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MANAGEMENT MODELS OF AGRARIAN PRODUCTION TAKING INTO ACCOUNT NATURAL AND TECHNOGENIC IMPACTS ON THE ENVIRONMENT

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It is proposed to take into account the damage from man-made and natural impacts in ecological and mathematical models for optimizing agricultural production by introducing coefficients of negative impact on the environment in the mathematical model. An algorithm for determining the coefficients of negative influence in conditions of incomplete information is proposed. These indicators characterize water and wind erosion of soils, land pollution and soil degradation as a result of the activities of agricultural producers. The formulation and solution of the problem of optimizing the production of agricultural products with an assessment of damage to nature in the conditions of economic activity and climatic phenomena are given. The developed linear programming model contains in the objective function and constraints the coefficients of negative influence in the form of interval estimates. An applied extreme problem was solved for two agricultural enterprises of Eastern Siberia. Its capabilities are shown for planning the production of agricultural products in conditions of minimizing damage to the external environment.

Keywords: *optimization; technogenic pollution; soil erosion; rainfed agriculture; irrigation*

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МОДЕЛИ УПРАВЛЕНИЯ АГРАРНЫМ ПРОИЗВОДСТВОМ С УЧЕТОМ ПРИРОДНЫХ И ТЕХНОГЕННЫХ ВОЗДЕЙСТВИЙ НА ОКРУЖАЮЩУЮ СРЕДУ

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Исследование предлагает учитывать ущерб от техногенных и природных воздействий в эколого-математических моделях оптимизации сельско-

хозяйственного производства путем введения в математическую модель коэффициентов негативного воздействия на окружающую среду. Предложен алгоритм определения коэффициентов негативного влияния в условиях неполной информации. Эти показатели характеризуют водную и ветровую эрозию почв, загрязнение земель и деградацию почв в результате деятельности сельскохозяйственных производителей. В работе дана постановка и решение задачи оптимизации производства сельскохозяйственной продукции с оценкой ущерба природе в условиях хозяйственной деятельности и климатических явлений. Разработанная модель линейного программирования содержит в целевой функции и ограничениях коэффициенты отрицательного влияния в виде интервальных оценок. Прикладная экстремальная задача была решена для двух сельскохозяйственных предприятий Восточной Сибири. Кроме того, показаны его возможности для планирования производства сельскохозяйственной продукции в условиях минимизации ущерба внешней среде.

Ключевые слова: *оптимизация; техногенное загрязнение; эрозия почв; богарное земледелие; орошение*

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Introduction

Ecological and mathematical modeling makes it possible to determine the main factors affecting the received volumes of agricultural products, as well as their quality. Extreme meteorological events and technogenic processes have a significant impact on the production of agricultural producers. Natural phenomena cause damage to the economy and provoke erosion processes. Emissions of pollutants into the atmosphere ultimately pollute soil and water.

In the context of the strong influence of negative phenomena on agriculture, it is relevant to use ecological and mathematical models of production planning with an objective function in the form of minimizing damage to the environment or maximizing profits, taking into account the damage caused to nature.

The research aims to describe the developed model of agricultural production management with the criterion of profit maximization, considering the damage from natural and human-made impacts on the environment in the form of empirical interval coefficients. To achieve this goal, the following tasks were formulated:

- Building adequate management models of agricultural production with minimizing natural and technogenic impacts on the environment with interval

parameters in the form of negative impact coefficients associated with water and wind erosion and pollution of soil and water with harmful substances;
- Development an algorithm of assessment of coefficients that characterize the negative impact of technogenic and natural impacts on the environment;
- Implementation of ecological and mathematical models on a real object.

The scientific novelty of the work lies in the development of an ecological and mathematical model for optimizing the production of agricultural products on irrigated and non-irrigated lands to minimize environmental damage from natural and human-made impacts. The latter are described by empirical interval coefficients obtained using the proposed algorithm.

The established model continues the development of the authors on ecological and mathematical modeling of various aspects in agricultural production [2, 6]. In particular, the work [6] describes the models developed by the authors to optimize the production of agricultural products associated with minimizing losses inflicted on the environment. At the same time, deterministic, stochastic, and models with interval estimates are considered. When constructing such models, it is of great importance to assess the coefficients of negative impact on the environment in the production of agricultural products. Therefore, one of the options for improving the modeling of production processes is to determine the most acceptable algorithm to obtain them. Studies of empirical data show that the coefficients of negative impact on the environment are interval estimates in general. This thesis was adopted as the basis for the developed ecological and mathematical model of agricultural production optimization.

