Raising bio-productivity of agroecosystems using intelligent decision-making procedures for optimization their state management

K E Tokarev¹,²
¹Volgograd State Agricultural University, 26, Universitetskii Avenue, Volgograd, 400002, Russia
²Volgograd State Technical University, 28, Lenina Avenue, Volgograd, 400005, Russia

E-mail: tke.vgsha@mail.ru

Abstract. The article deals with the problems of increasing the bio-productivity of agroecosystems with the help of intelligent decision-making procedures to optimize the management of their state. In the course of research, the author developed an algorithm for the interaction of operational and planned management of the state of the agroecosystem, characterized in that the values of the controlled parameters change due to changes in the initial formulation of the optimization problem and the actual content of humus at the beginning of rotation. This allows you to manage the state of the agroecosystem, taking into account the need to restore humus. In addition, the author proposes a method and algorithm for decision support system for managing the state of the agroecosystem, which allows to rationalize the process of fertilization, to ensure an increase in crop yields, profitability of agricultural production and preservation of soil fertility. With the help of decision support system (DSS), the conditions for preserving soil fertility (variants of applied mineral and organic fertilizers that stabilize humus) were determined and forecasts of bio-productivity and economic efficiency.

1. Introduction
The most important component of the strategy of scientific and technological development of the Russian Federation is agroecosystems, the importance of which is determined at the level of quality of life support, survival and security of the existence of regions and the state as a whole. In the process of operation of agroecosystems, the leading place is occupied by the task of rational management of their condition in order to increase the bio-productivity of crops and the economic efficiency of agricultural production. At the same time, it is necessary to ensure the preservation of soil fertility, which is determined primarily by humus reserves, which is the most important task in the field of nature protection management [1-7].

The complexity of solving this scientific problem is determined by the following properties and features of agroecological systems:
- multi-factor and multi-criteria, stochastic and nonlinear dependences of indicators of bio-productivity and soil fertility on anthropogenic and abiotic factors;
- unmanageability and a priori uncertainty of abiotic factors (weather conditions);
the aftereffect of agricultural processes, which consists in the fact that under the influence of anthropogenic factors, soil fertility changes, affecting the bio-productivity of systems in subsequent years.

Existing decision-making methods and mathematical models of agroecosystems are highly specialized and do not fully provide high-quality management of their condition. They are focused on solving problems related to obtaining a sufficiently high bio-productivity of individual mono-crops under certain weather conditions and specific values of soil fertility parameters. The modeling does not take into account the need for systematic achievement of high bio-productivity, profitability of production of all crops of crop rotation in all weather conditions, as well as the possibility of reducing the level of soil fertility. In connection with the above, there is an urgent task of scientific substantiation and development of methods and means of improving the management of the state of agroecosystems in the conditions of a priori uncertainty of abiotic factors. They include mathematical models of agroecosystems, as well as methods and algorithms for solving problems of managing their state [8-15].

2. Materials and methods
Based on the developed methods, algorithms and models, we propose a structural scheme of decision support for managing the state of the agroecosystem (Figure 1,2), which allows to rationalize the process of fertilization. This ensures an increase in crop yields, the profitability of agricultural production and the preservation of soil fertility.

The basis of the proposed decision support system is an algorithm implemented in the form of an intelligent software environment.

The intelligent system works according to the following algorithm:
1. The user (agronomist, farmer) enters into a dialogue mode with a computer system the source data is received at the input of the algorithm simulation models (economic parameters, the ranges in crop yields, the options of fertilizers, stabilizing humus).
2. Intelligent system implements the algorithm of the simulation model of agroecosystem and gives the user the results of the forecasts agroeconomic efficiency system.

3. Based on the results of the forecasts and in accordance with the decision-making criteria, AFON develops recommendations for the rational using management of the state of the agroecosystem.

The initial information comes from the external environment (agroecosystem and market conditions). It includes the data of weather conditions (average temperature and sum of precipitation for each decade), data field experiments (crop yields and content humus in soil at beginning of rotation) and economic parameters (prices of fertilizers, sales of products, cost for 1 ton/km transportation and etc.), market conditions. Some economic parameters (costs of agricultural production under the option without applying fertilizers, the cost of harvesting, etc.) are determined in accordance with the technological process of crop production. Information about the state of the natural environment is entered in the database of weather conditions, crop yields and soil fertility. Based on this information, the laws of distribution of weather conditions expressed in terms of the hydrothermal coefficient for the growing periods of crops are determined, and regression models of the dependence of crop yields on fertilizers are developed and weather conditions and soil fertility from the applied fertilizers, according to the soil fertility model, the options for applying fertilizers that stabilize humus are calculated. According to the technological maps of crop cultivation, economic and mathematical models of production profitability are developed, taking into account the main technological operations (fertilization and harvesting) and the scheme of placing fertilizers by crop rotation [16-21].

