

Methodological approaches to the analysis of the functioning of agricultural ecosystems in the context of anthropogenic environmental changes

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Abstract. The study provides methodological approaches to the analysis of the functioning of agricultural ecosystems in the context of anthropogenic environmental changes, based on the assessment of rationalization and efficient use of natural capital through energy consumption for the production of final products, and describes the agricultural ecosystem operating on the principles of market economy. A set of general methodological principles for analyzing the functioning of an agricultural ecosystem has been proposed. An algorithm for achieving optimal ecological and economic parameters of the functioning of the components of the agricultural ecosystem is presented, including a set of step-by-step actions, as well as multi-functional dependences of the reproductive capabilities of the main components of the agricultural ecosystem. A complex of ecological and economic parameters of the reproductive process of the agricultural ecosystem, used for its optimization, has been developed. The interpretation of terms and concepts, generalized in the course of the research within the framework of the presented approach, is carried out. A new principle of agricultural ecosystem organization is highlighted, considering it as a social, ecological and economic system.

1 Introduction

Intensification of human production activity, causing an increase in technogenic pressure on agricultural ecosystems, leads to a disruption of biological equilibrium, which manifests itself in a significant depletion of agrocenoses due to the death of useful microflora components, disorganization of microbiological processes in soil biota, production of phytotoxic elements, an increase in soil fatigue rates, transformation of the nature of infection plants, negative transformations in the immune status of cultivated plants. Self-limitation of the rate of continuous growth of productivity is the main reaction of the agricultural ecosystem in the established manifestations.

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The thesis put forward actualizes the research devoted to the formation of methodological approaches to the analysis of the functioning of agricultural ecosystems in the conditions of anthropogenic changes in the environment and the identification of functional relationships of the structural components of agricultural ecosystems with substantiation of the optimal parameters of their functioning. The solution of the tasks set will provide the requested level of environmental and economic efficiency, taking into account the limits of technogenic impacts on agricultural ecosystems, and will create conditions for their functional sustainability, as well as develop approaches to managing the agricultural ecosystem as an integral self-organizing structure functioning under the principle of operational closed condition.

2 Materials and Methods

In the process of functioning, the agricultural ecosystem concentrates substances and energy, transforming them into a new form, replenishing the expended elements in the form in which the dynamic optimum is maintained. The more nature contributes to the functioning of the agricultural ecosystem, the more efficient and cost-effective it looks. Moreover, the assessment of the efficiency of the functioning of the facilities, including agricultural ecosystems, is carried out within the framework of a generally accepted approach based on the theoretical provisions of a market economy: the ratio of the cost of the final product and its market price, the ratio of income and the cost of fixed assets. However, in our opinion, this approach presupposes some distortion of the actual production costs. In market environment, the products that have the lowest cost with the same market price are more competitive. Furthermore, the cost reduction is due to the performance of the natural resources involved in production processes. Thus, the improvement of economic parameters, and moreover, the progressive dynamics of social and economic development, presuppose a non-linear growth of the consumed natural energy.

In the framework of the modern economic approach, natural resources are not endowed with value, since no human labor is invested in their creation. The cost arises only at the moment the resource is processed into a new substance, or energy. Thus, the development of machinery and technology provides a reduction in the cost of a unit of production. We do not fully and completely share these views, since the cost of the final product does not take into account the cost of natural resources.

In the existing system of economic coordinates, labor is a meaningful, purposeful activity that is aimed at transforming natural components to meet the needs of the population. Therefore, labor is considered only that activity that is aimed at the removal of these natural components and their processing. However, in the conditions of industrialization and the gradual depletion of natural capital, another type of labor activity arises, associated with the restoration of damage to the environment as a result of its incorrect exploitation. Labor activity in this case does not contribute to the growth of incomes in the implementation of the economic process, which means that the cost of products increases if we translate the calculations into the energy calculus plane. The authors of the developed approach cite important parameters for the development of the social economic system in their works: the maintenance of society in energy terms costs an average of 270 thousand kcal/day per person, and an increase in gross output in agriculture by 1% is achieved by increasing involvement energy capacities by 3%, and the production of 1 ton of useful products is accompanied by the formation of 99 tons of waste [1, 2].

