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Original article

COMPREHENSIVE ASSESSMENT OF THE DEVELOPMENT POTENTIAL OF PLANT PRODUCTION IN THE MUNICIPAL DISTRICT

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Abstract

The work examines a comprehensive assessment of the variability of natural-climatic and production-economic characteristics to determine the potential for the development of crop production in a municipal district. This approach allows optimizing the resources of agricultural producers, improving forecasts, plans and increasing labor productivity. The goal of the work is to analyze the variability of climatic factors and production-economic characteristics to assess the potential for agricultural development in the municipal district. The scientific novelty of the study is associated with a comprehensive assessment of climatic and production-economic characteristics using mathematical modeling for forecasting and planning production for a long-term perspective, taking into account various conditions of the agricultural producer's activities. To achieve this goal, long-term changes in precipitation and temperatures for each month of the growing season were analyzed. The influence of these factors on crop yields was determined and the most significant of them were identified. Multi-level trends were highlighted in the series of bioproductivity of grain crops, vegetables and potatoes. Crop yield losses were determined. Based on a parametric programming problem with probabilistic characteristics, plans for obtaining volumes of the main types of agricultural products until 2026 were built. At the same time, predictive and stochastic values of crop yields were previously determined. Solutions to the extreme problem were obtained for average, favorable and unfavorable conditions of activity of agricultural producers.

The methodology for a comprehensive assessment of the potential for agricultural development is applicable to enterprises, municipal and agricultural landscape areas. In the article, the methodology was tested for the Irkutsk district.

Keywords: comprehensive assessment; meteorological factors; crop production; trend; yield; probability; optimization; municipal district

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Научная статья

КОМПЛЕКСНАЯ ОЦЕНКА ПОТЕНЦИАЛА РАЗВИТИЯ РАСТЕНИЕВОДСТВА МУНИЦИПАЛЬНОГО РАЙОНА

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Аннотация

В работе рассмотрена комплексная оценка изменчивости природно-климатических и производственно-экономических характеристик для определения потенциала развития растениеводства муниципального района. Такой подход позволяет оптимизировать ресурсы сельскохозяйственного товаропроизводителя, улучшая прогнозы, планы и увеличивая производительность труда. Целью работы является анализ изменчивости климатических факторов и производственно-экономических характеристик для оценки потенциала развития сельского хозяйства на территории муниципального района. Научная новизна исследования связана с комплексной оценкой климатических и производственно-экономических характеристик с помощью математического моделирования для прогнозирования и планирования продукции на многолетнюю перспективу с учетом различных условий деятельности сельскохозяйственного товаропроизводителя. Для достижения поставленной цели проанализированы многолетние изменения осадков и температур за каждый месяц вегетационного периода. Определено влияние этих факторов на урожайность сельскохозяйственных культур и выявлены наиболее значимые из них. Выделены многоуровневые тренды в рядах биопродуктивности зерновых культур, овощей и картофеля. Определены потери урожайности сельскохозяйственных культур. На основе задачи параметрического программирования с вероятностными характеристиками построены планы получения объемов основных видов сельскохозяйственной продукции до 2026 года с предварительной прогностической и стохастической оценкой урожайности культур. Решения экстремальной задачи получены для усредненных, благоприятных и неблагоприятных условий деятельности сельскохозяйственных товаропроизводителей. Методика комплексной оценки потенциала развития сельского хозяйства применима для предприятий, муниципальных и агроландшафтных районов. В работе она апробирована для Иркутского района.

Ключевые слова: комплексная оценка; метеорологические факторы; растениеводство; тренд; урожайность; вероятность; оптимизация; муниципальный район

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Introduction

The economy of the country and regions, including agriculture, is being transformed at a rapid pace due to the development of new technologies and their widespread dissemination. The digital transformation of production processes plays a significant role in this evolution [8; 18; 29]. One of the key advantages of digital transformation is the possibility to collect and to process data related to agricultural production and to use this information in order to increase the efficiency of agriculture.

Much attention must be paid to climate change [14; 16; 21; 22; 25]. The factors of these changes influence the location of agricultural sectors [2], crop yields, volumes and quality of produced goods in different regions of the country and the world [5; 9; 10]. At the same time, variability in temperatures and precipitation in different eras can have different effects on crop yields [15].

As crop production plays an important role for national economy and food security [28; 29], ability to evaluate and to forecast impact of various factors (technological, geographical, climatic etc.) on productivity is crucial for efficient agricultural management.

Goal of the research. The purpose of the article is to consider the variability of climatic factors and production and economic characteristics to assess the possibility of agricultural development in the municipal district. To achieve the goal, the following tasks were solved:

- assessment of the variability of long-term air temperatures and precipitation during the growing season;

- the influence of meteorological factors on the productivity of agricultural crops;
- identification of significant multi-level trends in the bioproductivity of agricultural crops and assessment of probable yield losses;
- determination of optimal plans for the development of agricultural producers in the municipal district by increasing production volumes.

In essence, the solution to the set tasks is a method for a comprehensive assessment of the possibility of developing agriculture in a certain territory, for example, a municipal district.

