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MODELING

Prospects of Application of Dynamic Models of Agricultural Ecosystems in the Problems of Midterm and Long-Term Planning of Agricultural Production and Land Management

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Abstract—Requirements for the infrastructure and functionality of dynamic models of the production process of agricultural plants, which are necessary for building computer systems to support long-term solutions in agriculture and land management, are described. The extent to which domestic and foreign developments meet these requirements is shown.

Keywords: land management, adaptive-landscape agriculture, dynamic crop model
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Intrafarm land management is carried out for the purposes of rational agricultural land use [1]. Land-management designing is traditionally linked to the agricultural enterprise theory; however, at the time level of decision-making, it is related to the challenge of long-term or strategic planning [2]. The main consumers of the developments are the managers of farms that were established on the area of former state farms and collective farms. They have to adapt an old intrafarm land management to new economic management conditions.

The land management of the 21st century should follow the principle of locating crops in optimal territorial ecological niches, i.e., areas with a steadily high plant productivity. The location of these niches is based on forecasting crop yields in reference points on a farm territory (or a regional territory) for different agroclimatic conditions. This procedure is performed using various mathematical models of production process of crops and geoinformation systems, which make it possible to obtain a number of crop yield forecast maps. These maps allow one to identify territorial niches where the forecasted crop yield is sufficiently high and is little dependent on weather conditions throughout the year. By comparing the maps of optimal territorial niches with different crops, forecast maps of optimal location of crop rotations are obtained [3].

Recently, it has become a trend to develop land-management plans based on the principles of an adaptive-landscape system of agricultural land management, which is a modern system for planning ecologically sound agricultural production. The opinion is becoming widespread that it is necessary to achieve the ecological sustainability of agricultural landscapes rather than their maximal productivity [3].

To assess crop yield, regression models were widely used in land-management forecasts. They allowed one to assess possible yields and necessary material and technical resources for their implementation. These models showed their efficiency and served as a basis for normative techniques according to which land-management plans were created. The scientific basis of regression models was based on the use of integrated indices and, in particular, on the calculation of integral parameters for assessment of the productivity of locations [4]. It is still relevant to develop the criteria of the ratio of farmlands, as well as the maximal territorial adaptation of types and kinds of crop rotations, cropping technologies, and cultivation of soils and other elements of farming systems. One should also solve the problem of overcoming the landscape indifference of models, i.e., the absence of the systemic relation of the results of yield forecasting between testing points. The model should be able to determine the microlandscape to which a specific point belongs and how this geosystem is associated with the neighboring ones.

The analysis of the existing situation allows one to conclude that most methods concerning the organization of rational agricultural land use have a qualitative nature. The models applied are based on integral indices and are regression and mostly linear ones, and optimization is associated with solving linear programming problems in which the functionals are also linear [5, 6]. Practical agronomists and farm managers simplify the problem even greater. The most qualified of them determine possible costs, revenues, and incomes from the sales of further yields, following the past or predicted data on yield [7] and prices on finished products, as well as proceeding from the recommendations of adaptive-landscape agriculture [8] and taking into account the theory of precursors and humus balance in soil [9]. A similar situation is also observed in the area of the scientifically substantiated assessment of melioration measures and in the development of land management strategies on already-formed agricultural territories. If we use the three-level classification of time levels of decision-making in agriculture [10], then, in this case, we deal with midterm planning, where it is required to make a forecast on farming development, taking into account the fact that the existing market conditions may be changed in a few (10–15) years. For this purpose, simplified economic-statistical models are also usually applied. However, it is clear that, with such an approach, the influence of most of future climatic, physical, technological, and other production processes is ignored, and many midterm and long-term decisions in farming are taken under the conditions of critical uncertainty of input data.

