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PARAMETRIC CONTROL OF AGRICULTURAL DEVELOPMENT BASED ON COGNITIVE MODELING

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Abstract. The concept of parametric control is used to prove the existence of a contradiction between the growth of agricultural production and the lack of conditions for expanded reproduction in Russian agriculture. This contradiction is the main limitation of agricultural growth in the country. The theoretical foundations of parametric control are specified for socio-economic systems and the parameterization stage of the controlled system is included in the control process. A control action should be chosen by comparing the estimates of two blocks of parameters. The first block assesses the potential of an external control action affecting the system. The second block of parameters shows the internal potential of the controlled system. If the estimates do not match, the control process has a contradiction, and the control action should be corrected. Fuzzy cognitive modeling is used to determine the contradiction in the control of agricultural development. A fuzzy cognitive map of Russian agriculture is constructed using expert assessments and correlation-regression analysis according to statistical data for the period 2000–2020. The structural-target analysis of this map is performed and its system indicators are calculated to identify the main limitations in agricultural dynamic processes. Agricultural development is forecasted through the scenario analysis of the fuzzy cognitive map. According to the cognitive modeling results, the control action potential exceeds the agricultural growth potential. Therefore, for sustainable long-term agricultural growth in Russia, it is necessary to change approaches to agricultural management.

Keywords: parametric control, socio-economic system, agriculture, agricultural growth, cognitive modeling, fuzzy cognitive map.

INTRODUCTION. PROBLEM STATEMENT

Under the current geopolitical confrontation, agricultural development is a prerequisite for achieving national security goals and, furthermore, an opportunity for the country to fulfill the mission of the world's food supplier in the global fight against hunger. In recent years, the Russian agro-industrial complex (AIC) has been developing actively: the volume of agricultural products and its contribution to economic growth have been increasing. However, Russia does not completely use its significant agricultural potential, in the author's opinion due to a contradiction between the growth of agricultural production and the lack of conditions for expanded reproduction in the AIC. Therefore, this study identifies and determines the contradiction as the main limitation of the country's agricultural development.

The key indicator of agricultural development is agricultural growth, which is understood as the process of socio-economic dynamics of the AIC to increase the volume and improve the content of the public agricultural product in accordance with the current and future values of consumers.

This limitation is manifested through the inconsistent parameters of basic legal and regulatory documents determining agricultural policy in the country (Table 1). This problem is exacerbated even more since the basic regulations use different indicators for the same functional areas of agricultural production. Of course, considering the specifics of program documents, the choice of target parameters should primarily be determined by the peculiarities of the object of

Table 1

The basic parameters of legal and regulatory documents on agricultural growth control

Parameter, unit of measurement	The State Program for Agricultural Development[1]	The Development Strategy for the Agro-industrial and Fishery Complexes[2]	The State Program "Integrated Development of Rural Areas"[3]	The Sustainable Development Strategy for Rural Areas[4]	The Federal Scientific and Technical Program for Agricultural Development for 2017–2025[5]
The index of agricultural production (in comparable prices) in 2030 to the level of 2020, %	114.6	125.4	-	-	-
Exports of agricultural products, billion USD	37	45	-	-	-
Gross value added in agriculture by 2024, billion RUB	4 029.6	5 374.8	-	-	-
The unemployment rate of the rural working-age population by 2025, %	-	6.0	5.7	-	-
The employment rate of the rural working-age population by 2025, %	-	80.0	80.0	69.3	-
The average monthly wage of agricultural workers (without small businesses) by 2024, RUB	43 473.0	-	-	-	-
The ratio of wages in agriculture to the national economy's average by 2024, %	-	-	-	64.1	-
The ratio of average per capita disposable resources of rural and urban households by 2024, %	-	-	79.0	77.9	-
The index of fixed capital investment quantum in agriculture by 2024, %	115.8	110.6	-	-	-
Investments in agriculture by 2024, thousand RUB	-	-	-	-	3 175 660

[1] The State Program for Agricultural Development and Regulation of Markets of Agricultural Products, Raw Materials, and Food. Approved by RF Government Decree No. 717 dated July 14, 2012.
[2] The Development Strategy for the Agro-industrial and Fishery Complexes of the Russian Federation for the Period up to 2030. Approved by RF Government Decree No. 993-r dated April 12, 2020.
[3] The State Program of the Russian Federation "Integrated Development of Rural Areas." Approved by RF Government Decree No. 696 dated May 31, 2019.
[4] The Sustainable Development Strategy for Rural Areas of the Russian Federation for the Period up to 2030. Approved by RF Government Decree No. 151-r dated February 2, 2015.
[5] RF Government Decree No. 996 dated August 25, 2017 "On Approval of the Federal Scientific and Technical Program for Agricultural Development for 2017–2025."

control and regulation. However, the consistency of such program documents should be provided by the correspondence of their basic target indicators in content and level.