Materials and methods

To determine the variability of meteorological factors, data on daily air temperatures and precipitation during the growing season in Irkutsk for 1996-2023 according to the Federal State Budgetary Institution "Irkutsk HMSD" were used.

When constructing the dependence of bioproductivity on meteorological factors, data on the yield of grain crops, potatoes, and vegetable crops of the Irkutskstat department for 1996-2023 in the Irkutsk district were involved. Statistical analysis of data and optimization of production volumes concerned all categories of farms.

To determine the characteristics of the parametric programming model, accounting reports of agricultural organizations were analyzed.

When constructing multi-level trends and multi-factor models, regression analysis was used. The determination of multi-level trends was based on the preliminary selection of local minima and maxima from time series [3].

Parametric programming methods under conditions of uncertainty were used to plan crop production volumes.

Results and discussion

Meteorological conditions greatly influence agricultural production even for stable producers. This was confirmed by the drought of 2015, which was observed in 14 municipal districts of the Irkutsk region. Agricultural organizations and peasant farms suffered significant losses in 2019, in which there was a catastrophic rain flood in the Iya River basin.

Research into the state of agriculture and modeling of its development must be carried out taking into account a complex of various factors: climatic, environmental, production and economic, social and others.

Let us consider the potential for the development of agriculture, or rather crop production, using the example of the Irkutsk district. To do this, it is proposed to analyze the variability of climate characteristics, assess trends in crop yields, identify the impact of meteorological factors on bioproductivity, forecast crop yields in the medium term, calculate probable losses in crop yields, and build optimal plans for production volumes.

In the development of works [5; 6], time series of average air temperatures and daily precipitation amounts for each month of the warm season (May – August) and the entire period were analyzed. Fig. 1 and 2 show the trends of average air temperature T^0C and precipitation amounts for May–August *Z*. Based on the results obtained, the trends for these characteristics are insignificant. The coefficient of determination for the trend of average air temperatures was 0.067, and for precipitation amounts almost 0.

Similar conclusions can be made by identifying the trend for the series of heat and humidity characteristics for each month of the specified season. In other words, there are no trends in the series of precipitation amounts and air temperatures during the warm period of the year. At the same time, no significant first autocorrelation coefficients were found in the series of meteorological characteristics.

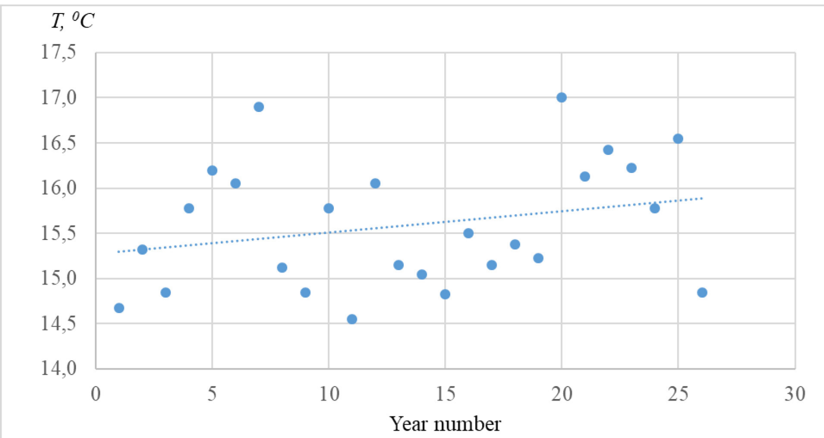

Figure 1. Changes in average air temperature for May – August according to Irkutsk data for 1996–2021

When determining trends of three levels (middle, lower and upper), the method of identifying local minima and maxima [3], criteria for assessing the significance of regression expressions (coefficient of determination R^2, Fisher's *F*-criterion, its significance level *a*, Student's *t*-statistics), as well as different functions, of which the most acceptable are logistic, linear and power functions, were used (Table 1).

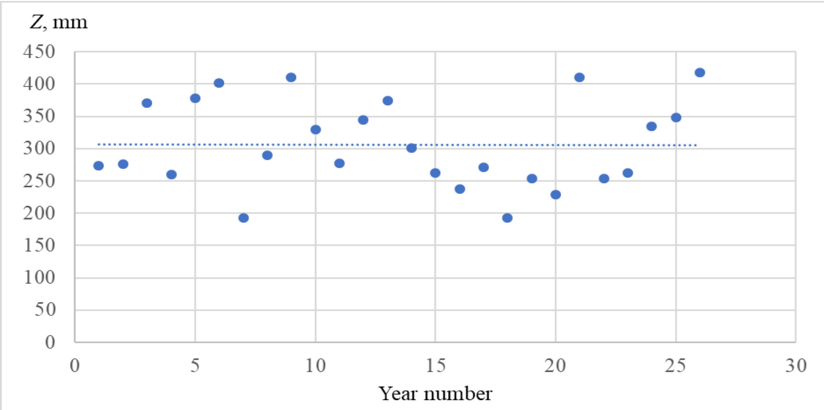

Figure 2. Changes in precipitation amounts
for May – August according to data
Irkutsk for 1996–2021

Table 1.