Dynamic simulation models can serve as an alternative tool for analysis and forecasting, which allows an adequate response to the posed challenges. The advantages of this approach over static models are well known: increase in the accuracy and adequacy of calculations due to a consideration of a broader range of factors; multiplicity of calculations, which is due to a wide range of possibilities with respect to the variety of input data; obtaining results in the form of distributions of indicators on the probability samples of external conditions with an output of risks to be analyzed; an unlimited extension of the number of the indicators of the state of an agricultural ecosystem, which are traced in the model (productivity, ecology, fertility, etc.); reduction in the degree of uncertainty of calculations; etc.

Undoubtedly, the potential power of a dynamic simulation model as a tool for analysis and forecasting is of great importance. Aside from the fact that the construction of an adequate dynamic model is a difficult research task, this model, as a rule, requires more extensive and detailed information support and computing resources compared with its static analogue. These are the considerations that, until recently, restrained in many respects the use of dynamic models in the spheres being considered. However, the achieved level of development of computer equipment, on the one hand, and networks services of information support, on the other hand, remove technical constraints to a large extent. Strict subject-specific requirements for the algorithmic "filling" of the models themselves and for the environments or shells of their performance have become the basic requirements. A brief list of these requirements, which results from the specifics of problems of midterm and long-term planning in agricultural land management is given below.

Additional requirements for the very dynamic models of production process are determined by two factors: the necessity to fully describe the change of crops in a multiannual farm crop rotation and to adequately consider various agromelioration measures with a prolonged period. Particularly, it follows from the first requirement that the *universal nature* of the model is desirable. In other words, a single model of simulation of the dynamics of production process should be ideally used for a wide range of agricultural crops of different types (annual and perennial crops, grain crops and grasses, spring crops, and winter crops). The presence of this model with a general data structure and an algorithmic architecture significantly simplifies its application in computer systems for the calculation of crop rotation, compared with the necessity to constantly switch between different models and import data from one format to another, using a "multimodel" approach. In addition, the model that is used to calculate crop rotations in the multiannual cycle should fully *take into account the history of the precursor-crop* with respect to all significant after-action aspects (decomposition of stubble remains, change in the physical and agrochemical properties of soil, symbiotic nitrogen fixation by legumes, etc.). The cyclical calculation in the mode of forecasting for several years assumes that the model must have the description of *"overwintering" mechanisms*, i.e., the dynamics of abiotic processes in the ecosystem beyond the period of active plant vegetation: soil freezing and warming, the growth and melting of snow cover, and other aspects. Besides, the model should support not only the declarative (with clear indication of time-periods and doses in each rotation unit) but also *reactive modes of control of agrotechnical measures* (automatic watering, determining a planting date, etc.), thereby increasing the resistance to the absence of actual information on agricultural technology.

At the same time, the special priority that is given to agromelioration measures during midterm planning determines the compulsory presence of algorithms for consideration of all kinds of operational and long-term agrotechnologies in the model: irrigation technology and preplanting fertilization and supplementary fertilization technologies during vegetation, as well as chemical melioration technologies (liming and plastering), different types of soil cultivations, and technologies of capital activities aimed at forming an optimal agricultural landscape and recultivating disturbed lands. Even more rigid should be requirements for computer shells or environments for model execution, compared with requirements for models themselves, in the case of the proposed extension of the area of application. The most conceptual of them are as follows.

(1) Providing a multivariant evaluation of the model, i.e., the sequential starting of the model to make a calculation for a large number of alternative variants with preliminary prepared sets of input data in the automatic mode. It should be noted that, unlike a "usual" procedure of multivariant analysis, the calculation taking into account crop circulation implies planning of an incomplete factorial experiment and the execution of separate scenarios in a strictly defined

Compliance of the opportunities of the integrated "APEX + AGROTOOL" environment with the requirements of strategic planning problems

