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СТРУКТУРА ИНФОРМАЦИОННО-УПРАВЛЯЮЩЕЙ СИСТЕМЫ ВОЗДЕЛЫВАНИЯ ЗЕРНОВЫХ КУЛЬТУР

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Рассмотрены проблемы построения и реализации структуры информационно-управляющей системы (ИУС) возделывания зерновых культур на основе оптимизации выбора агротехнологий с точки зрения методов теории управления, системного и компартментального подходов. В качестве объектов управления рассмотрены почва, возделываемая культура и экология используемого участка агроландшафта. Сделан вывод о том, что ИУС относится к классу систем адаптивного управления с прогнозированием многомерным динамическим стохастическим объектом. Показано новое качество системы управления, существенно определяющее ее структуру, – наличие контура управления поддержания плодородия почвы и экологии в севообороте и контура управления агроценозом культуры. Предложена иерархическая структурная схема системы управления объектом с прогнозированием, реализующая функциональные преобразования информационного потока в ИУС. В качестве критерия выбора альтернативной агротехнологии использована эколого-экономическая эффективность, модифицированная с учетом целей управления и состава машинно-тракторного парка. Аналитическое описание процессов агробиосистемы на современном уровне базируется на компартментальном подходе с описанием явлений в виде дифференциальных уравнений. Содержание компартмента описывает процесс переноса энергии и массы в системе почва – растительный покров – приземный слой воздуха на основе функционального (теоретического) динамического имитационного моделирования. По результатам информационного обзора, реализация подобной системы управления в настоящее время не выявлена. Использование эмпирических имитационных моделей в ИУС неприемлемо, так как смена культуры или природно-климатической зоны потребует разработки новой эмпирической модели. Проанализированы системы имитации биофизических процессов WOFOST, DSSAT, DSSAT Cropping System (CSM), APSIM и AGROTOOL, использующие методы функционального динамического имитационного моделирования в рамках компартментального подхода. Разработанная структура ИУС с использованием модели продуктивности посевов AGROTOOL реализуется при условии создания новых модулей компартментов.

Ключевые слова: адаптивно-ландшафтное земледелие, агротехнологии, математическое моделирование, информационно-управляющие системы, компартментальный подход

STRUCTURE OF THE INFORMATION MANAGEMENT SYSTEM OF CEREAL CROPS CULTIVATION

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The problems of constructing and implementing the structure of the information management system (IMS) for the cultivation of grain crops based on the optimization of the choice of agricultural technologies in view of the methods of the management theory, system and compartmental approaches are considered. The objects of management are soil, a cultivated crop and ecology of the agricultural landscape area used. It is concluded that the IMS belongs to the class of adaptive control systems with prediction by a multidimensional dynamic stochastic object. A new quality of the management system, which significantly determines its structure, is shown, namely the presence of a control loop for maintaining soil fertility and ecology in crop rotation and a control loop for the agrocenosis of the crop. A hierarchical block diagram of the object management system with forecasting is proposed, which implements functional transformations of the information flow in the IMS. As a criterion for choosing an alternative agricultural technology, environmental and economic efficiency was used, modified in view of the management goals and the composition of the machine and tractor fleet. The analytical description of the processes of the agrobiosystem at the modern level is based on the compartmental approach with the description of phenomena in the form of differential equations. The content of the compartment describes the process of energy and mass transfer in the system: soil – vegetation cover – ground layer of the air based on functional (theoretical) dynamic simulation. Based on the results of the information review, the possibility of implementation of such a management system has not been currently identified. The use of empirical simulation models in the IMS is unacceptable, since a change in a crop or natural-climatic zone will require the development of a new empirical model. The systems for simulating biophysical processes WOFOST, DSSAT, DSSAT Cropping System (CSM), APSIM and AGROTOOL, using methods of functional dynamic simulation within the framework of the compartmental approach, have been analyzed. The developed IMS structure using the AGROTOOL crop productivity model is implemented on condition that new modules of compartments are created.

Keywords: adaptive landscape agriculture, agricultural technologies, mathematical modeling, information management systems, compartmental approach

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The automation of the management of the cultivation of grain crops is aimed at introducing digital technologies. In particular, information management systems (IMS) are used to calculate the parameters of agricultural technologies that determine the performance of technological operations in the field. At the same time, the problem of creating an IMS system at the level of agricultural enterprises has not been solved at present, since many processes in the control object (soil, culture, ecology) are not described in an analytical form sufficient for the synthesis of the implemented IMS structure.