Multi-level trends in agricultural yields and their statistical estimates based on data from the Irkutsk district for 1997–2023

Series levels	Equation	R^2	Fisher's *F*-test	Significance level, *a*	Student's *t*-statistic	Number of events
Wheat yield						
Average (AL)	$y=24.6/(1+e^{-0.0693t})$	0.53	27.4	2.63×10^{-5}	-5.23	2
Lower (LL)	$y=17.6/(1+e^{-0.16t})$	0.64	11.0	0.0210	-3.32	
Upper (UL)	$y=24.6/(1+e^{-0.140t})$	0.64	10.9	0.0216	-3.29	
Oat yield						
Average (AL)	$y=20.4/(1+e^{-0.09t})$	0.54	27.2	0.0000311	-5.22	5
Lower (LL)	$y=16.8/(1+e^{-0.136t})$	0.53	6.8	0.0479	-2.61	
Upper (UL)	$y=20.4/(1+e^{-0.153t})$	0.63	11.9	0.0138	-3.44	
Cabbage yield						
Average (AL)	$y=7.54t+170.9$	0.61	35.9	0.00000413	5.99	5
Lower (LL)	$y=7.11t+147.0$	0.68	13.0	0.0113	3.60	
Upper (UL)	$y=9.42t+170.7$	0.69	11.35	0.0199	3.37	
Beet yield						
Average (AL)	$y=119.3t^{0.175}$	0.50	23.1	7.45×10^{-5}	4.81	5
Lower (LL)	$y=108.1t^{0.169}$	0.53	7.0	0.038	2.65	
Upper (UL)	$y=126.2t^{0.204}$	0.65	9.2	0.0288	3.03	

For the given expressions, the relative errors of each level are determined. In addition to the average values, the maximum values corresponding to rare events were calculated. The calculated errors of multilevel trend models are shown in Table 2. For all crop yields, approximately the same results were obtained. Oat yield has the greatest errors.

It should be noted that the yield series for barley and potatoes turned out to be random. For the first crop, the average value was 16.3 c/ha, the coefficients of variation and asymmetry were 0.085 and -0.32. Similar statistical parameters for potatoes correspond to 158.2 c/ha, 0.085 and 0.11.

The average values of local minima are equal to 12.6 and 149.7 c/ha for barley and potato yields. According to [7], the probability of losses associated with events, the number of which is given in the last column, can be defined as the difference between the actual values and the levels of the sequence of local minima corresponding to negative numbers. The smallest of them represent the most significant losses Δymin. Losses can also be considered in comparison with the trend of the entire series Δyc, which characterizes the average conditions of activity of an agricultural producer (Table 3). The calculated maximum losses correspond to the probability p_{min}. Grain yields obtained in the dry year of 2015 were rare.

Table 2.

Relative errors of multi-level trend models shown in table 1

Culture	Relative average error of the model, %			Relative maximum error of the model, %	
	AL	LL	UL	UL	LL
Wheat	9.5	7.4	9.3	17.8	51.3
Oat	15.2	11.1	14.0	31.9	79.4
Cabbage	12	9.2	7.0	18.1	33.2
Beet	11.5	6.4	7.4	19.3	24.2

Table 3.

Probabilistic assessment of agricultural yield losses crops according to data from the Irkutsk district for 1997–2023

Culture	p_{min}	Year	$y_{нп}$, c/ha	Year	y_{mim}, c/ha	Δy_{min}, c/ha	Δy_c, c/ha
Wheat	0.00872	2015	11.1	2001	10.7	-4.4	-8.3
Oat	0.0138	2015	8.8	2003	7.9	-6.8	-8.9
Cabbage	0.0165	2013	201.1	1998	180.2	-66.7	-98.1
Beet	0.0213	2011	137.3	1998	114.9	-33.2	-54.5
Barley	0.0131	2015	6.7	2015	6.7	-5.9	-9.6
Potato	0.0428	1998	135.4	1998	135.4	-14.3	-22.8

Let us analyze the influence of air temperatures and precipitation amounts on the yield of grain crops. Many authors, in search of significant factors affecting crop yield, propose different options for obtaining a significant factor model [4; 13; 19; 20].

In addition to this, attention should be paid to the technological and agroecological aspects of harvesting [12, 17]. The results of correlation analysis show that meteorological factors have the greatest influence on wheat yield. Moreover, these factors manifest themselves best in May, at the initial stage of vegetation. This confirms the conclusions presented in the work [6]. Of the possible options, two are highlighted:

$$y_t = a_0 + a_1 T_t + a_2 Z_t \ (t \in S) \quad (1)$$

$$y_t = a_0 + a_1 T_t + a_2 t, \quad (2)$$

where a_0, a_1, a_2 are the free term and coefficients of expressions; T, Z are average air temperature and total precipitation for May; S is the number of years.

The coefficient of determination of the first expression is 0.43, which is lower than the required value of 0.50. However, it is necessary to keep in mind the significant positive relationship between precipitation (R = 0.41) and wheat yield, as well as the negative significant relationship between air temperature (R = -0.58) and the outcome variable.