![Figure 2. Structure of the decision support system for improving the productivity of agroecosystems.](image-url)
Based on the synthesis of the considered models and regularities, an algorithm for the simulation model of the agroecosystem is developed, according to which the behavior of the agroecosystem is predicted in the case of fertilizer application options that stabilize humus.

Through the interface, the user (agronomist) enters these fertilizer application options, ranges of sustainable crop yields, economic parameters and receives forecast results in the form of average yield, profitability of crop production, percentage of crop yields that fall within the specified ranges, as well as above and below the specified ranges. Based on the results of forecasts, it develops recommendations for rational management the state of the agroecosystem and introduces them into production. Controlled parameters (doses of applied mineral and organic fertilizers) should ensure the achievement of decision-making criteria or, if it is impossible to solve the optimization problem, at least the maximum approximation to them.

DSS allows you to solve the following main types of tasks for managing the state of the agroecosystem:

1. Achieving the maximum yield of one of the crops of the crop rotation with restrictions on the sustainable yield of other crops, the profitability of agricultural production and the preservation of humus in the soil.
2. Achieving maximum profitability of agricultural production with restrictions on the sustainable yield of crop rotation and the preservation of humus in the soil.
3. Minimal application of mineral fertilizers, which ensures the lowest intake of toxic substances into the soil with restrictions on the eco-economic efficiency of the system and the preservation of humus in the soil.
4. Maximum growth of humus due to the introduction of organic fertilizers, provided that mineral fertilizers are excluded.
5. Maximum growth of humus under restrictions on the agro-economic efficiency of the system [22-37].

In the first two tasks, the issues of rational agriculture are considered, and at the same time, the requirements for preserving soil fertility are taken into account. The third, fourth and fifth tasks correspond to the situation when, as a result of improper land use, soil contamination with toxic substances has occurred, the humus content has decreased, and the goals of restoring soil fertility and environmental management are in the first place.

In the fifth task, the predicted agro-economic efficiency can be considered somewhat underestimated, since after several rotations, an increase in the humus content in the soil will lead to an increase in the yield and profitability of crop production. But if in this case the predicted agro-economic efficiency meets the specified criteria for decision-making, then the real one is all the more satisfied with the user of the DSS.

The fifth task can be implemented by sorting through all possible options mineral and organic fertilizers with a certain step in the area of the factor space where a positive balance of humus and a sufficiently high yield of agricultural crops are possible. Here we can recommend predicting the behavior of the agroecosystem in 2 stages: first, a macro forecast with a large step, then selecting the area of the factor space where the optimal solution of the problem is located, you should make a micro forecast. DSS can be used to determine the acreage required for the production of the planned volume of production and the required supply of fertilizers. To do this, it is necessary for each crop to find the ratio of the planned volume of production to the permissible minimum yield specified in the decision-making criteria. The maximum of these ratios can be recommended as the acreage. By multiplying the amount of fertilizers applied, determined as a result of solving the problem of managing the state of the agroecosystem, the required supply of fertilizers can be calculated per acreage.

3. Results and discussion

An algorithm of interaction between operational and planned management of the state of the agroecosystem is developed, taking into account external economic conditions and the actual value of humus at the beginning of the current rotation.
An algorithm of interaction between operational and planned management of the state of the agroecosystem is developed, characterized in that the values of the controlled parameters change due to changes in the initial formulation of the optimization problem and the actual content of humus at the beginning of rotation. This allows you to manage the state of the agroecosystem, taking into account the need to restore humus.

On the basis of the proposed methods, models and simulation algorithm, a decision support system for managing the state of the agroecosystem has been developed, which allows to rationalize the process of fertilization, ensuring an increase in crop yield, profitability of agricultural production and preservation of soil fertility. With the help of the DSS, the conditions for preserving soil fertility (variants of applied mineral and organic fertilizers that stabilize humus) were determined and forecasts of bio-productivity, as well as the economic efficiency of the system (average yield and profitability of crop production) were made.

4. Conclusion

The results of the conducted studies show that it is necessary to take into account three types of fertilizer management in the relationship:
- planned (rigid) management;
- operational management, taking into account the actual state of humus at the beginning of rotation;
- operational management, taking into account the external economic conditions of the current year.

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