). В тексте ссылка на источник отмечается порядковой цифрой в квадратных скобках, например [1]. Литература в списке дается на тех языках, на которых она издана. В библиографическое описание публикации необходимо вносить всех авторов, не сокращая их одним, тремя и т.п. Недопустимо сокращение названий статей, журналов, издательств.

Если необходимо сослаться на авторефераты, диссертации, сборники статей, учебники, рекомендации, учебные пособия, ГОСТы, информацию с сайтов, статистические отчеты, статьи в общественно-политических газетах и прочее, то такую информацию следует оформить в виде сноски в конце страницы. Сноски нумеруются арабскими цифрами и размещаются постранично сквозной нумерацией.

**Внимание!** Теоретические, обзорные и проблемные статьи могут иметь произвольную структуру, но обязательно должны содержать реферат, ключевые слова, список литературы.

## ПРИМЕРЫ ОФОРМЛЕНИЯ СПИСКА ЛИТЕРАТУРЫ, REFERENCES И СНОСОК

### СПИСОК ЛИТЕРАТУРЫ:

#### *Монография*

Климова Э.В. Полевые культуры Забайкалья: монография. Чита: Поиск, 2001. 392 с.

#### *Часть книги*

Холмов В.Г. Минимальная обработка кулисного пара под яровую пшеницу при интенсификации земледелия в южной лесостепи Западной Сибири // Ресурсосберегающие системы обработки почвы. М.: Агропромиздат, 1990. С. 230–235.

#### *Периодическое издание*

Пакуль А.Л., Лапшинов Н.А., Божанова Г.В., Пакуль В.Н. Технологические качества зерна мягкой яровой пшеницы в зависимости от системы обработки почвы // Сибирский вестник сельскохозяйственной науки. 2018. Т. 48. № 4. С. 27–35. DOI: 10.26898/0370-8799-2018-4-4.

### REFERENCES:

Составляется в том же порядке, что и русскоязычный вариант, по следующим правилам:

Фамилии И.О. авторов в устоявшемся способе транслитерации, англоязычное название статьи, *транслитерация названия русскоязычного источника (например, через сайт: <https://antropophob.ru/translit-bis>) = англоязычное название источника*. Далее для монографии должны быть указаны: город, англоязычное название издательства, год, количество страниц; для журнала: год, том, номер, страницы. (In Russian).

**Пример:** Avtor A.A., Avtor B.B., Avtor C.C. Title of article.

Транслитерация авторов. Англоязычное название статьи

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

*Транслитерация источника = Англоязычное название источника*

#### *Монография*

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

#### *Часть книги*

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).

#### *Периодическое издание*

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. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2018, vol. 48, no. 4, pp. 27–35. (In Russian). DOI: 10.26898/0370-8799-2018-4-4.

### СНОСКИ:

Цитируемый текст<sup>1</sup>.

<sup>1</sup>Климова Э.В., Андреева О.Т., Темникова Г.П. Пути стабилизации кормопроизводства Забайкалья // Проблемы и перспективы совершенствования зональных систем земледелия в современных условиях: материалы науч.-практ. конф. (Чита, 16–17 октября 2008 г.). Чита, 2009. С. 36–39.

**Цифровой идентификатор Digital Object Identifier – DOI** (когда он есть у цитируемого материала)

необходимо указывать в конце библиографической ссылки.

Пример:

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.

Наличие DOI статьи следует проверять на сайте <http://search.crossref.org/> или <https://www.citethisforme.com>.

Для этого нужно ввести в поисковую строку название статьи на английском языке.

## РИСУНКИ, ГРАФИКИ, ТАБЛИЦЫ, СКРИНШОТЫ, ФОТОГРАФИИ И ФОРМУЛЫ

Рисунки должны быть хорошего качества, пригодные для печати. Все рисунки должны иметь подрисуночные подписи. Подрисуночную подпись необходимо перевести на английский язык. Рисунки нумеруются арабскими цифрами по порядку следования в тексте. *Если рисунок в тексте один, то он не нумеруется*. Отсылки на рисунки оформляются следующим образом: «На рис. 3 указано, что ...» или «Указано, что ... (см. рис. 3)». Подрисуночная подпись включает порядковый номер рисунка и его название: «Рис. 2. Описание жизненно важных процессов». Перевод подрисуночной подписи следует располагать после подрисуночной подписи на русском языке.

Таблицы должны быть хорошего качества, пригодные для печати. Предпочтительны таблицы, пригодные для редактирования, а не отсканированные или в виде рисунков. Все таблицы должны иметь заголовки. Название табли-

цы должно быть переведено на английский язык. Таблицы нумеруются арабскими цифрами по порядку следования в тексте. Если таблица в тексте одна, то она не нумеруется. Ссылки на таблицы оформляются следующим образом: «В табл. 3 указано, что ...» или «Указано, что ... (см. табл. 3)». Заголовок таблицы включает порядковый номер таблицы и ее название: «Табл. 2. Описание жизненно важных процессов». Перевод заголовка таблицы следует располагать после заголовка таблицы на русском языке.