As for the second dependence, in which the factors are air temperature and time, it is significant. The determination coefficient is 0.53, Fisher's F-criterion is 12.2 with a significance level of 0.00027, and Student's t-statistics correspond to -2.8 and 3.0.

The identified properties of the characteristics are applicable to optimize the production volumes for planning. Time series characteristics described by significant multi-level trends can be forecasted. Stochastic characteristics are estimated by probabilities. This applies to events that affect the loss of agricultural products. Hence, to build a model for optimizing production of products with a criterion in the form of maximum revenue, a parametric programming problem with probabilistic characteristics is used [1]. In addition, such tasks take into account expert assessments [23; 24] and risks [26]. Table 4 shows optimal solutions to the parametric programming problem with probabilistic values of barley and potato yields.

In this problem, the probability p of the average value of the potato yield series is 0.505, and the probabilities of the average of local minima and maximums correspond to 0.267 and 0.250. For barley yield, similar probabilities are 0.477, 0.174 and 0.236.

According to the results obtained for the average operating conditions of an agricultural commodity producer, which correspond to trends in agricultural yields of complete time series and average sample values, revenue from the production of the agricultural crops in question can increase from 1.710 to 1.822 million rubles for 2024 – 2026. An increase in revenue for this period is achievable by 6.6 %, and production volumes by 6.1 %. For unfavorable conditions, production growth rates are slightly lower. Revenue could increase by almost 6.0 %, and production volumes by 6.4 %. At the same time, losses in comparison with average values amount annually to about 8.0 % in monetary terms and 6.6 % in volume. Favorable developments make it possible to obtain an additional annual increase of slightly more than 8.5 % of production and increase revenue by almost 8.9 % in comparison with the values obtained under average conditions.

Table 4.

Optimal solutions to the parametric programming problem with probabilistic characteristics according to data from the Irkutsk district for 1997–2023

Year	Characteristics	Wheat, x_1	Barley, x_2	Oats, x_3	Potatoes, x_4	Cabbage, x_5	Beet-root, x_6	Objective function, million rubles.
Average level								
2024	Volume, t	7938.7	3510.5	2891.3	57268.7	9330.5	2848.3	1 709.72
	Yield forecast, t/ha	2.15	1.82	1.92	15.59	38.22	21.4	
2025	Volume, t	8172.8	3580,7	2993.5	58414.1	9989.2	3152.2	1 764.77
	Yield forecast, t/ha	2.17	1.82	1.93	15.59	38.97	21.53	
2026	Volume, t	8413.0	3652.3	3099.3	59582.4	10693.2	3488.4	1 822.45
	Yield forecast, t/ha	2.19	1.82	1.94	15.59	39.73	21.66	
Lower level								
2024	Volume, t	6424.8	2430.3	2469.6	54991.2	8446.7	2520.9	1598.48
	Yield forecast, t/ha	1.74	1.26	1.64	14.97	34.60	18.9	
2025	Volume, t	6553.3	2478.9	2543.7	56091.0	9051.1	2789.1	1648.22
	Yield forecast, t/ha	1.74	1.26	1.64	14.97	35.31	19.05	
2026	Volume, t	6722.8	2528.5	2636.0	57212.9	9694.7	3085.7	1701.03
	Yield forecast, t/ha	1.75	1.26	1.65	14.97	36.02	19.16	
Upper level								
2024	Volume, t	8898.7	3684.0	3026.8	61383.0	10607.2	3311.5	1860.64
	Yield forecast, t/ha	2.41	1.91	2.01	16.71	43.45	24.88	
2025	Volume, t	9114.3	3757.7	3133.1	62610.6	11381.1	3669.0	1919.35
	Yield forecast, t/ha	2.42	1.91	2.02	16.71	44.4	25.06	
2026	Volume, t	9296.6	3832.9	3227.1	63862.9	12203.2	4063.3	1984.86
	Yield forecast, t/ha	2.42	1.91	2.02	16.71	45.34	25.23	

The results obtained allow us to conclude that the Irkutsk district has high potential for agricultural development. However, it is necessary to take into account the likely yield losses due to the frequent occurrence of extreme events, among which drought stands out.

It is obvious that each category of agricultural producers has different development dynamics [26]. In particular, peasant (farm) enterprises in a number of areas of production are developing somewhat faster than agricultural organizations.

Therefore, in addition to analyzing and assessing the potential of all categories of farms, it is necessary to consider the characteristics of the activities of different commodity producers.

Particular attention should be paid to crisis phenomena that have a significant impact on the development of agriculture [11].

Therefore, planning the activities of agricultural producers in favorable, average and unfavorable conditions must be supplemented by an assessment of the situation with unfavorable rare events that can significantly slow down the development process [27]. Moreover, this is not so much about prediction as about the readiness of the producer to overcome crisis phenomena.