Improving program documents often led to even greater inconsistency. For example, in 2018, the State Program for Agricultural Development and Regulation of Markets of Agricultural Products, Raw Materials, and Food was conceptually changed with highlighting the project and process parts and extending the term of the document to 2030. These modifications ensured strategic orientation and an integrated approach to agricultural growth control. However, the target indicators were completely replaced and a discrepancy with the parameters of other program documents appeared. According to the classical rule of management, "the goal defines the result." This rule leads to the conclusion that the inconsistency in the content and level of target indicators of program documents regulating agricultural production in the country is a barrier to effective control of a strategically important sector of the economy, including its growth. Some studies also actualized the organizational problems of agricultural development associated with the need for effective coordination and unification of the corresponding state programs of various levels [1].

The hypothesis about a contradiction between agricultural growth and the lack of conditions for expanded reproduction in the AIC is proved using the concept of parametric control. Fuzzy cognitive modeling is used as a toolkit for forecasting the parameters of agricultural growth. The proof includes the following stages:

- parameterization of agriculture as an object of agricultural growth control in the form of a fuzzy cognitive map (FCM) based on expert methods and correlation-regression analysis;
- structural-target analysis of the FCM to assess the parameters and relations of the agricultural growth control model;
- scenario analysis of the FCM to assess the effectiveness of agricultural growth control by comparing the potential of managerial actions in agriculture with the internally created potential of agricultural dynamics.

There are quite diverse approaches to formalize and solve control problems for agriculture as a large-scale system. One example is the study [2] of the development prospects of the Russian agro-industrial complex (AIC) based on probabilistic mathematical modeling methods, where an exactly measured structure of the complex was obtained. Another example of formalized decision support for the Russian AIC is the system of mathematical models (operational scenario games, models with a hierarchical structure, models of intersectoral balance, etc.) for designing an integrated digital platform in agriculture [3].

Cognitive modeling is chosen as a toolkit for this study due to several reasons. First, the hypothesis about a contradiction between agricultural growth and the lack of conditions for expanded reproduction in the AIC is proved within the comprehensive study on designing an agricultural growth control strategy using fuzzy logic [4–6]. Therefore, the same conceptual basis and toolkit are adopted for the proof. Second, the agricultural growth control system modeled below is identified as weakly structured: the model's structure is built using the expert method, the factors-concepts of the model are determined, and their cause-effect (causal) relations are established. At the same time, statistical analysis methods are applied to obtain quantitative data for assessing the strength of relations between the factors-concepts. Note that cognitive models based on a combination of expert assessments and the statistical approach were tested in several applied problems [7, 8]. Generally speaking, despite its limited use in control of socio-economic systems, cognitive modeling has been actively developed for such problems. In particular, an environmental regulation model of agricultural production based on the cognitive approach was designed in [9]; innovative development scenarios for the domestic AIC under sanctions were presented in [1]; a control model for the integrated development of rural areas was proposed in [8, 10]. The studies of agricultural growth control problems based on cognitive technologies are not complex in the scientific literature; they are represented by separate lines of improving the dynamics of agricultural production. For example, fuzzy cognitive logic and cognitive modeling were applied for increasing lifestock intensification [11] (decision support in this area), forecasting potential yields in crop production [12], and choosing a socio-economic development strategy for poverty reduction in rural areas [13].

1. THEORETICAL FOUNDATIONS OF PARAMETRIC CONTROL

The idea of parametric control was widely used for complex technical and biophysical systems [14–16]. In some studies, parametric control was described jointly with coordinate, structural, and mixed control [17, 18]. Considering the coordinate, parameter, and structure of a system as the factors of active impact on it, the authors singled out coordinate, parametric, structural, and mixed (coordinate-parametric, coordinate-structural, coordinate-parametric-structural) control.