Materials and methods

The theoretical and methodological basis of the research is based on the works of Russian and foreign scientists on ecological and mathematical modeling and methods of mathematical programming. Stochastic programming methods are described in [17]. The theoretical basis for solving mathematical programming problems is the work [12; 13]. The results of mathematical modeling under irrigation conditions are shown in the works [9; 14]. Separately, we highlight the models associated with soil erosion [11; 15]. Some authors [18; 19] propose the use of expert assessments in models for optimizing agricultural production. The influence of natural factors in models for optimizing the agricultural and forestry sectors was studied in [3; 20].

When constructing ecological and mathematical models for optimizing agricultural production, the following groups of parameters were used: production and economic, natural and climatic, and indicators of pollution and degradation of agricultural land. Production and economic parameters include: the area of agricultural land, crop yields, livestock and animal productivity, production costs for items of expenditure, profit per unit of area and head, the volume of water for agricultural needs, etc. Natural and climatic parameters include: precipitation, wind speed, terrain characteristics, soil quality, etc. Parameters of soil pollution and degradation characterize: background and actual content of harmful substances in soil and water, maximum permissible concentrations of pollutants, areas of eroded land as a result of water and wind erosion, etc.

Methods of probability theory and mathematical statistics, in particular, methods of constructing probability distribution laws, correlation and regression analysis, autocorrelation and autoregression analysis, and statistical testing method, are used to evaluate the properties of variability of parameters included in ecological and mathematical models for optimizing agricultural production. The solution of applied extreme problems is based on methods of mathematical programming under uncertainty.

As information, we used long-term data from the accounting reports of the agricultural organization, the regional Department for Hydrometeorology, materials of state reports, maps of the state of the soil cover of agricultural lands in the region, data from the territorial body of the Federal state statistics service.

Results and discussion

The authors in Bendik, Ivanyo & Kovaleva [2] present models for optimizing agricultural production with uncertain parameters, taking into account the technogenic and natural impact on land resources, in particular, erosion processes and soil contamination with heavy metals.

In continuation of studies of the application of ecological and mathematical models for the production of agricultural products on rainfed and irrigated lands, a linear deterministic model with interval coefficients determining the negative impact on the environment is proposed.

An ecological and mathematical model for the production of agricultural products, including rainfed and irrigated agriculture, with an assessment of the negative impact on the natural environment, is focused on maximizing profits::

$$f = \sum_{i \in I} (1 - \tilde{l}_i) c_i p_i x_i + \sum_{i \in I} (1 - \tilde{l}'_i) c'_i p'_i \; x'_i + \sum_{k \in K} (1 - \alpha_k) c_k r_k y_k \to \max, \qquad (1)$$

where c_i, c'_i are profits earned from the sale of 1 center of marketable products of culture of type i in rainfed and irrigated agriculture; c_k is the profit received from selling 1 center of commercial products animals of the species k ; x_i, x'_i are the land area for rainfed and irrigated areas; p_i, p'_i are productivity in rainfed and irrigated agriculture; r_k is the animal productivity k; $\underset{\sim}{l_i}$, $\underset{\sim}{l_i}'$ are lower estimates of the coefficients of the impact of negative processes on the soil in rainfed and irrigated agriculture for culture i; α_k is coefficient of negative impact on the resources of farm animals k; $\overline{\overline{l}}_i, \overline{\overline{l}}_i'$ are upper estimates of the coefficients of the impact of negative processes on the soil in rainfed and irrigated agriculture for culture i; y_k is number of different animal species k.

The conditions characterizing the lower volume of commercial crop production at the enterprise look like this

$$\sum_{i\in I}(1-\tilde{l}_i)p_i x_i + \sum_{i\in I}(1-\tilde{l}_i')p_i' x_i' \geq S_i, \tag{2}$$

where S_i is the minimum volume of crop production.

Restrictions of the minimum volume of production of livestock products are as follows

$$\sum_{k\in K}(1-\tilde{\alpha}_k)\, r_k y_k \geq S_k, \tag{3}$$

where S_k is the minimum volume of livestock production.

Restrictions of linking crop production and animal husbandry needs are written as follows

$$S_i \geq \sum_{k\in K} h_{ik} y_k \quad (i \in I), \tag{4}$$

where h_k is the need of animals of the species for food using culture i.

Restrictions of the availability of labor resources are as follows

$$\sum_{i\in I} b_i x_i + \sum_{i\in I} b_i' x_i' + \sum_{k\in K} b_k y_k \leq B, \tag{5}$$

where b_i, b_i' are the labor costs for processing 1 ha of rainfed and irrigated land, respectively, b_k – labor costs for caring for animals; B – available labor resources.