Conclusion

A comprehensive study of the state and development potential of agricultural producers was carried out using the example of the Irkutsk district. The variability of air temperatures and precipitation amounts by month of the warm season over a long-term period was determined. The absence of trends in the series of meteorological characteristics in the 21st century is shown. A significant relationship between wheat yields and average air temperatures and precipitation amounts for May was identified. A significant factor dependence of wheat bioproductivity on average air temperatures for May and time was constructed. Multilevel trends for the yield series of wheat, oats, cabbage and beets were identified. Probability distribution laws for the bioproductivity of potatoes and barley were constructed. The problem of parametric programming with probabilistic characteristics with the definition of optimal plans for production volumes of the main grain and vegetable crops was solved. This made it possible to assess the potential for crop production development in the Irkutsk district.

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References

1. Barsukova, M. N., & Ivanyo, Ya. M. (2017). Applications of parametric programming for solving optimization problems of food production. *Bulletin of Irkutsk State Technical University*, *21(4)*, 57-66. https://doi.org/10.21285/1814-3520-2017-4-57-66 EDN: https://elibrary.ru/yljjgf
2. Svetlov, N. M., Sipts, S. O., Romanenko, I. A., & Evdokimova, N. E. (2019). Impact of climate change on the location of agricultural industries in Russia. *Problems of Forecasting*, *(4)*, 59-74. https://doi.org/10.1134/S1075700719040154 EDN: https://elibrary.ru/ztsibe
3. Druzhinin, I. P., Smaha, V. R., & Shevny, A. N. (1991). *Dynamics of long-term fluctuations in river runoff*. Moscow: Nauka. 176 p.
4. Evdokimov, M. G., Yusov, V. S., & Pakhotina, I. V. (2020). Dependence of yield and quality of durum spring wheat on meteorological factors in the southern forest-steppe of Western Siberia. *Grain Farming of Russia*, *5(71)*, 26-31. https://doi.org/10.31367/2079-8725-2020-71-5-26-31 EDN: https://elibrary.ru/owkiuo
5. Ivanyo, Ya. M. (2009). Variability of climatic characteristics of Eastern Siberia and agricultural production. In *Climate, Ecology, Agriculture of Eurasia: Proceedings of the International Scientific and Practical Conference* (pp. 31-38). Irkutsk: NC RNH VSNRC RAMS.
6. Ivanyo, Ya. M., & Stolopova, Yu. V. (2019). Climate variability and agrometeorological conditions of Pre-Baikalia: experimental studies and modeling of grain crop yields. *Meteorology and Hydrology*, *(10)*, 117-124.
7. Ivanyo, Ya. M., & Petrova, S. A. (2022). On one algorithm for detecting anomalous levels of a time series for risk assessment. *Current Issues of Agricultural Science*, *(42)*, 48-57.
8. Sanzhina, O. P., Itigilova, E. Yu., Vanchikova, E. N., et al. (2022). Study of approaches to assessing the factors of digital transformation of agriculture. *Bulletin of Kazan State Agrarian University*, *17(3)*, 163-169. https://doi.org/10.12737/2073-0462-2022-167-173 EDN: https://elibrary.ru/xcarle
9. Kolyada, V. V. (2022). Impact of climate trends on the dynamics of grain crop yields in Minsk and Mogilev regions. *Nature Management*, *(1)*, 36-44. https://doi.org/10.47612/2079-3928-2022-1-36-44 EDN: https://elibrary.ru/nnxtim
10. Kundyus, V. A., Perova, T. N., & Galkin, D. G. (2022). Study of the impact of climate change on the efficiency of agriculture in the region. *Economics of Agriculture of Russia*, *(3)*, 27-31. https://doi.org/10.32651/223-27 EDN: https://elibrary.ru/dxmmvw
11. Ovcharov, A. O., & Terekhov, A. M. (2022). Impact of economic crises on the development of agriculture: theoretical approaches and multifactorial analy-

sis. *Bulletin of Voronezh State Agrarian University*, *15(3)*, 129-140. https://doi.org/10.53914/issn2071-2243_2022_3_129 EDN: https://elibrary.ru/almgws