Thus, the energy required for the development of the social and economic system is formed as the sum of the costs of energy created by man and the energy produced by the natural system:

$$E = E_{\text{man}} + E_{\text{natur}}$$

An objective measure for assessing the rationalization and efficient use of natural capital is, among other things, the measure of energy consumption for production [3]. In our opinion, this is the only reliable measure of the profitability and economic efficiency of an agricultural ecosystem.

The set of general methodological principles for analyzing the functioning of the agricultural ecosystem is:

- the principle of self-organization and orderliness of the expenditure of matter, information and energy, ensuring the formation of the integrity and stability of the agricultural ecosystem, characterized by fractal reversibility (systems that transform their structure only to the extent that external conditions are transformed [4]);

- the principle of consistency of the goals of the development of the natural and social system, which ensures directional movement towards sustainable and harmonious functioning;

- the principle of “we work for ourselves, we work for others”, which focuses on taking into account the contribution of nature to meeting the needs of the social and economic system (the contribution of nature to the development of the social and economic system in comparison with the contribution of the social and economic system itself);

- the principle of managing the agricultural ecosystem as a self-organizing structure, characterized by an integral structure, functioning according to the rules of conceptual and operational isolation and self-regulation due to permanently decreasing external energy and energy generated by the agricultural ecosystem itself;

- the principle of energy efficiency of the functioning of the agricultural ecosystem, aimed at the study of energy flows and the study of energy consumption, the growth of target output parameters, without environmental degradation [5].

3 Results and Discussion

This study outlines methodological approaches to the analysis of the functioning of agricultural ecosystems in the context of anthropogenic environmental changes and provides a description of the agricultural ecosystem operating on the principles of market economy. Within the framework of the presented approach, it becomes necessary to interpret the applied terminology and concepts generalized in the course of the study, including the functional stability of the agricultural ecosystem, the complex of ecological and economic parameters of the reproductive process of the agricultural ecosystem, the invariant of the structure of the agricultural ecosystem, the conceptual and operational closure of the agricultural ecosystem, self-organization and self-regulation of the agricultural ecosystem of development of the attractive goal of the agricultural ecosystem.

The functional stability is a significant sign of agricultural ecosystems, characterizing its resulting efficiency and is a dynamic optimum in the parameters and system functions of the agricultural ecosystem components, which is based on verified and empirically substantiated regulatory and design solutions [6, 7].

The functional stability of the agricultural ecosystem to the effects of biotic and abiotic factors is largely determined by the anthropogenic component and is due to the observance of the consistency of the interrelationships of the components that set the state “anthropogenic load - the ability to self-reproduction”. Establishment of dependencies between the reproductive abilities of the components of the agricultural ecosystem should take place within the framework of the rules for the functioning of complex natural and technogenic systems on the basis of a set of economic, ecological, social, and biological laws. The methods used to identify the relationships between the reproductive abilities of

the agricultural ecosystem include empirical and statistical, correlation and factor analysis. Within the framework of the indicated methods, biogeochemical, dynamic, balance and nonlinear models are used that establish multi-functional dependencies. The use of these models in the analysis makes it possible to obtain a fairly accurate statistical estimate with the determination of the degree of influence of anthropogenic impact on the reproductive capacity of the agricultural ecosystem component. The calculations make it possible to identify and substantiate the directions for reducing technogenic pressure and form a toolkit for ensuring the sustainable functioning of the agricultural ecosystem.

Egorov E.A. verified multi-functional dependencies of the reproductive capabilities of the main components for agricultural ecosystems with the placement of fruit plantations. Thus, exceeding the standard parameter of soil compaction by 1% or more affects the decrease in the yield of fruit crops by 0.5%; exceeding the permissible pesticide load by 1% or more reduces the reproductive potential of plantings by 2.7%; increasing the use of the biological method (replacing chemical pesticides with biologically active supplements) reduces the residues of insecticides and fungicides in the soil by 1.62%, increases the yield by 0.6%, reduces the cost of protective measures by 3.4%, on production in general by 2.5%, which leads to an overall increase in profitability by 2.4% [7].