Having directly investigated the scientific foundations of parametric control, A.S. Bondarevsky and A.V. Lebedev [18] compared it with second-order cybernetics. According to the cited authors, with the appearance of cybernetics in 1948 and the subsequent involvement of living-nature systems (societies) in its scope, there was a transition from one-dimensional (coordinate) control in N. Wiener's sense (first-order cybernetics [19]) to two- or multidimensional control (second-order cybernetics [20–22]). Parametric control belongs to this type of control. In the opinion of Bondarevsky and Lebedev [18], although parametric control is intended for real objects, it can only be implemented on models of controlled objects by including these models in the control loop.

Parametric control is also applied to solve management problems in economics. Several authors [23] used the theoretical provisions of parametric control in conducting macroeconomic analysis and estimating the optimal values of economic policy parameters for macroeconomic systems. According to A. Ashimov et al. [24], the potential of parametric control is important for solving the food problem. Within the Globe 1 General Equilibrium Model[6], they adopted

[6] GLOBE 1. Applied General Equilibrium Modelling. URL: www.cgemod.org.uk/globe1.html (accessed 10.10.2022).

parametric control to determine the optimal values of economic policy instruments in order to achieve the desired level of regional economic growth, reduce the gap between rich and poor regions, and increase agricultural production using parametric control. (Note that this model describes the interaction of the economies of nine regions.) The theoretical foundations of parametric control were applied in computational experiments within the general equilibrium model to diversify economic growth by stimulating individual sectors of the Republic of Kazakhstan and its regional trade partners [25].

The idea of parametric control also underlies the natural-science approach to theoretical economics, which designs the economy structure based on hard sciences with mathematical modeling. In particular, D.S. Chernavsky et al. [26, 27] investigated the parametric control of systems with multiple steady states and argued that dynamic models in economics qualitatively (and even semi-quantitatively) describe transitions between states of an economic system and serve to identify the main control parameters for these processes.

The application of parametric control in economics was also studied by A.Yu. Obydenov [28, 29]. The author revealed the concept of parametric control by modeling the behavior of economic agents with bounded rationality; according to his conclusions, parametric control can be used to solve the coordination problem of coordination [29]. As noted by Obydenov, the core of parametric control is to stimulate the evolution of a controlled economic system to one of its own stable states and functioning modes that are preferable for the manager. He called such states attractors and defined them as a discrete set for an economic system [29]. The state of a controlled economic system was determined by dynamic variables in the phase space, its behavior was described by an analytical equation, and the phase portrait was specified by control parameters. In the author's opinion, parametric control of the system can be implemented by changing in a certain order of the parameters. Obydenov identified the following advantages of parametric control: decreasing the resistance of a controlled system, eliminating the inefficient solutions of control problems, reducing costs, and minimizing the deviation of the real result from the desired one [28, 29]. Furthermore, he transferred the idea of parametric control to the methodology of strategic management [28, 30], correlated it with modern flexible control methods [31], substantiated this approach to the control of economic agents with bounded rationality [29], revealed mathematical formalizations of institutions for parametric control purposes [32], and used the parametric control model to select agricultural policy instruments [33].

Another example of parametric control is the balanced scorecard system (BSS) developed by D. Norton and R. Kaplan [34]. This control concept uses four groups of parameters ("finance," "customers," "business processes," and "employees"), which are dynamic variables determining the state of a controlled socio-economic system. However, despite the declared significance of the cause-and-effect relations between these parameters, it is rather difficult to determine them qualitatively and quantitatively in practice: BSS has no explicit mechanism to consider and establish such relations. In other words, the variation of parameters as the basis of parametric control is not considered within this method. Therefore, BSS in control practice is often used formally: target values of indicators are set without ensuring their balance in values considering their weights. This situation is even exacerbated by the turbulent environment of economic systems. It often violates the main idea of the method: the achievement of non-financial indicators should provide the desired financial results [35].

Thus, the following conclusions can be drawn. There is no unified concept of parametric control with an unambiguous description of its content and mechanism of use. This approach has many applications in practical control and management and is therefore rather universal. The experiment to design an agricultural growth control strategy for Russia allowed specifying the theoretical foundations of parametric control of socio-economic systems and demonstrating its mechanism of use with justifying the toolkit for sustainable agricultural dynamics.