12. Dmitriev, N. N., Solodun, V. I., Sultanov, F. S., Zaitsev, A. M., et al. (2018). *Features of agricultural crop cultivation technologies taking into account the moisture supply of arable land in the Irkutsk region: scientific and practical recommendations*. Irkutsk. 62 p.
13. Otambekova, M. G., Solikhov, B. T., Khusenov, B. Yu., & Muminjanov, Kh. A. (2020). Limiting factors and prospects for sustainable yield increase of wheat in Tajikistan. *Bulletin of Kazan State Agrarian University*, *15(3)*, 31-36. https://doi.org/10.12737/2073-0462-2020-31-36 EDN: https://elibrary.ru/lnojnr
14. Khan, V. M., Vilfand, R. M., Tishchenko, V. A., Emelina, S. V., et al. (2023). Assessment of temperature regime changes in Northern Eurasia over the next five years based on the RAS Earth System Model forecasts and their possible consequences for agriculture. *Meteorology and Hydrology*, *(9)*, 14-28. https://doi.org/10.52002/0130-2906-2023-9-14-28 EDN: https://elibrary.ru/fdioum
15. Pavlova, V. N., & Karachenkova, A. A. (2023). Changes in agroclimatic resources of grain-producing regions of Russia and grain crop productivity in the new climate period of 1991-2020. *Meteorology and Hydrology*, *(9)*, 29-42. https://doi.org/10.52002/0130-2906-2023-9-29-42 EDN: https://elibrary.ru/epvmpc
16. Perevedentsev, Yu. P., & Vasilyev, A. A. (2023). Climate change and its impact on agriculture. *Meteorology and Hydrology*, *(9)*, 5-13. https://doi.org/10.52002/0130-2906-2023-9-5-13 EDN: https://elibrary.ru/ingeqc
17. Solodun, V. I., & Lugovnina, V. V. (2023). Agroecological aspects of the formation of arable land use structure in the Irkutsk region. *Geography and Natural Resources*, *44(3)*, 111-116. https://doi.org/10.15372/GIPR20230311 EDN: https://elibrary.ru/jtmtas
18. Sharipov, Sh. I., Mutuyev, Ch. M., & Kurbanov, Z. M. (2019). Digital transformation of agriculture: trends and ways of stimulation. *Achievements of Science and Technology of Agroindustrial Complex*, *33(11)*, 88-90. https://doi.org/10.24411/0235-2451-2019-11119 EDN: https://elibrary.ru/glekba
19. Shpanev, A. M., & Smyk, V. V. (2022). Influence of abiotic and anthropogenic factors on spring rapeseed yield formation in the North-West of the Russian Federation. *Agrarian Science of Euro-North-East*, *23(3)*, 351-359. https://doi.org/10.30766/2072-9081.2022.23.3.351-359 EDN: https://elibrary.ru/xxzcov
20. Yaromenko, N. N., Kulak, A. A., & Ovsyenko, A. A. (2020). Econometric analysis of factors affecting grain yield (on the example of agricultural organizations of the central zone of the Krasnodar Territory). *Natural and Humanitarian Studies*, *30(4)*, 269-274. https://doi.org/10.24411/2309-4788-2020-10428 EDN: https://elibrary.ru/liswuu

21. Zakrutkin, V. E., Ryshkov, M. M., Shishkina, D. Yu., & Tsvylev, E. M. (2002). Agricultural ecosystems of extreme natural conditions, their economic capacity and the prospects of stable functioning. *Izvestiya Rossiiskoi Akademii Nauk. Seriya Geograficheskaya*, (3), 69-78. EDN: https://elibrary.ru/mpmkcd
22. Rogatnev, Y. M., Dolmatova, O. N., Aleschenko, V. V. et al. (2018). Evaluation of conditions for effective agricultural land-use as a basis for sustainable development of plant-growing production in the Omsk Region. *Ecology, Environment and Conservation*, 24(4), 1546-1554. EDN: https://elibrary.ru/auhtlm
23. Ivanyo, Ya. M., Asalkhanov, P. G., & Bendik, N. V. (2019). Management of the agro-industrial enterprise: optimization uncertainty expert assessments. *International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon 2019*. P. 8934788.
24. Ivanyo, Ya. M., & Petrova, S. A. (2019). Optimization models of food processing wild-growing products with expert assessments. *Critical infrastructures: contingency management, intelligent, agent-based, cloud computing and cyber security (IWCI 2019)*. Proceedings of the VIth International Workshop, pp. 108-113.
25. Ivanyo, Ya. M., Petrova, S. A., & Kovaleva, E. A. (2022). Ecological-Mathematical Modeling in Planning Production of Agricultural Products in Conditions of Risks. *IOP Conference Series: Earth and Environmental Science*, 022083. https://doi.org/10.1088/1755-1315/988/2/022083 EDN: https://elibrary.ru/guydcd
26. Kotliarov, I. D. (2022). Heterogeneity of stakeholders as an obstacle to the development of agricultural cooperatives in Russia. *Russian Peasant Studies*, 7(4), 20-32. https://doi.org/10.22394/2500-1809-2022-7-4-20-32 EDN: https://elibrary.ru/ljkeen
27. Ivanyo, Ya. M., Petrova, S. A., Polkovskaya, M. N., & Fedurina, N. I. (2018). Modeling of the production of agrarian products under the conditions of influence of droughts, rainfall and their combinations. *Critical infrastructures: Contingency management, Intelligent, Agent-based, Cloud computing and Cyber security*. Proceedings of the Vth International workshop, pp. 78-84. https://doi.org/10.2991/iwci-18.2018.14 EDN: https://elibrary.ru/idrnl
28. Plotnikov, V., Nikitin, Y., Maramygin, M., & Ilyasov, R. (2021). National food security under institutional challenges (Russian experience). *International Journal of Sociology and Social Policy*, 41(1-2), 139-153. https://doi.org/10.1108/IJSSP-03-2020-0074 EDN: https://elibrary.ru/ffrhyz
29. Bakharev, V. V., Mityashin, G. Yu., Stelmashonok, E. V. et al. (2023). Trends of evolution of food security: digital transformation, social entrepreneurship and human dignity. *Siberian Journal of Life Sciences and Agriculture*, 15(2), 363-391. https://doi.org/10.12731/2658-6649-2023-15-2-363-391 EDN: https://elibrary.ru/kbwsda

