Ecological-Mathematical Modeling in Planning Production of Agricultural Products in Conditions of Risks

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Abstract. The article proposes an ecological-mathematical model to optimize the production of agricultural products, taking into account the risks associated with climatic events. The model describes a combination of crop and livestock production on irrigated and non-irrigated agricultural land. In this model, the target function characterizes the maximum income and damage to the environment as a result of farming in conditions of natural risks. Restrictions describe the availability of land and labor resources, production volumes, soil and water pollution, erosion of agricultural land, the combination of crop and livestock products in conditions of severe droughts or heavy rainfall. When implementing the model, a special case was considered: an ecological-mathematical model for non-irrigated lands, taking into account severe drought. The proposed model is implemented on the example of an agricultural enterprise in the Irkutsk region, which is subject to significant risks caused by extreme climatic events, primarily drought.

1. Introduction
Ecological-mathematical models with the criterion of optimality in the form of minimizing damage to the environment or maximizing profits, taking into account the minimum negative impact on the natural system, are of scientific and practical interest in solving problems of planning the production of agricultural products. Similar models with interval and probability coefficients with unknown objective functions and constraints were tested on real agricultural objects [1, 2, 3, 4].

At the same time, agriculture is largely exposed to extreme climatic events that increase the risks of agricultural production [13, 14, 15, 16]. The greatest harm to agriculture in the south of Eastern Siberia is caused by droughts, frosts, early snowfalls, hail, heavy rainfall, hurricane winds, rain leashes and spring floods. These phenomena destroy crops, contribute to the death of farm animals, and cause damage to farm buildings and structures.

To manage risks, in addition to ecological-mathematical models that allow optimizing the activities of an agricultural producer for some averaged climatic conditions, a model is proposed that takes into account the production of products during the formation of extreme events.

In the conditions of a sharply continental climate, the influence of extreme agrometeorological phenomena on the production of agricultural products increases. In recent years, the yield of agricultural crops is strongly influenced by arid conditions, which manifest themselves in an increase in temperatures and a decrease in precipitation in the initial growing season [9].
Therefore, it is relevant to consider ecological-mathematical models for optimizing agricultural production in conditions of risk with minimizing damage to the environment. The aim of the article is to develop an ecological-mathematical model that allows optimizing the production of agricultural products in conditions of natural risks with minimal damage to water and landing resources.

To achieve the goal, two tasks are set:
1) build an ecological-mathematical model for combining the production of crop and livestock products on irrigated and non-irrigated lands;
2) to test the ecological-mathematical model, taking into account natural risks at a real agricultural facility.

2. Materials and methods
For statistical processing of parameters characterizing extreme agrometeorological phenomena, long-term data of the Irkutsk Department for Hydrometeorology and Environmental Monitoring were used. In addition, we analyzed information about the yield of agricultural crops and prices for products obtained from the database of municipalities of the Irkutsk region.

When solving the problem of stochastic description of long-term series of observations of maximum daily precipitation, solid precipitation during the harvesting period, potential soil washout as a result of water erosion and maximum water consumption of rainfall floods, we used the results presented in [1, 9]. At the same time, to assess drought and combine this phenomenon with heavy rainfall, the materials presented in the monograph [14] were used.

Sources of information describing production at agricultural enterprises are long-term accounting data of an agricultural organization.

Indicators of pollution and soil degradation (background and actual content of harmful substances in soil and water, concentration of pollutants, area of erosion, etc.) were extracted from the materials of state reports "On the state and protection of the environment of the Irkutsk region", maps of the state of the soil cover of agricultural land in the region, information of the territorial body of the Federal State Statistics Service.

To model the indicators included in the problem of optimizing the production of agricultural products taking into account risks, the Monte Carlo method was used, since some of the indicators characterizing, first of all, external conditions and climatic events are random values [7, 8, 9, 11, 12].

To assess the losses, the methodology was used to determine the insurance value and the amount of loss (death) of agricultural crops and plantings of perennial plantings and the methodology for determining the insurance value and the amount of loss (death) of farm animals [6].

