Formation of a model of a closed production cycle in an agricultural enterprise based on the use of biological waste

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Abstract. An ecologically safe agroecosystem can be thought of as a model of a closed cycle of matter and energy. Increasing the adaptive potential of the production system is achieved by creating flexible production facilities, improving infrastructure, as well as researching and preparing new types of raw materials, energy and technologies for inclusion in the production cycle. The use of an ecological-economic model, in the form of a computer program, will allow, using dynamic mathematical functions, combined into a structure according to the feedback principle, to process a large amount of information about the current state of production sectors, predicted climatic parameters, dynamics of market prices, etc. The result is a tactical modernization of production to ensure maximum sustainable profitability and environmental safety. The introduction of vermicompost into the soil, at a dose of 8-12 t / ha, provides a return of carbon to the agroecosystem (280-330 kg), which compensates for the losses of the humus mineralization process (285 kg) during the cultivation of grain crops, for example, spring barley, with a planned grain yield of 2.0 t / ha. The field of application of the model can be peasant and farm enterprises, state agricultural enterprises, regional departments of agriculture with the possibility of regulating the social and agricultural policy of the region.

1. Introduction
The production of high-quality agricultural products is one of the most important tasks of the plant growing industry. An equally important circumstance is the need to preserve soil fertility, maintain the ecological purity of agricultural production, and resource conservation. Scientists and practitioners argue that agricultural production needs systemic changes in order to be sustainable in solving the problem of food security and food security, and a simple change in some methods and parameters of the system is not enough - a reorganization of such systems and the application of agroecological principles in their work [1]. Several authors draw attention to the benefits of integrating crop and livestock production in mixed farming systems in terms of sustainable food production, improving living conditions or increasing the efficiency of the system [2]. Others consider such integration in practice to improve animal feeding and increase the efficiency of the use of manure or crop by-products [3, 4]. Thus, the study of such interactions between industries, as well as the disposal of the accumulated waste of agricultural enterprises are still urgent problems in the scientific world [5].
2. Results and Discussion
The irrepressible process of growth in the technological equipment of all aspects of our civilization has brought not only positive results. It also caused various and profound complications, irreversible destruction of natural resources, the extinction of many species of animals and plant organisms. Monitoring programs are being created abroad and in Russia to identify pollution sources and neutralize them, develop waste-free technologies. For example, in order to work with the regions and strengthen Russia's environmental policy, the Preparation and Implementation of International Technical Assistance Projects Center was established in 1995 and still operates. Its tasks include monitoring the Upper Volga region (Vologda, Kostroma, Ivanovo, Tver and Yaroslavl regions), identifying zones with unfavorable environmental conditions and the main sources of impact. Although at present the ecological situation in the region is not catastrophic, at the same time there are arable lands with a high content of heavy metals, subject to erosion, highly acidified and having a very low level of fertility indicators.

To mitigate negative trends in the region, purposeful work is being carried out to transfer agricultural production to adaptive landscape farming systems with widespread use of grass crop rotations. Scientific research is being conducted on the development and implementation of resource-saving technologies that provide opportunities for maintaining soil fertility, ecological safety of the environment, increasing the yield and quality of crop production.

In this regard, along with traditional organic fertilizers obtained using cattle manure, which accumulates up to 1.5 million tons, pork (101.7 thousand tons), poultry manure (213.5 thousand tons), the region has a huge amount (more than 360 million tons) of sapropels of Galich and Chukhloma lakes, peat reserves (573.2 million tons), as well as unclaimed large-tonnage waste of acid-free hydrolysis production - cellolignins (more than 3 million tons).

However, the use of this raw material is not always economically feasible, due to the remoteness of the location from agricultural enterprises. Nevertheless, without the use of organic fertilizers, it is impossible to maintain and increase soil fertility, crop yields and improve the quality of crop and livestock products. The alienation of biomass from the cycle of the agroecosystem leads to a shift in energy exchange between organic and mineral substances of the soil towards the latter. This slows down the cycle of carbon-containing compounds in the agroecosystem, which leads to soil degradation and a decrease in fertility.

The emergence of new forms of organization of agricultural enterprises led to the need to develop modern energy-saving landscape farming systems adapted to local conditions. This problem requires deep theoretical and experimental research. The development and implementation of new alternative systems, and the improvement of land use based on theory, in particular a systematic approach, in Russia was carried out limitedly by the efforts of the Moscow Agricultural Academy named after K.A. Timiryazeva, St. Petersburg State Agrarian University, Agrophysical Institute, Research Institute of Agriculture of the Central regions of the Non-Black Earth Zone of Russia, Bryansk State Agricultural Academy. New methods of biologization of the plant growing industry were developed, mathematical models were created that determine the limiting factors of plant life and conditions for the reproduction of soil fertility, and more. Research on the biologization of agriculture has been extensively developed in the USA, Germany, Holland, Great Britain, and Sweden. However, our natural, ecological and economic conditions are inadequate to those of these countries, which limits the use of these results in Russia.