Список литературы

1. Барсукова, М. Н., & Иваньо, Я. М. (2017). Приложения параметрического программирования для решения задач оптимизации получения продовольственной продукции. *Вестник Иркутского государственного технического университета*, 21(4), 57-66. https://doi.org/10.21285/1814-3520-2017-4-57-66 EDN: https://elibrary.ru/yljjgf
2. Светлов, Н. М., Сиптиц, С. О., Романенко, И. А., & Евдокимова, Н. Е. (2019). Влияние изменения климата на размещение отраслей сельского хозяйства России. *Проблемы прогнозирования*, (4), 59-74. https://doi.org/10.1134/S1075700719040154 EDN: https://elibrary.ru/ztsibe
3. Дружинин, И. П., Смага, В. Р., & Шевнин, А. Н. (1991). *Динамика многолетних колебаний речного стока*. Москва: Наука, 176 с.
4. Евдокимов, М. Г., Юсов, В. С., & Пахотина, И. В. (2020). Зависимость урожайности и качества зерна твердой яровой пшеницы от метеорологических факторов в южной лесостепи Западной Сибири. *Зерновое хозяйство России*, 5(71), 26-31. https://doi.org/10.31367/2079-8725-2020-71-5-26-31 EDN: https://elibrary.ru/owkiuo
5. Иваньо, Я. М. (2009). Изменчивость климатических характеристик Восточной Сибири и аграрное производство. В *Климат, экология, сельское хозяйство Евразии*: Материалы международной научно-практической конференции (с. 31-38). Иркутск: НЦ РВХ ВСНЦ СО РАМН
6. Иваньо, Я. М., & Столопова, Ю. В. (2019). Климатическая изменчивость и агрометеорологические условия Предбайкалья: экспериментальные исследования и моделирование урожайности зерновых культур. *Метеорология и гидрология*, (10), 117-124.
7. Иваньо, Я. М., & Петрова, С. А. (2022). Об одном алгоритме выделения аномальных уровней временного ряда для оценки рисков. *Актуальные вопросы аграрной науки*, (42), 48-57.
8. Санжина, О. П., Итыгилова, Е. Ю., Ванчикова, Е. Н. и др. (2022). Исследование подходов к оценке факторов цифровой трансформации сельского хозяйства. *Вестник Казанского государственного аграрного университета*, 17(3), 163-169. https://doi.org/10.12737/2073-0462-2022-167-173 EDN: https://elibrary.ru/xcarle
9. Коляда, В. В. (2022). Влияние климатических трендов на динамику урожайности зерновых культур в Минской и Могилёвской областях. *Природопользование*, (1), 36-44. https://doi.org/10.47612/2079-3928-2022-1-36-44 EDN: https://elibrary.ru/nnxtim
10. Кундиус, В. А., Перова, Т. Н., & Галкин, Д. Г. (2022). Исследование воздействия изменений климата на эффективность сельского хозяйства в

регионе. *Экономика сельского хозяйства России*, (3), 27-31. https://doi.org/10.32651/223-27 EDN: https://elibrary.ru/dxmmvw
11. Овчаров, А. О., & Терехов, А. М. (2022). Влияние экономических кризисов на развитие сельского хозяйства: теоретические подходы и многофакторный анализ. *Вестник Воронежского государственного аграрного университета*, 15(3), 129-140. https://doi.org/10.53914/issn2071-2243_2022_3_129 EDN: https://elibrary.ru/almgws
12. Дмитриев, Н. Н., Солодун, В. И., Султанов, Ф. С., Зайцев, А. М. и др. (2018). *Особенности технологий возделывания сельскохозяйственных культур с учетом влагообеспеченности пашни в Иркутской области: научно-практические рекомендации*. Иркутск, 62 с.
13. Отамбекова, М. Г., Солихов, Б. Т., Хусенов, Б. Ю., & Муминджанов, Х. А. (2020). Ограничивающие факторы и перспективы устойчивого повышения урожайности пшеницы в Таджикистане. *Вестник Казанского государственного аграрного университета*, 15(3), 31-36. https://doi.org/10.12737/2073-0462-2020-31-36 EDN: https://elibrary.ru/lnojnr
14. Хан, В. М., Вильфанд, Р. М., Тищенко, В. А., Емелина, С. В. и др. (2023). Оценка изменений температурного режима в Северной Евразии на предстоящее пятилетие по прогнозам модели земной системы ИВМ РАН и их возможных последствий для сельского хозяйства. *Метеорология и гидрология*, (9), 14-28. https://doi.org/10.52002/0130-2906-2023-9-14-28 EDN: https://elibrary.ru/fdioum
15. Павлова, В. Н., & Караченкова, А. А. (2023). Изменение агроклиматических ресурсов зернопроизводящих регионов России и продуктивности зерновых культур в новом климатическом периоде 1991-2020 гг. *Метеорология и гидрология*, (9), 29-42. https://doi.org/10.52002/0130-2906-2023-9-29-42 EDN: https://elibrary.ru/epvmpc
16. Переведенцев, Ю. П., & Васильев, А. А. (2023). Изменение климата и его влияние на сельское хозяйство. *Метеорология и гидрология*, (9), 5-13. https://doi.org/10.52002/0130-2906-2023-9-5-13 EDN: https://elibrary.ru/ingeqc
17. Солодун, В. И., & Луговнина, В. В. (2023). Агроэкологические аспекты формирования структуры использования пашни в Иркутской области. *География и природные ресурсы*, 44(3), 111-116. https://doi.org/10.15372/GIPR20230311 EDN: https://elibrary.ru/jtmtas
18. Шарипов, Ш. И., Мутуев, Ч. М., & Курбанов, З. М. (2019). Цифровая трансформация сельского хозяйства: тенденции и пути стимулирования. *Достижения науки и техники АПК*, 33(11), 88-90. https://doi.org/10.24411/0235-2451-2019-11119 EDN: https://elibrary.ru/glekba