First, consider the essence of this type of control for socio-economic systems. Parametric control is control by parameters that formalizes the operating mode of a socio-economic system in order to bring the system to a stable state according to control targets. The parameters are dynamic variables that determine the state of a controlled system; they are varied to find control actions (management decisions) for achieving the targets. Two groups of parameters are considered to choose a control action. The first group determines the effectiveness of a control action as an external impact on the controlled object. The second one characterizes the internal potential of the controlled system to maintain its stability in a given state without resistance to the control action.

Parametric control expands the content of the classical process of making and implementing management decisions. Traditionally, this process represents a sequence of several stages as follows: goal-setting, situation assessment, problem definition, and design and implementation of management decisions to obtain the desired state of the controlled system (Fig. 1). In other words, the values of the controlled system parameters are achieved by designing and implementing a management decision. The content of a management decision is based on the contradiction between the goal and the situation in which the system operates. According to this approach, the manager is not capable to eliminate all ineffective management decisions: it is rather difficult to forecast the result of a control action (the desired state of the controlled system). Therefore, there is a risk of increasing the gap between the real result (the achieved state of the controlled system) and the desired one.

When using parametric control, the stage of control parameterization is introduced. It generates a set of parameters through enumerating their different combinations to reflect the state of the controlled system. The content of this stage determines the content of the management decision itself considering the identified problem (Fig. 2). To choose an appropriate management decision, it is necessary to compare the parameterization data of the controlled system as the result of external control action with its internal state. The relative equality of the parameterization results between each other and their correspondence to the control target values are a criterion for choosing a management decision. In the case of their inequality, the management decision should be corrected.

Depending on their variations, the parameters of the controlled system are therefore initially intended to choose management decisions by eliminating inefficient ones from the admissible set. Such a situation a priori minimizes the resistance of the controlled system and its elements to the changes determined by the chosen management decision. As a result, the resources are optimized and the gap between the achieved values of the system stability parameters and their desired level is reduced. In addition, the set of parameters—the indicators of the controlled system's state—can be used to effectively control the process and find the source of failure at each control stage.

The control parameterization stage should involve a preformed theoretical framework with the following elements:

– a theoretical concept to determine the approaches and rules for identifying the control factors of a socio-economic system and establishing the relations between them;

– principles to determine the state parameters of the socio-economic system (its stability in the context of the control problem to be solved);

– approaches to differentiate the parameters (separate control parameters as levers of management impact to achieve targets and a favorable operation mode of the socio-economic system);

– a toolkit to model the state of the socio-economic system based on parameter variations in order to achieve the desired stability level;

– criteria to choose management decisions (and assess their effectiveness) in order to solve the problem and achieve the desired stable state of the socio-economic system.

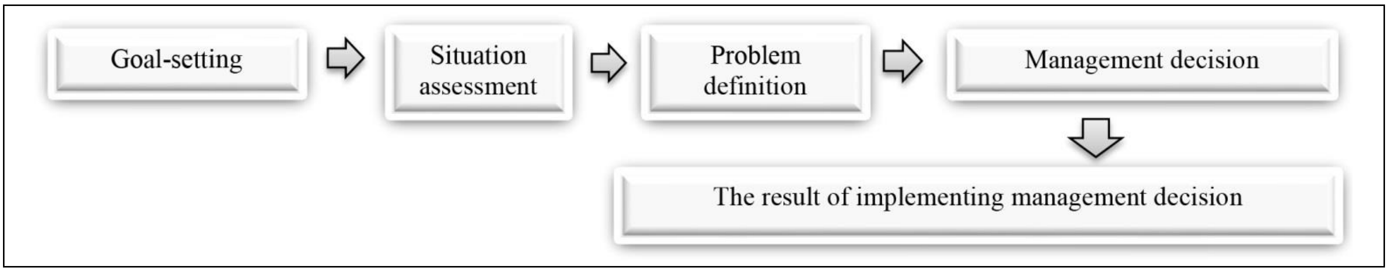


Fig. 1. Control of socio-economic systems (the classical approach).