Requirements	Degree of implementation
For the model	**AGROTOOL**
universal nature	Common algorithm for all supported crops; configured models for grain crops (wheat, rye, barley, oats), corn, potatoes, root crops, annual and biennial forage grasses, rape, and legumes
"overwintering"	A through calculation is implemented; improved description of snow melt
precursor history consideration	Separate consideration of ground litter and root residues in the carbon-nitrogen interaction block in the soil; submodel of symbiotic nitrogen-fixation and nodulating nitrogen transformation
description of closed-loop technologies	Automatic determination of dates of planting and harvest time; automatic irrigation control
consideration of soil cultivations and melioration measures	*At a setting stage*
For infrastructure	**APEX**
multiple calculations	Technology of multivariant analysis and automation for computer experiment is tested and their environment is implemented
crop rotation	*Mechanisms for planning an incomplete factorial experiment and supporting sequential-parallel calculation schemes are in the process of implementation*
GIS-interface	Mechanisms of APEX integration with external GIS-systems are implemented [15]
forecasts	Built-in weather generator available with a consideration of climatic changes
economic calculations	*Setting up a problem on integration with an external economic model of the **FECG** (Farm Economy Coefficient Generator)*

order during its implementation (in general, a certain sequential-parallel implementation scheme should be rigidly specified).

(2) Full-fledged GIS-interface in the form of electronic map of the fields of a study farm with spatial binding of data on soil phases and a visualization of modeling results in the form of thematic maps of estimated economic or ecological indicators.

(3) The support of procedures for the automatic formation of "synthetic" input data of the model to make forecast calculations (a built-in generator of daily weather data).

(4) Maximally close integration with a built-in or an exterior module of economic calculations for the interpretation of obtained characteristics of productivity and dedicated resources in terms of the indicators of potential profit and cost items (entry to economy). It should be noted that the matter here concerns just the integration with an independent economic model at a postprocessor level, since, in our view, the algorithm of the dynamic modeling of production process should "know" nothing about the economic or financial aspects of farming.

Despite the rigidity and extension of requirements for the functionality of the "model-centric" computer system for supporting decisions in land management, the prototypes of similar products have already been created in the West. Particularly, in the current version 4.6, the platforms produced by DSSAT, the worldwide leader in the area of computer modeling in agroecology [11], applications have been implemented for the analysis of the interseasonal dynamics of plantings in the set crop rotation scheme. They enable one to obtain the grounded assessments of economic risks and ecological consequences of different farming strategies (irrigation, introduction of mineral and organic fertilizers, and precision farming techniques) for a broad class of current and forecasted soil-climatic conditions. One should also note the development of LandCare-DSS system by the specialists of the German Center for Agricultural Landscape Research [12]. Its unique features are integration with a powerful economic calculated block and the use of models of a different type and a level of detail within one architecture, depending on the spatial resolution of the problem being considered: from the regression-statistical YieldStat model at a regional level to the dynamic ecophysiological Monica model at a field or farm level.

As a possible prospective source for creating an adequate domestic system, we consider the integrated environment of the information support, planning, and conduction of multifactorial computer experiments, which was developed by the specialists of the Agrophysical Research Institute and includes the dynamic model of the production process of the third productivity level AGROTOOL [13] and the specialized shell of the multivariant analysis of models of APEX agricultural systems [14]. The summary table illustrates the level of compliance of the available or developed functionality of the relevant solutions with the claimed requirements for the system to support solutions in the problems of midterm and long-term planning of agricultural production.

The analysis of the existing situation in land-management design makes it possible to determine the role and potential demand in this area of models of the production process of agricultural plants. Users wish to have a computerized project that would enable them to assess the consequences of management solutions over a midterm and long-term period based on a wide variety of information sources, including remote (as well as satellite) sensing data. To solve these problems, which are associated with the implementation of scenarios like "what will happen if...", simulation models should be used, which represent the best environment and operate together with geoinformational technologies. It has become clear that the dynamic models of agricultural ecosystems can be a powerful tool in solving the relevant problems of organization of the rational use of agricultural lands to promote an increase in the quality of decisions taken. In addition, the development of an adequate information system will allow agricultural producers to take decisions in one environment and will make it possible for local government bodies, which are responsible for regional agricultural development, to monitor the consequences of these decisions [15].

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