The conditions of the maximum permissible concentration of certain harmful substances in the soil look like this

$$\sum_{i\in I}\varphi_{ij}x_i + \sum_{i\in I}\varphi_{ij}' x_i' + \sum_{i\in I}\nu_{kj}x_i + \sum_{i\in I}\nu_{kj}' x_i' \leq \omega_j \;\; (j \in J), \tag{6}$$

where $\varphi_{ij}, \varphi_{ij}'$ are the initial concentration of the harmful substance j on the rainfed and irrigated lands, respectively; ν_{ij}, ν_{ij}' are the concentration of the harmful substance j that fell on the rainfed lands and irrigated lands; ω_j is the maximum permissible concentration of the harmful substance j in the soil.

Restrictions of water intake in the river have the form

$$\sum_{i\in I} q_i x'_i \leq T'\xi, \tag{7}$$

where q_i is the irrigation norm of culture i; T' is the vegetation period; ξ is the water discharge of the river.

Conditions for the maximum permissible concentration of certain harmful substances in the river are written as

$$\psi_j T'\xi + \mu_j \sum_{i\in I}((q_i + \lambda)x'_i + \lambda x_i) \le W_j \quad (j \in J), \tag{8}$$

where ψ_j is the initial concentration of hazardous substance j in the river; μ_j is the concentration of harmful substance j per unit volume of return water management; λ is the precipitation during the vegetation period; W_j is specified values of the maximum permissible concentration of harmful substance j in the river.

The restriction of soil losses from water and wind erosion is as follows

$$\sum_{i\in I} RU_i D_i V_i C_i P_i x_i + \sum_{i\in I} RU_i D_i V_i C_i P_i x'_i + \sum_{i\in I} M_i T \le \eta, \tag{9}$$

where η_i is maximum annual soil losses (t / ha); R is the eroding capacity of rains; U_i is the factor of soil pliability of erosion (t / ha); D_i is the factor of slope length; V_i is the factor of slope steepness; C_i is the factor of vegetation and crop rotation; P_i is the factor of effectiveness of anti-erosion measures; M_i is the intensity of soil removal, t / ha in 1 hour, T is time during which the soil is destroyed, h.

The intensity of soil erosion as a result of wind activity is related to the speed of the meteorological parameter and soil connectivity $M_i = f(\nu_d)$. In turn, the wind speed depends on the shape of the relief and the protection of the territory. The design wind speed ν_d (m / s) to determine the volume of soil loss is calculated according to the well-known formula, often used in land management design:

$$\nu_d = \nu_f K_s K_p, \tag{10}$$

where ν_f is the wind speed of dust storms recorded by weather stations and reduced to wind speed in the wind tunnel [4]; K_s is the coefficient of wind speed change taking into account the terrain; K_p is the coefficient of protection of the territory.

In the given model, losses from technological and natural phenomena are included as coefficients of negative influence in the optimality criterion and restrictions on the established volumes of agricultural production.

The algorithm for assessing the coefficients of the negative impact of natural and technogenic factors on the environment is given.

It is proposed to calculate the damage from land pollution by multiplying the normative value of agricultural land on the area of polluted land and the coefficients characterizing the degree of land pollution, the ecological significance of the territory, and the depth of land pollution [7]. The difficulty is finding the area of contaminated land, the depth of land contamination and determining the degree of land contamination, since this requires the availability of data on the concentration of pollutants in the territories.

The area, depth of land pollution, content and concentration of chemicals are determined based on materials for land survey, laboratory analyses in accordance with the relevant regulatory and methodological documents.

In addition to assessing land pollution, in many cases it is necessary to assess soil degradation associated with technological disruption, physical (overconsolidation, trampling, changing terrain), agricultural depletion (decrease in humus reserves, decline or complete loss of fertility); erosion (ravines, ravines, desertification); salinization (salinization, salinization; waterlogging).

In work [8] a formula is given to calculate the damage from soil destruction. In this analytical expression the economic indicator depends on the following parameters: the standard for the value of agricultural land, the annual income per unit area, the territory of degraded land, the coefficient of the ecological situation, the conversion factor associated with the times of land restoration, a conversion factor that takes into account the degree of land degradation.