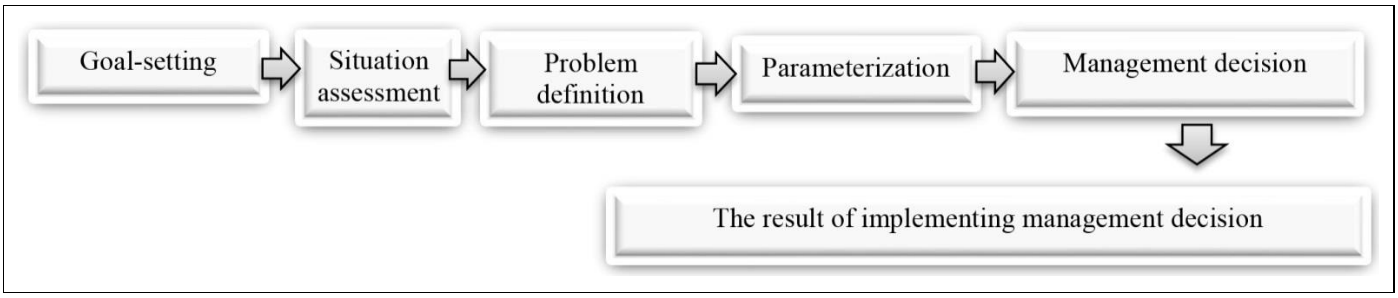


Fig. 2. Parametric control of socio-economic systems (the author's approach).

By introducing the parameterization stage in the control of socio-economic systems, it becomes possible to obtain an initial portrait of the controlled system and determine the content of the management decision. Due to the parametric portrait, the resulting state of the controlled system (obtained by implementing the chosen management decision) will minimize the deviation from the target parameters compared to the classical control approach.

These theoretical provisions of parametric control for socio-economic systems are experimentally proved below by cognitive modeling of the agricultural growth control strategy to identify the contradiction between agricultural development and the lack of conditions for expanded reproduction in the AIC.

2. COGNITIVE MODELING OF AGRICULTURAL GROWTH CONTROL PARAMETERS: KEY METHODOLOGICAL PROVISIONS

The fuzzy cognitive map proposed by V.B. Silov [36, 37] and the IGLA decision support system [38] were used for modeling. A fuzzy cognitive map is a causal network that represents the system under study as a graph

$$G = <E, W>$$

with the following notations: $E = \{e_1, e_2, ..., e_k\}$ is a set of factors (concepts) and W is a binary relation on the set E (the relations between its elements). The relation W is a set of numbers w_{ij} determining the direction and intensity of influence between concepts e_i and e_j (the influencing and dependent concepts, respectively):

$$-1 \le w_{ij} \le 1.$$

In the practical cognitive modeling of weakly structured systems, the direction and intensity of influence can be determined using various methods [6, 8, 39]. Several simplifications and assumptions used in cognitive models cause approximate (to a greater extent, qualitative) modeling results. Therefore, it was decided to use only quantitative concepts to increase accuracy and unambiguously comply with the real trends in agricultural development. Note that the intensities of relations between them were calculated using regression models based on statistical data for the period 2000–2020 (not expert methods).

In fuzzy cognitive maps, transitive closure is used to assess the direct and indirect influence of concepts on each other. This operation transforms the original mutual influence matrix W into a transitively closed matrix Z. It consists of the pairs of values: z_{ij} and $\overline{z}_{ij}$, characterizing the strength of positive and negative influence of the ith concept on the jth one, respectively. The fuzzy transitive closure algorithm was described in detail by Silov [36]. The transitive matrix in FCM static analysis allows calculating the system indicators [10]. In this study, the following indicators are used:

- the estimated influence of the ith concept on the system and the estimated influence of the system on the jth concept:

$$\vec{P}_i = \frac{1}{n}\sum_{j=1}^{n} p_{ij}, \tag{1}$$

$$\overleftarrow{P}_j = \frac{1}{n}\sum_{i=1}^{n} p_{ij}, \tag{2}$$

where n is the number of concepts and p_{ij} denotes the influence of the ith concept on the jth one:

$$p_{ij} = \text{sign}(z_{ij} + \overline{z}_{ij})\max(|z_{ij}|, |\overline{z}_{ij}|),\ |z_{ij}| \ne |\overline{z}_{ij}|, \tag{3}$$

where the function sign(x) returns the sign of an expression x;

- the consonance of the influence of the ith concept on the system and consonance of the influence of the system on the jth concept:

$$\vec{C}_i = \frac{1}{n}\sum_{j=1}^{n} c_{ij}, \tag{4}$$

$$\overleftarrow{C}_j = \frac{1}{n}\sum_{i=1}^{n} c_{ij}, \tag{5}$$

where c_{ij} is the consonance of the influence of the ith concept on the jth one:

$$c_{ij} = \frac{|z_{ij} + \overline{z_{ij}}|}{|z_{ij}| + |\overline{z_{ij}}|}. \tag{6}$$