In modern conditions, agricultural ecosystems should be tuned to reduce the technogenic component and reduce the consumption of resources used in the production process. The key criteria for optimizing the ecological and economic state of the agricultural ecosystem and its components are the limiting minimization of the negative anthropogenic impact on the environment, the maximization of the productive potential of the agricultural ecosystem, and the maximization of the yield per unit of consumed technogenic resources.

The main methods for achieving the indicated criterion values are a selection of plant varieties adapted to the corresponding agricultural ecosystem, rational placement of fruit plantations, and the use of biomass. The indicated methodological approaches allow the development of instructions and regulations for production activities in the agricultural ecosystem.

The algorithm for achieving optimal ecological and economic parameters of the functioning of the components of the agricultural ecosystem includes a set of step-by-step actions:

- formulation of a local task within the agricultural ecosystem;
- development of a system of assessment indicators;
- identification of interdependencies and interactions between the components of the agricultural ecosystem;
- formation of a system of criteria for optimizing the ecological and economic state of the agricultural ecosystem;
- modeling of processes and calculation justification of the ecological and economic parameters of the system.

The functional stability of the agricultural ecosystem is associated with the achievement of a dynamic optimum in the system functions and parameters of its biological components for the realization of the production potential, which is achieved primarily on the basis of adaptability, i.e., the wide involvement of biological resources in reproduction processes.

Zhuchenko A.A. considers the construction of sustainable agricultural ecosystems based on an increase in the species and genotypic diversity of cultivated plants, their adaptive distribution; genetic determination of the ability of agricultural ecosystems to utilize the natural and anthropogenic resources of the environment with the greatest efficiency in the process of life as the main factors of biologization and ecologization of intensification processes in crop production [8].

In his studies, Shchukin S.V. considers the choice of species and breeds, taking into account the produced crop products, as well as with local agricultural and climatic conditions; calculation of the optimal number of animals depending on the existing resource base and cultivated crops; ensuring the functioning of the agricultural ecosystem with the minimization of the used fossil energy and the leveling of the harm caused to the environment among the main factors of biologization and ecologization of animal husbandry [9].

Table 1 shows the generalized parameters of the ecological and economic state of the agricultural ecosystem and the reproduction process, the observance of which ensures functional stability and a given level of efficiency. Modeling the functional stability of the agricultural ecosystem allows you to obtain a reliable statistical assessment of the systemic relationships that are formed within the agricultural ecosystem, and formulate regulations for the impact on its reproductive potential with a calculated justification for reducing technogenic pressure in a set of areas, as well as develop tools for achieving sustainability parameters.

Table 1. Complex of ecological and economic parameters of the reproductive process of the agricultural ecosystem, used for its optimization.

Stage of the reproductive process	System component	Estimated indicator
<i>Agricultural ecosystem</i>		
Formation of means of production (distribution chain)	biocenosis	
	plants (producers) animals (consumers)	stress fluctuation of the realizability of the production potential of system components
		acceptable levels of pesticides
		preservation of biologically inherent yield and productivity
	soil (destructors) microbiota	Physical and chemical and particle size distribution of the soil; density; moisture supply and mineralization; humus content; the volume of microbial biomass; the ratio of symbiotes and pathogens; pesticide residues
	agrocenosis	
	agrotechnical regulations	implementing the potential of yield and productivity
		indicators of excess of the average economic yield and productivity
		break-even point indicators
	infrastructure systems	relative indicators of the functionality of the agricultural ecosystem
infrastructure systems	relative performance indicators of the use of infrastructure systems	
<i>Social and economic system</i>		
Implementation of the production process (production area)	production and technological activities	need for infrastructure, human and natural resources
		return on capital investment; income to capital investment ratio
		identification of optimal proportions in the ratio: yield/productivity - costs - income
		ratio of fixed and variable costs; ratio of income and costs; ratio of income and working capital
		integral indicator of resource efficiency
<i>Market system</i>		
Conversion of produced value into monetary value. (distribution chain)	commodity, economic and marketing activities	indicators of product standardization; product quality indicators
		indicators of product competitiveness
		indicators of profitability of production and sales