3. Main results and discussion
The production of agricultural products is influenced by various natural and man-made factors: water and wind erosion, soil and water pollution as a result of the deposition of harmful substances from the atmosphere, as well as the use of pesticides and herbicides. In addition, the production of agricultural products is highly exposed to the risks associated with extreme climatic events in the form of droughts and heavy rainfall. For such conditions of activity of an agrarian enterprise, an ecological-mathematical model is proposed, which allows minimizing damage from negative natural and man-made factors caused to the environment.

In general, the task of optimizing the production of agricultural products is formulated, taking into account the damage to the environment and the risk of a natural event. The objective function characterizes the profit taking into account negative factors:

\[ f = \sum_{i \neq l} (1 - l_i)c_i p_i x_i - \sum_{i \neq l} (1 - l_i)c_i^F p_i^F \omega_i + \sum_{i \neq l} (1 - l_i')c_i' p_i' x_i' - \sum_{i \neq l} (1 - l_i')c_i'^F p_i'^F \omega_i' + \sum_{k \neq K} (1 - \alpha_k) c_k^F r_k^F \omega_k \rightarrow \max, \]

(1)
where \( c_i \), \( c_i' \) is profit received from the sale of 1 centner of marketable products of a culture of the type \( i \) in rainfed and irrigated agriculture; \( c_k \) is a profit received from the sale of 1 centner of marketable products of animals of the type \( k \); \( c_k', c_k'^F \) is a profit received from the sale of 1 centner of marketable products of a culture of the type \( i \) n rainfed and irrigated agriculture, associated with the influence of a climatic event; \( c_k^F \) is a profit received from the sale of 1 centner of marketable products of animals of the type \( k \), associated with the influence of a climatic event; \( p_i, p_i' \) is a yield in rainfed and irrigated agriculture of a type of agricultural crop \( i \); \( x_i, x_i' \) are areas of rainfed and irrigated lands; \( \omega_i, \omega_i' \) are areas of rainfed and irrigated lands affected by a climatic event; \( p_i^F, p_i'^F \) is a yield in rainfed and irrigated agriculture of the type of agricultural crop \( i \), taking into account the influence of a climatic event; \( \eta_k \) is the productivity of animals \( k \); \( r_k^F \) is the productivity of animals \( k \), taking into account the influence of a climatic event; \( l_i, l_i' \) are coefficients of the negative impact of man-made and natural processes on the soil on rainfed and irrigated lands during crop cultivation \( i \); \( \alpha_k \) is a coefficient of negative impact on the environment when raising animals \( k \); \( y_k \) is a number of animals; \( \omega_k \) is a number of animals affected by a climatic event; \( F \) is a possibility of an event.

The restrictions on the minimum volume of commercial crop production at the enterprise look like this

\[
\sum_{i \in I} (1-\ell_i) p_i x_i + \sum_{i \in I} (1-\ell_i') p_i' x_i' - \sum_{i \in I} (1-\ell_i) p_i^F \omega_i - \sum_{i \in I} (1-\ell_i') p_i'^F \omega_i' \geq S_i - Z_i^F - Z_i'^F,
\]

where \( S_i \) is minimum volume of crop production; \( Z_i^F, Z_i'^F \) is a summand of a decrease in the minimum volume of crop production under the influence of a climatic event on rainfed and irrigated lands.

Restrictions on the minimum volume of livestock production are as follows:

\[
\sum_{k \in K} (1-\alpha_k) r_k y_k \geq S_k - Z_k^F,
\]

where \( S_k \) is a minimum volume of livestock production; \( Z_k^F \) is the summand of a decrease in the minimum volume of livestock production under the influence of a climatic event

Restrictions on linking the production of crop products and the need for it of livestock are recorded as follows

\[
S_i \geq \sum_{k \in K} h_{ik} y_k \quad (i \in I),
\]

where \( h_{ik} \) is a need for animals of species \( k \) for food using culture \( i \).