The dynamics analysis of the agricultural growth control system given by the FCM involves the pulse process model. In this model, the dynamics of the system parameters are given by

$$v_i(t+1) = S(v_i(t) + q_i(t+1) + o_i(t+1) + \sum_{j=1}^{K} T(w_{ij},\ p_j(t))), \tag{7}$$

with the following notations: $v_i(t+1)$ and $v_i(t)$ are the values of the ith concept at time instants (t + 1) and t, respectively; $q_i(t+1)$ is the external influence on the ith concept at time instant (t + 1); $o_i(t+1)$ is the control action applied to the ith concept at time instant (t + 1); $w_{ij} = w(e_j, e_i)$ is the strength of the relation between the jth and ith concepts; $p_j(t)$ is the variation in the value of the *j*th concept at time instant *t*; *T* stands for the *T*-norm operation (multiplication); finally, *S* means the Łukasiewicz *S*-norm.

3. THE FUZZY COGNITIVE MODEL OF AGRICULTURAL GROWTH CONTROL: DESIGN AND STRUCTURAL-TARGET ANALYSIS

According to the parametric control scheme developed for socio-economic systems, first of all, a theoretical framework should be formed to identify the factors of the parametric agricultural growth control system, to choose the approaches to their differentiation, and to define methodologically the relations between them. This study involves the agricultural growth control methodology described in detail in [4]. This methodology is based on a structural-dynamic model of the agricultural growth control system (Fig. 3).

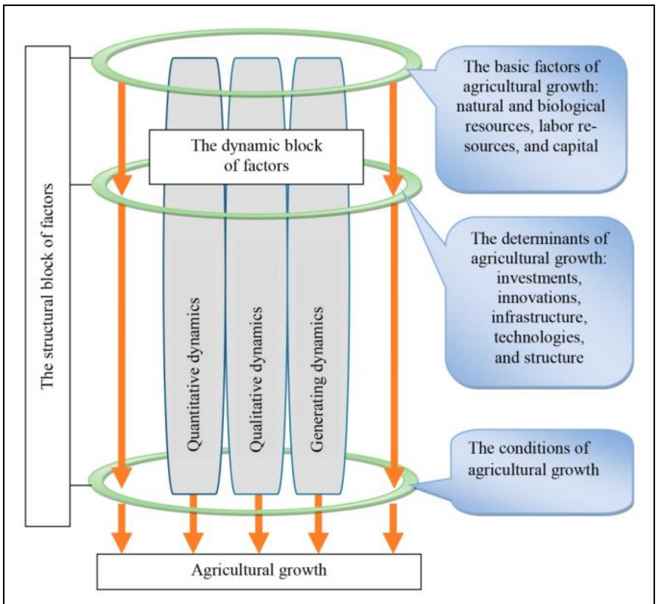


Fig. 3. The structural–dynamic model of the agricultural growth control system.

The model defines the parametric content of the control system based on identification for choosing the control action of the factors of the structural block and assessing the resulting agricultural dynamics of the factors of the dynamic block (quantitative, qualitative, and generating dynamics). In view of the AIC specifics, the structural block includes the following factors: natural and biological resources, labor resources, and capital (the basic factors of growth); investments, innovation, infrastructure, technology, and structure (the determinants of growth). The basic factors directly affect agricultural dynamics: growth is impossible without them. The determinants have an indirect influence on agricultural dynamics for the reproduction and more efficient use of the basic factors. The quantitative component of agricultural growth reflects the volumetric expansion of the agricultural economy and determines the quantitative increase in the public agricultural product. Qualitative agricultural dynamics are associated with the intensive development of agriculture and provide the duration, intensity, and innovation of growth. Separating the quantitative and qualitative components of agricultural growth is a generally accepted approach. However, the current conditions (resource constraints, the importance of environmental factors, and the need to keep the prerequisites for satisfying the demands of future generations) lead to a contradiction between intensive agricultural growth and the opportunities to solve all these problems. Therefore, it is necessary to consider the third important component of agricultural growth (called generating). This component reflects the conditions for making agricultural growth sustainable, balanced, and irreversible as well as levels the contradiction.