For these reasons, we have carried out and are conducting research on the adaptation of the land use system. It turned out that an ecologically safe system can be represented as a model of a closed cycle of matter and energy. The main condition for providing the agroecosystem with renewable organic matter without replacing (or reducing to a minimum percentage of replaceability) it with artificial energy, man-made and chemical means is to increase the circulation of energy.

Increasing the adaptive potential of the production system is achieved by creating flexible production facilities, improving infrastructure, as well as researching and preparing new types of raw materials, energy and technologies for inclusion in the production cycle. The most important criterion
for the effectiveness of a particular farming system is the achievement of the planned needs, the receipt of economic profit with a simultaneous expanded reproduction of the resources of the agroecosystem, including soil fertility, the productive capacity of agrophytocenoses and production forces.

When building a model of the agroecosystem's activity on the principles of adaptability and resource-saving, a bank of information is collected about natural and socio-economic conditions, the structure of agroecosystems, energy connections within it and with the environment.

Based on many years of research work we have developed and are improving an ecological and mathematical model of agricultural production on the example of the educational farm of the Kostroma State Agricultural Academy "Borovikovskoe" and applicable for any enterprise (figure 1).

**Figure 1.** The scheme of the conceptual model of agricultural production on the example of the educational enterprise of the Kostroma State Agricultural Academy "Borovikovskoe".

The ecological and economic model of the agricultural biotechnological complex is implemented in a computer program consisting of modules: the main branches of production, additional branches of production, ecological and economic. The model differs from the existing ones by a comprehensive analysis of the ecological and economic state of production, possible options for its modernization, forecasts of environmental consequences and sustainable economic effect. The model is built on a block-modular basis. The input of the model is information about the current state of production sectors, predicted climatic parameters, and the dynamics of market prices. The input information is processed within the model using dynamic mathematical functions combined into a structure based on the feedback principle. The result is a tactical modernization of production with maximum sustainable profitability and environmental friendliness. The area of application of the model can be small peasants and farms, state agricultural enterprises, regional departments of agriculture with the ability to regulate the social and agricultural policy of the region.

When collecting and analyzing information, it is assumed that environmental and socio-economic restrictions are identified, that is, the introduction of adaptive capabilities, the level of responsiveness and stability of the agroecosystem when one or another type of substance and energy is introduced into
it. This is the determination of the maximum loads on the soil of fertilizers; identification of the risk of erosion; pollution by waste from various industries of the environment in specific places of the agro-landscape; identification of possible losses of biosphere resources and economic profit.

From a formal point of view, the construction of a system of models of agricultural complexes based on cyclically and acyclically oriented graphs is reduced to a set of relatively elementary mutually reversible algorithms that describe the movement of certain types of agricultural products, raw materials and waste, both vertically and horizontally. At the same time, it can solve the inverse problem, based on resource availability, to predict the dynamics of soil fertility, yield and quality of agricultural products, to calculate the necessary and possible level of agricultural production. Decision-making is based on environmental and economic principles, considering the assessment of the conformity of economic activities, to those natural laws that determine the balance and stable state of agroecological systems of agricultural production.

To substantiate the return of carbon to the agroecosystem, the calculation of the movement of organic matter in the system of a closed production cycle with the creation of additional units operating with the use of organic waste inside an agricultural enterprise was carried out (figure 2).

![Figure 2. The scheme of carbon return to the agroecosystem with a waste-free production cycle.](image)

In such, additionally introduced, biotechnological divisions, such as mushroom growing and vermicomposting, wastes from crop and livestock industries are used. In addition to additional products (California worms and edible oyster mushrooms), the waste of these units is used in the fermentation process and in the production of organic fertilizers in the form of vermicompost. The introduction of vermicompost into the soil, at a dose of 8-12 t / ha, provides a return of carbon to the agroecosystem (280-330 kg), which compensates for the losses of the humus mineralization process (285 kg) during the cultivation of grain crops, for example, spring barley, with a planned grain yield of 2.0 t / ha.

Consequently, the search for opportunities to maximize the use of local resources and the introduction of additional low-cost structural units in an agricultural enterprise for managing the production process of an agroecosystem is archaic.
3. Conclusion
To improve the efficiency and environmental safety of agricultural production, it is recommended to introduce technologies for biological processing of waste, which contributes to the receipt of additional products, ensures the closed production cycle and maintains the cycle of substances in the agroecosystem. The use of an ecological-economic model, in the form of a computer program, will allow, using dynamic mathematical functions, combined into a structure according to the feedback principle, to process a large amount of information about the current state of production sectors, predicted climatic parameters, dynamics of market prices, etc. The result is a tactical modernization of production to ensure maximum sustainable profitability and environmental safety. The introduction of vermicompost into the soil, at a dose of 8-12 t/ha, provides a return of carbon to the agroecosystem (280-330 kg), which compensates for the losses of the humus mineralization process (285 kg) during the cultivation of grain crops, for example, spring barley, with the planned grain yield 2.0 t/ha.

The field of application of the model can be peasant and farm enterprises, state agricultural enterprises, regional departments of agriculture with the possibility of regulating the social and agricultural policy of the region.

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