Restrictions on the availability of labor resources are as follows

\[
\sum_{i \in I} b_i x_i + \sum_{i \in I} b_i' x_i' + \sum_{k \in K} b_k y_k + \sum_{i \in I} b_i^F \omega_i + \sum_{i \in I} b_i'^F \omega_i' + \sum_{k \in K} b_k^F \omega_k \leq B,
\]

where \( b_i, b_i' \) are labor costs for the cultivation of 1 hectare of rainfed and irrigated land, respectively; \( b_i^F \) and \( b_i'^F \) are labor costs for the cultivation of 1 hectare of rainfed and irrigated lands, taking into account the influence of a climatic event; \( b_k, b_k^F \) are labor costs for caring for animals without taking into account and taking into account the impact of a climatic event; \( B \) are available labor resources.

The conditions for the maximum permissible concentration (MPC) of some harmful substances in the soil look like this

\[
\sum_{i \in I} \varphi_i(x_i + \omega_i) + \sum_{i \in I} \varphi_i'(x_i' + \omega_i') + \sum_{i \in I} \nu_i(x_i + \omega_i) + \sum_{i \in I} \nu_i'(x_i' + \omega_i') \leq \Omega_j \quad (j \in J),
\]
where $\varphi_{ij}$, $\varphi'_{ij}$ is the initial concentration of harmful substance $j$ on rainfed and irrigated lands, respectively; $V_{ij}$, $V'_{ij}$ is a concentration of a harmful substance $j$ that got on rainfed and irrigated lands; $\Omega_j$ is the value of the maximum permissible concentration of harmful substances $j$ in the soil. Indicators $\varphi_{ij}$, $\varphi'_{ij}$, $V_{ij}$ and $V'_{ij}$ are reduced to a unit area of agricultural land.

Restrictions on water intake in the river are as follows

$$\sum_{i=1}^{l} q_i \lambda^i \leq T' \xi,$$

(7)

Where $q_i$ is an irrigation rate of culture $i$; $T'$ is a growing season; $\xi$ is the flow of the river.

The condition for the maximum permissible concentration of some harmful substances in the river is written in the form

$$\psi_j T' \xi + \mu_j \sum_{i=1}^{l} [ (q_i + \lambda)(x_i + \omega_i) + \lambda(x_i + \omega_i) ] \leq W_j \ (j \in J),$$

(8)

where $\psi_j$ is the initial concentration of the harmful substance $j$ in the river; $\mu_j$ is the concentration of the harmful substance $j$ per unit volume of return water from the farm $\lambda$ is precipitation during the growing season; $W_j$ are the given values of the maximum permissible concentration of the harmful substance $j$ in the river.

The limitation on soil losses from water and wind erosion has the form

$$\sum_{i=1}^{l} RU_i D V_i C_i P_i (x_i + \omega_i) + \sum_{i=1}^{l} RU_i D V_i C_i P_i (x_i' + \omega_i) + \sum_{i=1}^{l} M_i T \leq \eta_i,$$

(9)

where $\eta_i$ is the maximum annual soil loss (t / ha); $R$ is the eroding ability of rains; $D_i$ is the slope length factor; $V_i$ is the slope steepness factor; $C_i$ is the factor of vegetation and crop rotation; $P_i$ is a factor in the effectiveness of erosion control measures; $M_i$ is the rate of soil removal (t/ha per hour); $T$ is the time during which the soil is destroyed (h). To calculate the parameters included in (9), normative methods are used.

Condition for non-negativity variables

$$x_i, x'_i, \omega_i, \omega'_i, y_k, \omega_k \geq 0.$$  

(10)

A feature of the proposed ecological-mathematical model for optimizing the production of agricultural products is the assessment of damage from the negative impact of man-made and natural factors in conditions of natural risks. Damage to the environment is characterized by coefficients of negative impact in the criterion of optimality and restrictions on the established volumes of agricultural production. The article [1] shows a diagram of sequential operations to determine the coefficient of the negative impact of natural and man-made factors on the soil and aquatic environment. In addition, parameters characterizing the impact of extreme climatic events on agricultural production are introduced into model (1) - (10).