Accordingly, the structural-dynamic model conceptually rests on the following provision: each basic factor and each determinant are crucial for quantitative, qualitative, and generating agricultural dynamics in combination with other basic factors and determinants rather than as separate system elements. As a result, each block of the control system will perform appropriate functions and generate additional opportunities for agricultural growth. The structural block determines the factors of external control action for agricultural growth; the dynamic block characterizes the state of agriculture and its internal ability to maintain the controlled agricultural dynamics.

The cognitive modeling technology was used to determine the parameters of the agricultural growth control system for Russian agriculture. The cognitive agricultural growth control methodology was described in detail in [4, 5]. The fuzzy cognitive model (FCM) in this study involves the quantitative concepts only; they generally correspond to the indicators of regulatory documents for the Russian AIC. All the identified concepts were differentiated using the expert method according to the structural-dynamic model. The content of the model also determined the approach to establishing relations between the concepts.

Note that 14 concepts were selected in the structural block and 16 concepts in the dynamic block, with 3 common target concepts in each block. At this stage of the study, cognitive modeling produced the FCM (Fig. 4) as a visualization of the fuzzy cognitive matrix. The intensities of relations between concepts

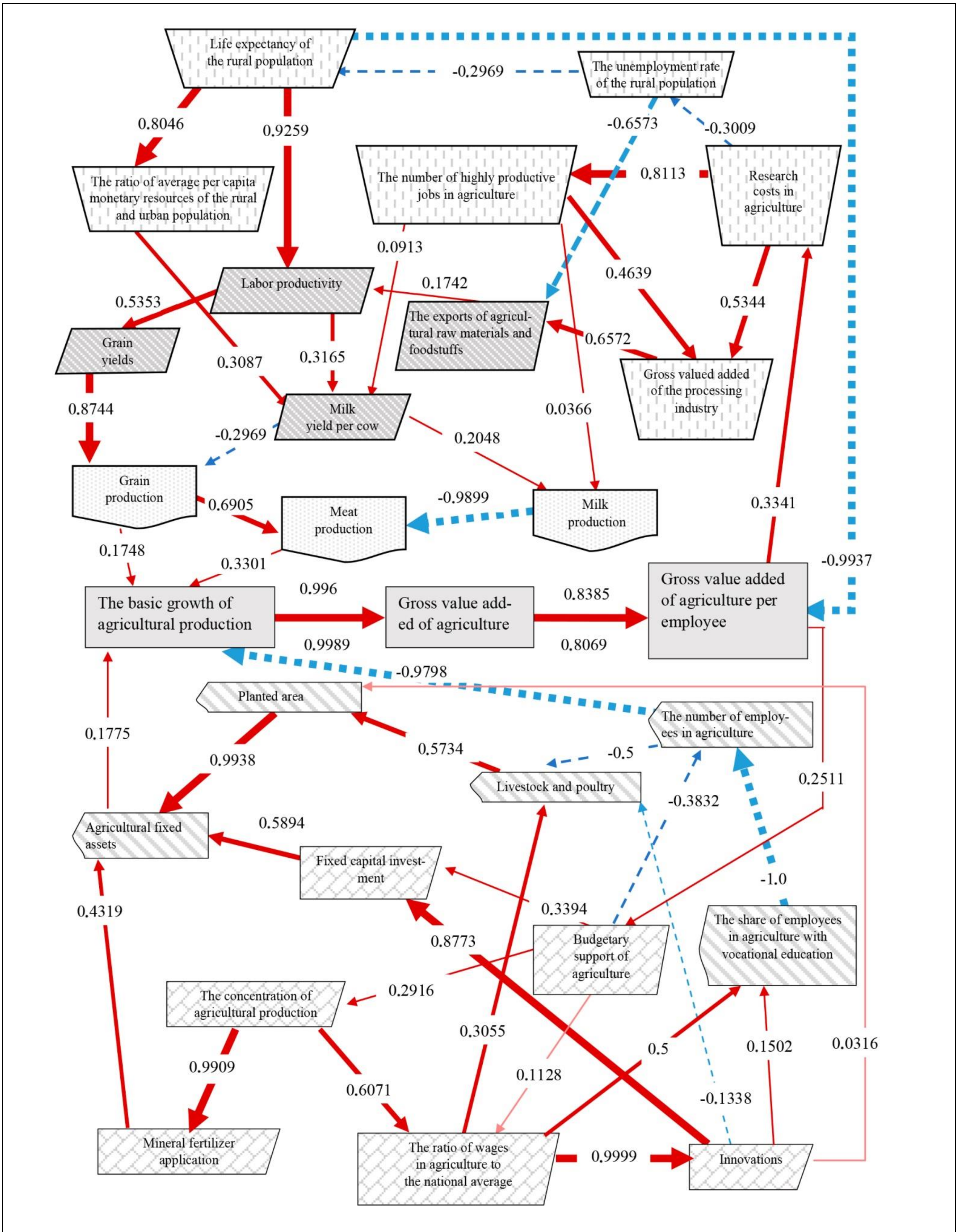
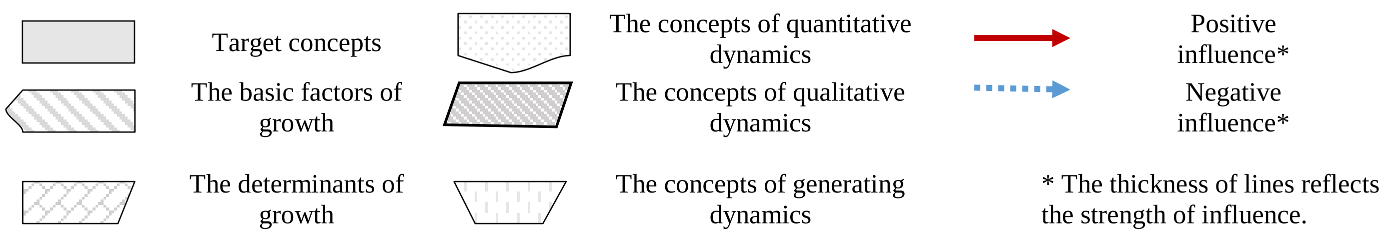