19. Шпанев, А. М., & Смук, В. В. (2022). Влияние абиотических и антропогенных факторов на формирование урожайности ярового рапса на Северо-Западе Российской Федерации. *Аграрная наука Евро-Северо-Востока*, 23(3), 351-359. https://doi.org/10.30766/2072-9081.2022.23.3.351-359 EDN: https://elibrary.ru/xxzcov
20. Яроменко, Н. Н., Кулак, А. А., & Овсиенко, А. А. (2020). Эконометрический анализ факторов, влияющих на урожайность зерновых (на примере сельскохозяйственных организаций центральной зоны Краснодарского края). *Естественно-гуманитарные исследования*, 30(4), 269-274. https://doi.org/10.24411/2309-4788-2020-10428 EDN: https://elibrary.ru/liswuu
21. Zakrutkin, V. E., Ryshkov, M. M., Shishkina, D. Yu., & Tsvylev, E. M. (2002). Agricultural ecosystems of extreme natural conditions, their economic capacity and the prospects of stable functioning. *Izvestiya Rossiiskoi Akademii Nauk. Seriya Geograficheskaya*, (3), 69-78. EDN: https://elibrary.ru/mpmkcd
22. Rogatnev, Y. M., Dolmatova, O. N., Aleschenko, V. V. et al. (2018). Evaluation of conditions for effective agricultural land-use as a basis for sustainable development of plant-growing production in the Omsk Region. *Ecology, Environment and Conservation*, 24(4), 1546-1554. EDN: https://elibrary.ru/auhtlm
23. Ivanyo, Ya. M., Asalkhanov, P. G., & Bendik, N. V. (2019). Management of the agro-industrial enterprise: optimization uncertainty expert assessments. *International Multi-Conference on Industrial Engineering and Modern Technologies, FarEastCon 2019*. P. 8934788.
24. Ivanyo, Ya. M., & Petrova, S. A. (2019). Optimization models of food processing wild-growing products with expert assessments. *Critical infrastructures: contingency management, intelligent, agent-based, cloud computing and cyber security (IWCI 2019)*. Proceedings of the VIth International Workshop, pp. 108-113.
25. Ivanyo, Ya. M., Petrova, S. A., & Kovaleva, E. A. (2022). Ecological-Mathematical Modeling in Planning Production of Agricultural Products in Conditions of Risks. *IOP Conference Series: Earth and Environmental Science*, 022083. https://doi.org/10.1088/1755-1315/988/2/022083 EDN: https://elibrary.ru/guydcd
26. Kotliarov, I. D. (2022). Heterogeneity of stakeholders as an obstacle to the development of agricultural cooperatives in Russia. *Russian Peasant Studies*, 7(4), 20-32. https://doi.org/10.22394/2500-1809-2022-7-4-20-32 EDN: https://elibrary.ru/ljkeen
27. Ivanyo, Ya. M., Petrova, S. A., Polkovskaya, M. N., & Fedurina, N. I. (2018). Modeling of the production of agrarian products under the conditions of influence of droughts, rainfall and their combinations. *Critical infrastructures: Contingency management, Intelligent, Agent-based, Cloud computing and Cyber*

security. Proceedings of the Vth International workshop, pp. 78-84. https://doi.org/10.2991/iwci-18.2018.14 EDN: https://elibrary.ru/idrnl

28. Plotnikov, V., Nikitin, Y., Maramygin, M., & Ilyasov, R. (2021). National food security under institutional challenges (Russian experience). *International Journal of Sociology and Social Policy*, 41(1-2), 139-153. https://doi.org/10.1108/IJSSP-03-2020-0074 EDN: https://elibrary.ru/ffrhyz
29. Bakharev, V. V., Mityashin, G. Yu., Stelmashonok, E. V. et al. (2023). Trends of evolution of food security: digital transformation, social entrepreneurship and human dignity. *Siberian Journal of Life Sciences and Agriculture*, 15(2), 363-391. https://doi.org/10.12731/2658-6649-2023-15-2-363-391 EDN: https://elibrary.ru/kbwsda

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