Let us consider the ways of solving the problem posed, limiting the analysis of the management of the cultivation of grain crops to a plot of the agricultural landscape (field) with a given system of crop rotation and a seasonal nature of control actions. Such a control method relates to predictive control[1] based on the creation of new information in the course of forecasting during generation and the choice of alternatives.

To do this, we synthesize the structure of the IMS system in accordance with its classification in terms of general control theory, the control properties of the control object (OC), and a functional set of descriptions of informa-

[1]Kasperovich S.A. Forecasting and planning of the economy: a course of lectures for students. Minsk: BSTU, 2007.172 p.

tion flow transformation processes for control purposes. At the same time, we will evaluate the possibility of its implementation within the framework of known solutions.

The purpose of the functioning of the adaptive landscape farming system is the production of products of an economically and ecologically determined quantity and quality in accordance with social (market) needs, natural and production resources while ensuring the sustainability of the agricultural landscape and reproduction of soil fertility [1].

Achieving this goal requires the management of a complex of interrelated agrotechnical, reclamation and organizational measures that make up the essence of agro-technologies.

Note that the parameters of soil, culture and ecology are stochastic in nature and are mainly determined by climatic conditions and the intensity of solar radiation. In addition, the properties of OC depend on the agroclimatic zone of the agricultural landscape, which determines the adaptive mechanisms of the IMS functioning.

Therefore, in general, the control system can be attributed to the class of adaptive control systems with prediction by a multidimensional dynamic stochastic object [2] with the ability to change the parameters or structure of the controller depending on the parameters of the control unit or external disturbances[2].

The IMS structure is based on analytical models describing the physical processes in the OC, and a mathematical model for calculating control actions on the OC to achieve the control goal.

In the mathematical modeling of agroecosystem processes, the main directions in the class of simulation models can be distinguished [3, 4]:

– an empirical approach with extensive use of a heuristic description of the determining processes (regression relations, allometry equations, numerous stress functions, etc. are used);

– functional or theoretical (mechanistic or ecophysiological) approach considering the essence of processes and cause-and-effect relationships in the agroecosystem with a description of their dynamics based on physically interpreted dependencies.

The analytical description of the processes of the agrobiosystem at the modern level is based on the compartmental approach[3]. In this case, it is assumed that within the volume of the compartment, the processes are not a function of the spatial variable, therefore, description in the form of ordinary differential equations is allowed. This approach is used to study the processes of transfer of matter and energy within a living system and their exchange with the environment, in particular, in the system soil - vegetation cover - surface air layer. The structure of the analytical description of biophysical processes is based on functional (theoretical) dynamic simulation and is presented in the form of interconnected compartments. The use of empirical simulation models is unacceptable, since a change in culture or natural climatic zone will require the development of a new empirical model. In the case of the compartmental approach, the physical essence of the OC processes remains unchanged when changing the OC parameters, which determines the variability of the simulation model.

Let us define the structure of the IMS of adaptive control with forecasting the cultivation of grain crops from the standpoint of functional transformations of the information flow. Let us note the properties of the OC regulation process determined by the decomposition of the main goal:

– management has two management objectives: managing sustainability, maintaining soil fertility and ecology in crop rotation (management objective 1) and managing the agrocenosis of a crop, including changing soil con-

[2]Adaptive management. URL: https://ru.wikipedia.org/

[3]Novoseltsev V.N. Control theory and biosystems. Analysis of preservation properties. M .: main edition of physical and mathematical literature of the publishing house "Nauka", 1978. 320 p.

ditions, crop ecology (management objective 2) and, accordingly, two management loops with management periods equal to the period of full rotation of the crop rotation and the season of crop cultivation;

– management prediction is carried out by choosing an alternative from $k1 = 0, ..., N1$, $k2 = 0, ..., N2$ numbers of agro-technology alternatives and from $k3 = 0, ..., N3$, $k4 = 0, ..., N4$ numbers of alternatives for the composition of the machine and tractor fleet (MTF), respectively, control loops 1, 2 in accordance with the criterion function and their adaptation to the zonal conditions of use.