Identification of the optimal range of indicators of the ecological and economic efficiency of the agricultural ecosystem highlighted in the table creates the basis for

increasing its capabilities, taking into account the combination of factors of the external and internal environment and ensuring the growth of qualitative and quantitative factors, which will form a solid basis for sustainable development.

The invariant of the structure of the agricultural ecosystem consists of a set of elements of the social and economic system and ecosystem, including the components of the natural environment, society and the infrastructural basis of a certain territory, taking into account its area and ecological capacity. The presence of these elements creates the basis for its stability and ability to self-reproduction, determines the formation of coordinated multifunctional interconnections of the components that set the state of “anthropogenic load - self-reproduction”. The establishment of dependencies between the reproductive components of the agricultural ecosystem occurs within the framework of the rules for the functioning of complex natural and technogenic systems on the basis of a set of economic, environmental, social, and biological laws. The invariant structure of the agricultural ecosystem is characterized by the ratio of matter and energy flows along the formed food chains: "plant - cattle - man" and "plant - man". Thus, specialization of the agricultural ecosystem arises. The society determines the choice of primary and secondary biological products, forms a set of plant and animal species, as well as methods of growing them, which will ensure the highest productivity and yield. The state of the agricultural ecosystem resources, i.e., soil properties, biodiversity, hydrological and hydrochemical regimes of the agricultural ecosystem are largely determined by the parameters of agricultural ecosystem exploitation and the level of technogenic pressure. As a result of the management of the agroecosystem by the society, the "conservative" circulation of matter and energy is accelerated, and it goes into an abiotic state. The agricultural ecosystem suppressed and transformed the mechanisms of self-regulation inherent in natural systems, which leads to a decrease in resistance. The intensity and direction of the processes of exchange of matter and energy between cultivated crops and raised animals determines the productivity of the agricultural ecosystem.

Conceptual and operational closure of the agricultural ecosystem is separation from the environment in the sense of the independence of the results of recursive evolution and structural accommodation from the influences of the external environment. This is a system property determined by a set of processes, which is clearly visible only within the system. In this case, we are not talking about the isolation of the agricultural ecosystem, but only about the operational closure, i.e., its self-sufficiency. The notion of “structural fit” helps explain the relationship of the agricultural ecosystem to the environment, and how the system is adapted to it. Put in other words, the mutual consistency of the agricultural ecosystem and the environment determines the mechanism of coexistence of systems and forms a space of opportunities for each of them. Structural correspondences do not affect or limit the self-determination of the agricultural ecosystem. Furthermore, they, being reflected in the forms and operations of the agricultural ecosystem, will make it possible to form a structure that will be ready for resonant processes. In this case, we are talking about identity achieved by structural correspondence, that is, a completely different composition of elements of the agricultural ecosystem and the environment, with deep structural coherence, allows them to act as a form of something one. Structural conformities limit the agricultural ecosystem's capabilities, but leave it free at such an optimal level that it can behave “unadapted”. The adaptation of the agricultural ecosystem to the surrounding world occurs by compensating for the internal excess of its capabilities, reacting with various limitations of these capabilities. By the closed nature of the agricultural ecosystem, we mean "operational closed condition", not thermodynamic one. The operations carried out by the agricultural ecosystem in the process of functioning do not allow it to go beyond the limits of functioning; on the contrary, they ensure its closure. Otherwise, the agricultural ecosystem would not be able to isolate itself and form the boundaries of the complexity of

the external world, and, therefore, would not be able to arise and exist. Closed condition, at the same time, concerns only the operations of the agricultural ecosystem, acting as a condition for its openness and presupposes purposeful development towards a certain spontaneously formed given state.