The method of analyzing the state of soils and water bodies is applicable for assessing damage to the enterprise. At the same time, the research costs are borne by the company itself. For calculating damages, for example, for an district or enterprise that does not have the ability to conduct expensive tests and field calculations, this technique is expensive. Therefore, data from statistical collections, agrometeorological information, reports from organizations, environmental assessments, author's research, and other sources can be used to assess damage from pollution and land degradation.

In other words, the negative impact of human activity and hydrometeorological phenomena on the soil and water environment in agricultural production can be estimated using coefficients that take into account: water, wind erosion and soil contamination with harmful substances.

Depending on the availability of information on soil contamination and soil erosion, several methods for finding the negative impact coefficient are proposed.

The coefficient of negative impact on the soil as a result of extreme processes can be determined by the ratio of degraded land to the total area of agricultural land. Instead of area, production volumes are applicable. In this ray, the coefficient of negative impact is calculated by dividing the loss of production in the degraded area by the volume of the harvest obtained over the entire area. Besides, it is possible to involve experts to determine this coefficient.

Cases often arise when there is little reliable information on soil erosion and pollution. Then it is suggested. involve data from municipal districts, taking into account the amendments characterizing the features of the territory under consideration.

Using materials from work [5], 5 groups of districts were identified according to the degree of state of degrading soils and the corresponding coefficients of negative influence. Of the 5 groups of districts, Osinsky district is the most susceptible to erosion, with a degradation coefficient of 0.50-1.00. Alarsky, Balagansky Bayandaevsky, Nukutsky, Olkhonsky, Usolsky, Ust-Udinsky and Ekhirit-Bulagatsky districts belong to the group with a strong erosion and degradation coefficient equal to 0.25-0.49.

In Denisov, Solodovnikov, Denisov & Letuchij [1], indicators of the resistance of various agrotechnical backgrounds to erosion and deflation according to M.I. Lopyrev and E.I. Ryabov [10]. So, for example, the highest coefficient of erosion and deflation hazard, equal to 1, has pure steam. Perennial grasses are characterized by maximum soil protection effectiveness, their coefficient is 0.1.

The coefficient of soil degradation obtained from the erosion map is proposed to be corrected by multiplying by the index of resistance of various agricultural backgrounds to wind and water erosion.

Based on the information on the maximum permissible concentrations of pollutants, the background content of harmful substances in the soil in the districts of the Irkutsk region [16], as well as the methodology for assessing damage as a result of soil pollution, the region was zoned according to the levels of soil pollution. The analysis of these data shows that there are no municipal districts in the region with an average, strong and very strong level of soil contamination with harmful substances. Slightly polluted territories include the Angarsk, Bratsk, Irkutsk, Kirensk, Nizhneudinsk, Usolsk, Cheremkhovsk and Shelekhovsk municipal districs.

The total coefficient of negative impact can be calculated by adding up the coefficients characterizing soil degradation and pollution by harmful substances.

In case of unknown coefficient of degradation or pollution for the farm, it is possible to use the coefficient obtained for the district. In this case, it is necessary to evaluate the representativeness of farm information in relation to the district data.

We give examples of the implementation of the ecological-mathematical model (1) - (10) on real objects.

The problem of optimizing the production of agricultural products was solved by the example of two enterprises: CJSC Irkutsk Semena and ACJSC Primorskij.

For the ACJSC Primorskij model is implemented to combine rainfed agriculture and irrigation As for the economy of CJSC Irkutsk Semena, the problem of optimizing agricultural products in the absence of irrigation was solved for it.

The areas of nine agricultural crops are used as unknowns in the ecological and mathematical problem of optimizing the production of agricultural products in rainfed agriculture at ACJSC Primorskij. These include cereals (x_1), rapeseed (x_2), annual grasses for hay (x_3) and green fodder (x_4), perennial grasses for hay (x_5), green fodder (x_6) and seeds (x_7), silage crops (x_8) and fodder corn (x_9). When optimizing the placement of crops for rainfed and irrigated agriculture, the model is supplemented with the parameter of irrigated corn yield (x_{15}). In addition, five variables of the livestock industry are used in the models: the number of cows of the main herd (x_{10}), the number of cows on fattening (x_{11}), the number of horses of the main herd (x_{12}), the number of horses on fattening (x_{13}), and the number of bee colonies (x_{14}).

When solving the problem for CJSC Irkutsk Semena, the areas of five types of crops were determined: industrial grain, fodder, rapeseed, potatoes, and perennial grasses for hay. In addition, two livestock variables were calculated: the number of pigs in the main herd and fattening.