The efficiency of management for practical purposes can be assessed by the indicator of ecological and economic efficiency Eee $_{gen}$, reflecting the amount of net income (or profit), taking into account the prevented environmental damage [1] according to the formula

$$E_{ee_{gen}} = \frac{В_п - З_п - (У - К \cdot З_у)}{З_{ээ}}, \tag{1}$$

where $В_п$ is the cost of gross output; $З_п$ - operational costs; У is the amount of environmental and economic damage to agricultural production; К - coefficient of efficiency of environmental protection measures; $З_у$ - costs aimed at preventing and eliminating damage in agriculture; $З_{ээ}$ - costs that provide an ecological and economic effect, including environmental protection measures.

Taking into account the array of alternatives, the criterial control function will have the form

$$F = \max_{\substack{0 \le k1 \le N1 \\ 0 \le k2 \le N2}} \left\{ \frac{В_{п_{k1,\,k2}} - \min_{0 \le k3 \le N3} \left(З_{nyps_{k1,\,k3}}\right) - \min_{0 \le k4 \le N4} \left(З_{nypk_{k2,\,k4}} + З_{nyak_{k2,\,k4}}\right)}{\left(\min_{0 \le k3 \le N3} \left(З_{ээps_{k1,\,k3}} / N_{ps}\right) + \min_{0 \le k4 \le N4} \left(З_{ээpk_{k2,\,k4}} + З_{ээak_{k2,\,k4}}\right)\right)} \right\}, \tag{2}$$

where $З_{nypsk1,\ k3}$, $З_{nypkk2,\ k4}$, $З_{nyakk2,\ k4}$ - ecological and economic costs of alternative agricultural technology, including the cost of performing agricultural technology operations with units from alternative sets of MTF; $З_{epsk1,\ k3}$, $З_{ee}$, $З_{eakk2,\ k4}$ are the costs that ensured the ecological and economic effect, including environmental protection measures when the soil condition changes in the crop rotation cycle (indices *ps*, *k*1, *k*3), respectively, when the soil condition changes when managing the agrocenosis of the crop (indices *pk*, *k*2, *k*4) and when the state of the culture changes (indices *ak*, *k*2, *k*4); N_{ps} is the number of crop rotation periods.

We will consider functional transformations of the information flow in a predictive control system from the standpoint of the elements of set theory. The information flow is represented by a set of parameters of the form v = {*v1 (t),..., vn (t)*}, where *vn (t)* is an element of the set (parameter) describing the state of the system at time t and having functional relations f with the set *w: w = f {v}*. In the general case, *f* is a functional (any mapping from an arbitrary set to an arbitrary one), an operator is a mapping that associate a function with another function. Then the information flow transformations can be described as follows:

a) *a, b, c, d, a p* , b_p , *cp* , *dp* , *at* , *bt* , *ct* , *dt* , where *a, b* are the sets of soil parameters that ensure stability, fertility and ecology in the crop rotation cycle and season, respectively, *c* is the state of the agrocenosis of the crop, *d* are climatic conditions, while the * *p*, * *t* index determines the predicted and current sets of parameters;

b) the set of parameters of agricultural technology for maintaining soil fertility alternatives *k*1 and agrocenosis of the culture *k*2 are determined, respectively, by the functionals, taking into account the set of MTP mtp_{k1}, mtp_{k2}: $AT_{ps,\ k1} = f_{atps}\{a, b, c, d, mtp_{k1}\}$, $AT_{ak,\ k2} = f_{atak}\{a, b, c, d, mtp_{k2}\}$, the sets of unit parameters for technological operations are determined by the functionals $mtp_{pk1} = f_{umtps}\{AT_{ps,\ k1}\}$ and $mtp_{pk2} = f_{umtak}\{AT_{ak,\ k2}\}$. The predicted sets of parameters of the state of the object, yield and the parameter of stability and preservation of soil fertility are calculated by operators:

$$a_p = A_{Ta_{k1,\,k2}}(a,\, b),$$
$$b_p = A_{Tb_{k1,\,k2}}(a,\, b),$$
$$c_p = A_{TC_{k1,\,k2}}(a,\, b,\, c),$$
$$c_p = A_{TC_{k1,\,k2}}(a_p,\, b_p,\, c_p),$$
$$W_a = A_{Tow}\{AT_{ps,\,k1},\, AT_{ps,\,k2}\},$$