Self-organization and self-regulation as properties of an agricultural ecosystem are a symbiosis of its structure and processes in which a complex dynamic system is formed, improved and reproduced due to the supply of external energy. This is an immanent property of a complex system that tends to a state of dynamic optimum. In this case, we mean the imbalance of the inflow and outflow of matter and energy, which initiates the presence of a positive "balance", which acts as the basis for the self-development of the agricultural ecosystem. The alienated energy and substance of the agricultural ecosystem concentrates and spends on self-improvement and strengthening of the organizational structure. We call this property self-organization of the agricultural ecosystem. From the standpoint of self-organization, agricultural ecosystems are social and ecological and economic formations that, resulting from the mutual expediency of these systems, achieve maximum stability and productivity.

The systems are considered self-organizing because they are formed without an estimated goal. Their goal is attractive in the sense that, being formed, the system entails a process, since it acts as the most effective opportunity for the production of products. We call an attractive goal a goal that arises under the influence of interrelated events at the initial moment, which predetermine the development of the process towards a given goal, all other things being equal. Put in other words, the task is not to identify the optimal transition to the desired goal, but to organize the state of the system according to the goal, that is, to create in the present an attractor of the future that initiates the present. Self-organizing holistic agricultural ecosystems are endowed with their own attractor, that is, such a state that they form together with the environment, and which they can achieve if all the initial conditions of the internal and external environment remain unchanged throughout the entire period of movement of the system towards achieving its goal. However, under natural conditions in agricultural ecosystems, on the way to achieving an attractive goal, random or non-random events occur that change the attractor as such. Thus, the attractive target becomes wandering or "strange", changing its coordinates in space and time. It acts as a limit, in the process of approaching which the development of the agricultural ecosystem stagnates, the processes taking place inside it stabilize, and the system reaches the level of sustainable development and dynamic optimum. The paradox is that an attractive goal allows you to form the prospects for the development of an agricultural ecosystem in accordance with its future state. The state has not yet been reached, but it is determined by the future. In a methodological sense, positioning an attractor as a goal of developing an agricultural ecosystem turns out to be quite effective. Attractive goals are critical for all types of agricultural ecosystems.

4 Conclusions

Within the framework of the existing methodology for the functioning of agricultural ecosystems in the management structure, there are no elements that, upon reaching a certain predetermined level of productivity, would compensate for the harm caused to the environment from further growth of its performance [10]. Once this level of productivity is reached, the agricultural ecosystem should switch to intensive methods that increase resilience and productivity. The activity of the social and economic system should be anti-entropic in relation to the ecological system in which it is located. There is a given state of the agricultural ecosystem, which it must achieve after a specified time, including the qualitative and quantitative parameters of the products produced, as well as the structure,

forms and amount of consumed energy, information and mass of matter. Social and economic systems are able to identify their given state. Thus, the agricultural ecosystem can be based on new principles of organization and be considered as a social, ecological and economic system, provoking the inter-penetration of systems, which presupposes the improvement of their condition. The status of the agricultural ecosystem and the output characteristics are changing. In addition to cost-effectiveness, sustainability and productivity of the system arises. The part of the ecosystem that is part of the agricultural ecosystem should be transformed into the plane of market relations and operate on the principles of "supply - demand - price", with the determination of prices in energy and monetary terms. The governing body of the agricultural ecosystem must implement the function of comparing the given state of the agricultural ecosystem with the one achieved at the current moment. A given state is formed for specific goals and is, in principle, achievable. The ratio of the given and current state allows you to establish the action of negative feedbacks and assess the performance of the agricultural ecosystem, as it moves towards a given state. Energy analysis and the results of energy assessment of production activities due to the functioning of the agricultural ecosystem allows one to compare agricultural ecosystems of various specializations, to quantify the share of energy introduced by the society and nature. Within the framework of the proposed methodological approach, the productivity and efficiency of the agricultural ecosystem are determined by the energy contribution of the ecosystem. We consider this circumstance to be a strategic guideline for the development of agricultural ecosystems.

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