The implementation algorithm of the given model consists in performing the following operations [1]. First, on the basis of the initial data from different sources, the coefficients for the unknowns and the right-hand sides are determined. Secondly, the coefficients of negative impact on the environment are calculated. Third, the values of events affecting the production of products are assessed. Fourthly, with the help of the developed software package, the linear programming problem is solved. Fifth, the model is implemented for different situations related to the repeatability and value of the event, using the Monte Carlo method.

The general ecological and mathematical model of agricultural production in the conditions of manifestation of extreme events, taking into account the damage to the environment with a
combination of rain-fed and irrigated agriculture, is described by formulas (1) - (10). Let us consider a particular case of a mathematical programming problem in conditions of natural risks.

This task took into account rain-fed agriculture, a combination of livestock and crop production, the impact of erosion, soil and water pollution under conditions of severe droughts affecting the activities of an agricultural producer.

When implementing an ecological-mathematical model for ASJSC Primorsky located in the Nukutsk district, taking into account the severe drought, the yield of agricultural crops was used to assess it. In particular, the variability of grain crops is described by the normal law of probability distribution, and the yield of annual and perennial grasses for green fodder is subject to a three-parameter power-law gamma distribution [5].

The areas of nine agricultural crops were used as unknowns in the problem of optimizing the production of agricultural products. These include: cereals ($x_1$), rapeseed ($x_2$), annual grasses for hay ($x_3$) and green forage ($x_4$), perennial grasses for hay ($x_5$), green forage ($x_6$) and seeds ($x_7$), silage crops ($x_8$), feed corn ($x_9$). In addition, the models used five variables of the livestock industry: the number of cows in the main herd ($x_{10}$), the number of cows for fattening ($x_{11}$), the number of horses in the main herd ($x_{12}$), the number of horses for fattening ($x_{13}$) and the number of bee colonies ($x_{14}$).

With the help of the program complex "Ecological-mathematical modeling of agricultural production" [5] in drought conditions, the following results were obtained.

When calculating an ecological-mathematical model with deterministic parameters, a profit of 22092.4 thousand rubles was obtained.

The solution of the problem with random parameters in the form of the yield of grain crops, annual and perennial grasses for green fodder showed that the enterprise will incur the greatest losses when the probability of joint events of these indicators is 0.056. In this case, the profit of the organization will be 16199.0 thousand rubles. Damage to the environment from the negative impact of natural and man-made factors corresponds to 2367.2 thousand rubles. In comparison with the profit obtained at the average indicators, the total loss is 5893.4 thousand rubles. In such conditions, the area of annual grasses for green fodder (2002 ha) and the number of cows (1000 head) is reduced. At the same time, the area of rapeseed (806 hectares), perennial grasses for green fodder (2019 hectares) and the number of fattening cows (2088 heads) may increase.

In 2015, the territory of the Irkutsk region was subject to severe drought, agricultural producers suffered heavy losses. Calculation of the ecological-mathematical model with indicators of crop yields at the level of 2015 showed a decrease in profit by 3,547.9 thousand rubles. compared to the results obtained with the average.

4. Conclusions

The article proposes an ecological-mathematical model to optimize the production of agricultural products on rainfed and irrigated lands, taking into account soil degradation and pollution of water flow under the conditions of a natural event.

A particular case of the model for rain-fed agriculture, taking into account a severe drought, was implemented for the Primorsky agricultural enterprise of the Irkutsk region. In addition, the applied extreme problem was solved under drought conditions, which is similar to the event in 2015.

The proposed model makes it possible to increase the efficiency of agricultural production management by reducing losses in extreme conditions with an assessment of the minimum damage caused to the environment by a commodity producer.

5. References

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