functionally interconnected with the parameters of agricultural technologies:

$$A_{Ta_{k1,\,k2}} = f_{oa}\{AT_{ps,\,k1}, AT_{ak,\,k2}\},$$
$$A_{Tb_{k1,\,k2}} = f_{ob}\{AT_{ps,\,k1}, AT_{ak,\,k2}\},$$
$$A_{TC_{k1,\,k2}} = f_{oc}\{AT_{ps,\,k1}, AT_{ak,\,k2}\},$$
$$A_{TC_{k1,\,k2}} = f_{oC}\{AT_{ps,\,k1}, AT_{ak,\,k2}\},$$
$$A_{Tow} = f_{ow}\{AT_{ps,\,k1}, AT_{ak,\,k2}\}.$$

The values of the sets of parameters of impacts on the soil and soil ecology in the cycle of crop rotation, season, agrocenosis and culture ecology are determined, respectively, by the functionals:

$$U_{Ps} = f_{ups}\{AT_{ps,\,k1}\},$$
$$U_{es} = f_{ues}\{AT_{ps,\,k1}\},$$
$$U_{p_k} = f_{upk}\{AT_{ak,\,k2}\},$$
$$U_{ak} = f_{uak}\{AT_{ak,\,k2}\},$$
$$U_{ek} = f_{uek}\{AT_{ak,\,k2}\},$$

and the set of parameters of the units for the implementation of technological operations in the rotation cycle of crop rotation and season is determined by the functionals:

$$mtp_{p_{k1}} = f_{umtps}\{AT_{ps,\,k1}\} \text{ и } mtp_{p_{k2}} = f_{umtak}\{AT_{ak,\,k2}\}.$$

The listed set of functions and operators, using the systematic approach [5], can be represented as a hierarchical structure of the object management system shown in the figure. Management is carried out by the following actions:

– for a given area-specific zone of an agrarian landscape plot (agro-technological type and type of land), type of crop rotation, sowing culture, predicted climatic conditions and a basic set of MTF, a set of *k*1, *k*2 predicted functions is synthesized. You can choose from the known values corresponding to the functionals f_{atps}, f_{oa}, f_{ups}, f_{ues}, f_{umtps}, f_{atak}, f_{ob}, f_{uak}, f_{uek}, f_{umtpk}, f_{oc}, which are also determined by the type of agricultural technology (extensive, normal, intensive, high-intensity), taking into account the state a control object determined by the set of parameters a, b, c, d_p, MTF. At the same time, the necessary set of functions is generated that connect the output and input sets of parameters of this functional;

– many parameters of predicted agricultural technologies for maintaining soil fertility in the cycle of crop rotation AT_{ps}, agrocenosis of the AT_{ak} crop are calculated;

– transformation operators of a set of parameters are synthesized or selected from the known $A_{Tak1,\ k2}$, $A_{Tbk1,\ k2}$, $A_{Tck1,\ k2}$, a set of parameters of the basic set of MTF $mtpp_{,\,k1}$, $mtpp_{,\,k2}$, predicted to carry out the necessary operations on the field;

– the predicted sets of parameters of soil fertility and agrocenosis of the culture of the controlled object *a, b, c* are calculated by transformation operators;