For ACJSC Primorskij, negative impact coefficients were estimated, which characterize the ratio of contaminated and eroded lands to the area of agricultural land. They range for different crops from 0.03 to 0.404. For the farm of the Irkutsk district, the coefficients of negative influence vary for different crops from 0.127 to 0.448.

Modeling allowed obtaining optimal solutions and corresponding negative impact coefficients. At the enterprise of the Nukutsky district (Primorskij) in crop production, the area varies from 0 to 11110 hectares, and the number of animals ranged from 91 to 4898 heads. At CJSC Irkutsk Semena, the sown area varied from 50 to 2335 ha, and the number of pigs remained at the level of 635 heads.

The results of obtaining optimal values of the objective function for enterprises of the Irkutsk region are shown in table 1.

Modeling for two farms according to (1) - (9) allowed determining the worst, median, and best options for optimizing crop areas and livestock. CJSC Irkutsk Semena, the discrepancy between the maximum and minimum values of the objective function relative to the median was 16.2%. In the more successful ACJSC Primorskij, this value reached 4.17% for rainfed farming and 1.14% for a combination of two types of farming. At the same time, the damages for the two farms in relative terms turned out to be close - at the level of 35.5%–36.4%.

According to the second version of the model (1) - (9), where, in addition to the interval coefficients of the negative impact, the interval estimates of the coefficients for unknown left parts of the constraints were taken into account, Table 2 shows the minimum, median, and maximum values of the objective function. It is clear that in this case, the discrepancy between the optimality criteria will be higher than for the previous version of the model. For rainfed agriculture, they amounted to 42.2%; for a combination of irrigated and rainfed agriculture – 40.3%. As for environmental damage, they are 98.6% and 89.2%.

Table 1.

Optimal values of the objective function for enterprises in the Irkutsk region (thousand rubles)

Model with deterministic production parameters and interval coefficients of negative influence		CJSC Irkutsk semena	ACJSC Primorskij, dry farming	ACJSC Primorskij, rainfed and irrigated agriculture
Minimum value	*(f)*	4,791.3	21,173.3	21,899.3
	damages	2,732.6	3,739.1	3,902.1
Median value	*(f)*	5,200.8	21,837.4	22,003.9
	damages	2,323.2	3,699.9	3,784.1
Maximum value	*(f)*	5,633.8	22,083.4	22,149.5
	damages	1,890.2	2,425.3	2,525.3

Modeling of agricultural production showed that the minimum and maximum values of land profits with a combination of irrigated and rain-fed agriculture are 1.0-3.2% higher than production without irrigation. The deviations of losses were 4.8-14.0%. Agricultural production with irrigation is more stable compared to rainfed agriculture.

Table 2.

Optimal values of the objective function for ACJSC Primorskij of the Irkutsk region (thousand rubles)

Model with interval production parameters and negative impact coefficients		Dry farming	Rainfed and irrigated agriculture
Minimum value	*(f)*	18,218.4	19,246.8
	damages	2,003.4	2,431.0
Median value	*(f)*	23,542.1	24,900.8
	damages	3,374.9	3,680.7
Maximum value	*(f)*	28,142.5	29,293.1
	damages	5,330.4	5,713.1

Comparison of the simulation results for a model with interval coefficients of negative impact on the environment and interval coefficients with unknown constraints in the left parts and a model with interval coefficients describing production indicators [6] shows the possibility of increasing the options for solving the problem in the first case. In the second case, the mathematical model describes a simplified version of the real situation. The optimal plans obtained for the first model differ from the second one in 6 variables when considering rainfed agriculture, and in 11 variables for a combination of rainfed and irrigated agriculture. At the same time, discrepancies can be more than 3,000 hectares, as in the case with the production of cereals.

Conclusion. The article presents an ecological-mathematical model with interval coefficients of the negative impact of different processes on the soil, which allows to optimize the production of agricultural products in conditions of pollution and soil erosion.

An algorithm for determining the coefficients of negative impact on land is described, which takes into account water and wind erosion of soils and its pollution.

Ecological and mathematical models for optimizing the production of agricultural products were implemented in the enterprises of the Nukutsky district (ACJSC Primorskij) and the Irkutsk region (CJSC Irkutsk Semena) in two versions. In the first version, the model includes deterministic production indicators and interval coefficients that reflect the negative impact of natural and human-made impacts on the environment. In the second version, the model contains interval coefficients of a negative impact and interval estimates of production indicators.

According to the results obtained, agricultural producers can increase profits and minimize damage to the environment using rainfed and irrigated agriculture due to the correct planning of their activities in conditions of partial degradation and soil pollution.

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