Фотографии, скриншоты необходимо загружать отдельно в виде файлов формата \*.jpeg (\*.doc и \*.docx – в случае, если на изображение нанесены дополнительные пометки). Разрешение изображения должно быть > 300 dpi. Файлам изображений необходимо присвоить название, соответствующее номеру рисунка в тексте. В описании файла следует отдельно привести подрисовочную подпись, которая должна соответствовать названию фотографии, помещаемой в текст.

Графики, диаграммы, гистограммы и т.д. должны прилагаться отдельным файлом в программе Microsoft Excel.

Следует обратить внимание на написание формул в статье. Все формулы должны быть редактируемые, то есть должна быть возможность внести в них изменения. Во избежание путаницы необходимо греческие ( $\alpha$ ,  $\beta$ ,  $\pi$  и др.), русские (А, а, Б, б и др.) буквы и цифры писать прямым шрифтом, латинские – курсивным (*W, Z, m, n* и др.). Математические знаки и символы нужно писать также прямым шрифтом. Необходимо четко указывать верхние и нижние надстрочные символы ( $W^1, F_1$  и др.).

## ВЗАИМОДЕЙСТВИЕ МЕЖДУ ЖУРНАЛОМ И АВТОРОМ

Редакция просит авторов при подготовке статей руководствоваться изложенными выше правилами.

Все поступающие в журнал «Сибирский вестник сельскохозяйственной науки» статьи проходят предварительную проверку на соответствие формальным требованиям. На этом этапе редакция оставляет за собой право:

- принять статью к рассмотрению;
- вернуть статью автору (авторам) на доработку с просьбой устранить ошибки или добавить недостающие данные;
- вернуть статью автору (авторам) без рассмотрения, если она оформлена не по требованиям журнала;
- отклонить статью из-за несоответствия ее целям журнала, отсутствия оригинальности, малой научной ценности.

Переписка с авторами рукописи ведется через контактное лицо, указанное в рукописи.

Все научные статьи, поступившие в редакцию журнала «Сибирский вестник сельскохозяйственной науки», проходят обязательное двухстороннее «слепое» рецензирование (double-blind – автор и рецензент не знают друг о друге).

Рукописи направляются по профилю научного исследования на рецензию членам редакционной коллегии, а также приглашенным рецензентам – ведущим специалистам по тематике рецензируемых материалов. Решение о выборе того или иного рецензента для проведения экспертизы статьи принимает главный редактор, заместитель главного редактора, научный редактор. Срок рецензирования составляет 4–6 недель.

В спорных случаях редактор может привлечь к процессу рецензирования нескольких специалистов, а также главного редактора. При положительном заключении рецензента статья передается редактору для подготовки к печати.

При принятии решения о доработке статьи замечания и комментарии рецензента передаются автору. Автору дается 2 месяца на устранения замечаний. Если в течение этого срока автор не уведомил редакцию о планируемых действиях, статья снимается с очереди на публикацию.

При принятии решения об отказе в публикации статьи автору отправляется соответствующее решение редакции.

Ответственному (контактному) автору принятой к публикации статьи направляется финальная версия верстки, которую он обязан проверить.

## ПОРЯДОК ПЕРЕСМОТРА РЕШЕНИЙ РЕДАКТОРА/РЕЦЕНЗЕНТА

Если автор не согласен с заключением рецензента и/или редактора или отдельными замечаниями, он может оспорить принятое решение. Для этого автору необходимо:

- исправить рукопись статьи согласно обоснованным комментариям рецензентов и редакторов;
- ясно изложить свою позицию по рассматриваемому вопросу.

Редакторы содействуют повторной подаче рукописей, которые потенциально могли бы быть приняты, однако были отклонены из-за необходимости внесения существенных изменений или сбора дополнительных данных, и готовы подробно объяснить, что требуется исправить в рукописи для того, чтобы она была принята к публикации.

## ДЕЙСТВИЯ РЕДАКЦИИ В СЛУЧАЕ ОБНАРУЖЕНИЯ ПЛАГИАТА, ФАБРИКАЦИИ ИЛИ ФАЛЬСИФИКАЦИИ ДАННЫХ

Редакция научного журнала «Сибирский вестник сельскохозяйственной науки» в своей работе руководствуется традиционными этическими принципами научной периодики и сводом принципов «Кодекса этики научных публикаций», разработанным и утвержденным Комитетом по этике научных публикаций, требуя соблюдения этих правил от всех участников издательского процесса.

## ИСПРАВЛЕНИЕ ОШИБОК И ОТЗЫВ СТАТЬИ

В случае обнаружения в тексте статьи ошибок, влияющих на ее восприятие, но не искажающих изложенные результаты исследования, они могут быть исправлены путем замены pdf-файла статьи. В случае обнаружения в тексте статьи ошибок, искажающих результаты исследования, либо в случае плагиата, обнаружения недобросовестного поведения автора (авторов), связанного с фальсификацией и/или фабрикацией данных, статья может быть отозвана. Инициатором отзыва статьи может быть редакция, автор, организация, частное лицо. Отозванная статья помечается знаком «Статья отозвана», на странице статьи размещается информация о причине ее отзыва. Информация об отзыве статьи направляется в базы данных, в которых индексируется журнал.

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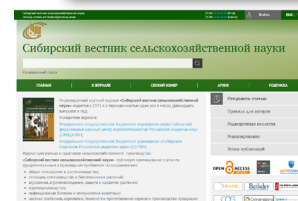
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