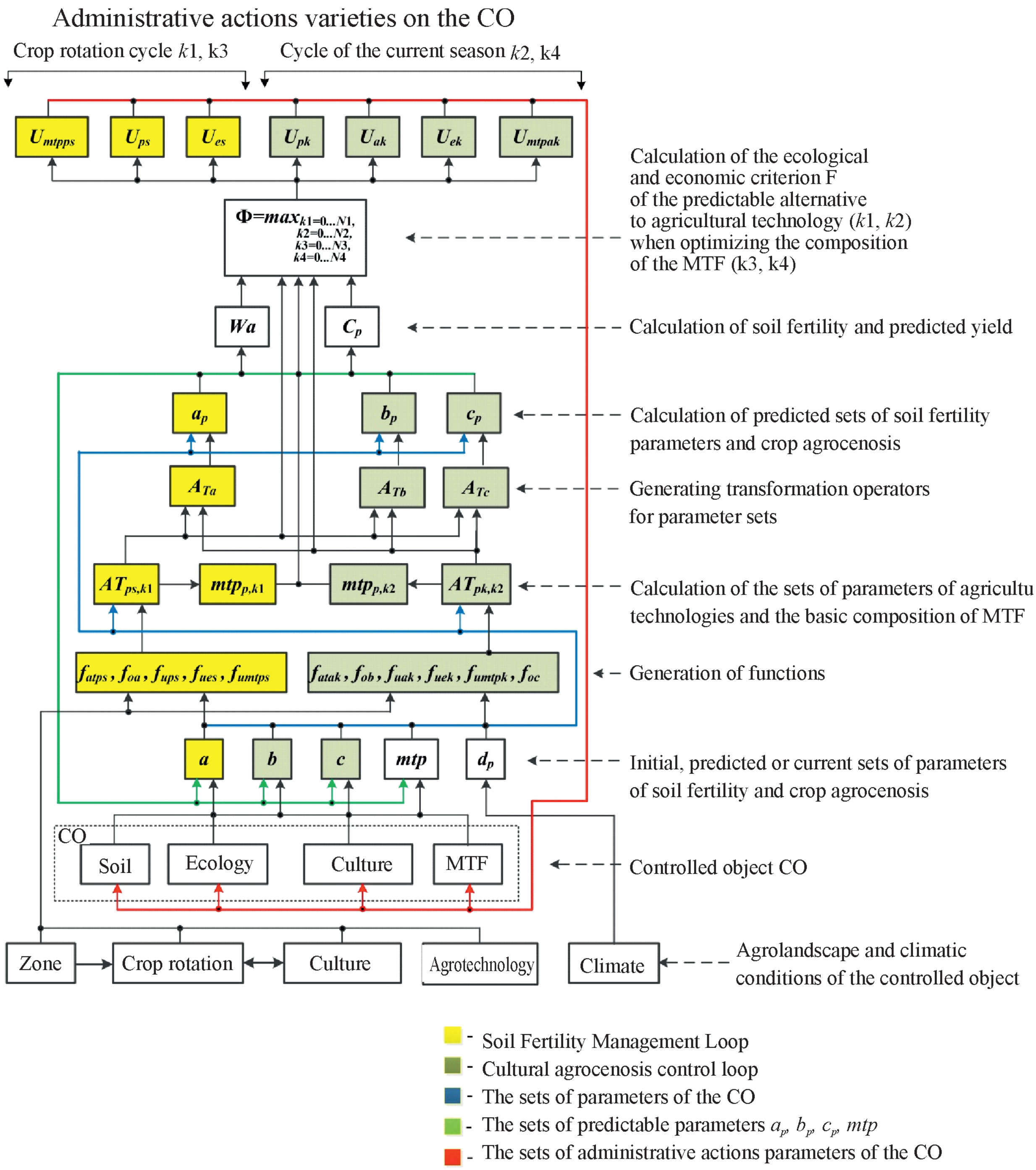
– the conditions of soil fertility *Wa* and the predicted yield C_p are calculated;

– when the condition of the soil fertility $Wa \geq 0$ is fulfilled, the ecological and economic costs, the set of parameters of the units for the implementation of technological operations $U_{mtpps\ k1,\ k3}$, $U_{mtpak\ k2,\ k4}$ and the value of the ecological and economic criterion F according to expression (2) are calculated;

– an alternative option *k*1, *k*2, *k*3, *k*4 of agricultural technologies is searched for, corresponding to the maximum value of the ecological and economic criterion F;

– the values of the set of parameters of impacts on the soil and soil ecology in the cycle of crop rotation, season and agrocenosis and the ecology of culture are determined, respectively, by the functional *Umtpps, Ups, Ues, Upk, Uak, Uek, Umtpak*;

– the deviation of the predicted state of the control object from the actual one is determined in accordance with the control cycle. At the same time, the actual value of the ecological and economic criterion F is calculated and the procedure for generating functions in the control system is adjusted to minimize deviations in the next management cycle.



Иерархическая структура системы управления объектом с прогнозированием
Hierarchical structure of the object management system with forecasting

Let us evaluate the possibility of implementing the synthesized structure of the IMS with forecasting (hereinafter IMS) by the known solutions in the field of information technology and mathematical modeling of agroecological problems (see the figure). A review of information sources[4] was carried out [6].

The management system based on heuristic models includes, for example, a multilevel model of intelligent control of an agro-technological process in a bio-production system [7]. It is based on heuristic correction of mathematical models of agroecosystems with heuristic knowledge of farmers. The system "Eidos-X ++" is based on the system-cognitive statistical relationship of the required parameters for the known set of implementations of the agrotechnological process. The application of this system is limited by knowledge of the real statistics of the history of the application of agricultural technologies over a long period of time [8]. In most cases, such information is not available on farms.

Other well-known methods or mathematical models describe individual processes of an agrobiosystem without describing their relationship. Such systems are the models for determining the optimal doses of fertilizers[5] and the dynamics of humus [9], the automated bank of fertility models “PLOMOD” [6], in which the relationship of crop rotation parameters with the state of fertility and soil ecology is determined mainly at the level of methodologies and belongs to the category of knowledge [10]. These methods cannot be applied in the IMS without finalizing the analytical description of the interconnection processes within the framework of the compartment approach.

Mathematical models of processes that are not related to the agrocenosis of a culture or models for assessing results deserve attention. These are the agrometeorological information and forecasting system of the IPS of the All-Russian Scientific Research Institute of Agricultural Meteorology (ARRIAM) based on the synoptic-statistical method[7], mathematical models and algorithms for predicting the yield of grain crops using satellite data (EPIC model)[8], the assessment of the stability of soil organic matter based on mathematical theory of catastrophes [11, 12], optimization of the composition of MTF[9] [13, 14]. Such models can be applied in the structure of the IMS system when they are being finalized.

There are known systems for simulating biophysical processes based on functional (theoretical) dynamic simulation of agrobiosystem processes within the framework of the compartment approach. These are WOFOST[10] (Netherlands), DSSAT - The Decision Support System for Agrotechnology Transfer[11], DSSAT Cropping System (CSM)[12], IBSNAT project (USA), APSIM modeling system - Agricultural Production Systems SIMulator[13], (Australia) and the AGROTOOL crop productivity model (Russia) [15]. These models are semi-empirical, have a similar structure and differ mainly in the nomenclature and details of the description of individual blocks. These systems are not control systems, since they simulate the processes soil - surface air layer - plant without taking into

[4]Khomyakov D.M., Iskandaryan R.A. Information technology and mathematical modeling in environmental management tasks. URL: http://fadr.msu.ru/rin/ecol/model.htm

[5]Arlantseva E.R. Mathematical support for decision-making to optimize the intensity of crop production: author. dis. PhD. Economics: 08.00.13. Moscow Agricultural Academy in the name of K.A. Timiryazev, department of economic cybernetics. M., 2008.

[6]Frid A.S. Fertility Models Bank "PLOMOD”. URL: http://www.esoil.ru/databases/bank.html

[7] Lebedeva V.M. Synoptic-statistical forecasting method. URL: http://cxm.obninsk.ru/index.php?id=157

[8] Bryksin V.M. Development of a mathematical model and software for assessing the yield of grain crops in the conditions of Western Siberia: author. dis. PhD. in Engineering: 05.13.18. Barnaul, 2009. 22 p.

[9]Artemiev Yu.G. Improving the efficiency of agricultural production in the conditions of the Leningrad region by optimizing resource provision and the composition of the machine and tractor fleet: author. dis. PhD. in Engineering: 05.20.01. St. Petersburg; Pavlovsk, 2013, p. 19.

[10]Hadiya N., Kumar N., Mote B.M. Use of WOFOST model in agriculture-A review- URL: https://www.researchgate.net/publication/327098320_Use_of_WOFOST_model_in_agriculture-A_review

[11]Jones J.W. Hoogenboom G., Porter C.H., Boote K.J., Batchelor W.D., Hunt L.A., Wilkens P.W., Singh U., Gijsman A.J., Ritchie J.T. The DSSAT cropping system model // European Journal of Agronomy. 2003. №18 (3–4). C. 235–265.

account the processes of adaptive management with forecasting.

Let us consider the implementation of the IMS structure, taking into account the model of crop productivity AGROTOOL, which includes a description of the following processes taking place in the system soil - vegetation cover - surface air layer:

– soil compartment - dynamics of soil moisture, dynamics of nitrogen compounds in the soil, growth and development of the root system;

– compartment of the surface layer of air - modes of sowing, photosynthesis and photorespiration, transpiration of plants and evaporation of moisture from the soil surface, the choice of norms and terms of irrigation in irrigated agriculture;

– plant compartment - moisture transfer to the plant, plant growth and development (aboveground organs), yield prediction (starting from the earing phase).

Let us represent the IMS structure as a set of compartments that analytically describe the functional transformations of the information flow: soil stability and fertility *fatps, foa, ATak1, k2,* agrocenosis of the culture *fatak, fob, foc, foC, ATbk1, k2, ATck1, k2, ATCk1, k2*, formation of predicted parameters *ap, bp, cp*.

At the same time, the processes of agrocenosis of a culture and the predicted parameters of soil, crops can be represented by similar compartments soil - vegetation cover - surface air layer of the AGROTOOL system. The rest of the processes of functional transformations of the information flow in the IMS and the conditions for the implementation of control have no analogues in the compartment structure of the AGROTOOL system. Therefore, the IMS compartments should additionally contain an analytical description of the following processes and conditions for the implementation of management: - soil compartment - soil stability and fertility, the formation of a predictable set of soil parameters, the relationship of soil parameters with the crop rotation cycle; - additional compartment soil and plant ecology - the relationship between the parameters of the intensity of the planned agricultural technology with the parameters of the soil. - conditions for the implementation of management - the formation of an alternative version of agricultural technology, containing the planned operations in the field and the composition of the MTF, can be carried out in accordance with the federal (regional) register of agricultural technologies. The timing of the operation in the field, the amount of fertilizers is determined by the results of running the mathematical models of the IMS. Adaptation of management by the types of crop rotation and the soil-climatic zone of the agricultural landscape can be carried out by adjusting the analytical content of the compartments by the OM parameters.

CONCLUSION

As a result of the analysis of information materials, it was found that the analytical description of the processes of the agrobiosystem at the modern level is based on a compartment approach using the methods of functional (theoretical) dynamic simulation. The use of empirical models is unacceptable, since a change in culture or natural-climatic zone requires the development of a new model with the inclusion of research and verification stages.

The synthesis of the structure of the information management system was carried out with the limitation of the area of management of a plot of the agricultural landscape (field) with a given system of crop rotation and the seasonal nature of control actions. The seasonal nature of the control actions and the change in the natural and climatic zone determine the class of the information and control system as an adaptive control system with forecasting.

The information and control system has two control loops: the first is the maintenance of soil fertility and ecology in crop rotation, the second is the agrocenosis of the culture, includ-

[12]Keating B.A. Modelling crops and cropping systems – Evolving purpose, practice and prospects. European Journal of Agronomy. 2018. Vol. 100. P. 163-176.

[13]Keating B.A., Carberry P.S., Hammer G.L. An overview of APSIM, a model designed for farming systems simulation // European journal of Agronomy. 2003. N 18. P. 267–288.

ing changes in the state of the soil, the ecology of crops.

Based on the functional transformation of the information flow, a hierarchical structure of the information management system has been synthesized, the functional of which in terms of describing the processes in the control object can be represented in the form of compartments. Based on the results of the information review, the implementation of such an information management system has not been identified. The possibility of implementing the developed structure of the information management system, taking into account the systems for simulating biophysical processes WOFOST, DSSAT, DSSAT Cropping System (CSM), APSIM and AGROTOOL, using the methods of functional (theoretical) dynamic simulation within the framework of the compartment approach is considered.

A comparative analysis of the composition of the compartments necessary for the analytical description of the functionals of the processes in the control object of the structure of the information management system and the AGROTOOL system is carried out. It has been established that the processes of agrocenosis of a crop and the predicted parameters of soil, crops can be represented by similar compartments soil - vegetation cover - surface air layer of the AGROTOOL system. In this case, the structure of the IMS system must additionally contain, at least, an analytical description of the following processes and conditions for the implementation of management:

– compartment soil - soil stability and fertility, the formation of a predictable set of soil parameters, the relationship of soil parameters with the crop rotation cycle;

– additional compartment soil and plant ecology - the relationship of the parameters of the intensity of the planned agricultural technology with the parameters of the soil;

– the conditions for the implementation of control are determined by the algorithm for the formation of an alternative version of agricultural technology, containing the planned operations in the field, the amount of fertilizers and the composition of the machine-tractor fleet, and the algorithm for adapting the analytical content of the compartments to the types of crop rotation and the soil-climatic zone of the agricultural landscape.

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