Fig. 4. The cognitive map of agricultural growth control.

Legend for Fig. 4



were determined by constructing two-dimensional (2D) and multivariate regression models based on the Rosstat data for the years 2000–2020. In the course of the study, the variables for the indicators in monetary terms were transformed using the direct deflation method. Variables with an appropriate lag were included in some models considering the specifics of their indicators.

The following criteria were used to verify the relations based on 2D and multivariate regressions:

– the high level of the statistical significance of the equation and its coefficients,

– the absence of multicollinearity (for the multivariate regression),

– the Gaussian distribution of the residuals,

– the model compliance with the requirements of the Wald and Breusch–Pagan tests.

As a result, 30 models of 2D and multivariate regressions satisfying these criteria were designed. The weights of the relations were calculated using the elasticity coefficient

$$e_{ij} = k_{ij} \frac{i_{\text{avg}}}{j_{\text{avg}}},$$

where i_{avg} and j_{avg} are the average values of the factor and resultant features, respectively, and k_{ij} is the regression coefficient in the linear regression model.

The chosen FCM involves a qualitative (linguistic) scale with values in the range [–1, 1]. Therefore, the elasticity coefficients were normalized using the sigma function

$$S_b(e_{ij}) = \frac{1 - \exp(-be_{ij})}{1 + \exp(-be_{ij})},$$

where b is the slope coefficient.

The expert method can be used to determine the coefficient b: an expert specifies an elasticity value $e_0 > 0$ for which the weight of a relation will be equal to a desired value α. In this study, α = 0.5 and, hence, $e_0 = e_{\text{med}}$ for the positive and negative coefficients (the median for the corresponding set of coefficients). Then the coefficient b is given by

$$b = -\frac{1}{e_{\text{med}}} \ln \frac{1-\alpha}{1+\alpha}.$$

Table 2 shows an example of calculating the weights of the FCM relations.

The structural-target analysis of the FCM of agricultural growth control was carried out and the basic system indicators were calculated by formulas (1)–(6); see Table 3. The influence of concepts on the system and the converse influence have rather high values of the estimated consonance: the sign and strength of the

Table 2

The weights of FCM relations between target concepts

Relation	Regression coefficient	Elasticity coefficient	Relation weight
The structural block of parameters			
The influence of the concept “The basic growth of agricultural production” on the concept “Gross value added in agriculture”	46.1928	3.6383	0.9989
The influence of the concept “Gross value added in agriculture” on the concept “Gross value added per employee in agriculture”	0.2569	1.2462	0.8589
The dynamic block of parameters			
The influence of the concept “The basic growth of agricultural production” on the concept “Gross value added in agriculture”	46.1928	3.6383	0.996
The influence of the concept “Gross value added in agriculture” on the concept “Gross value added per employee in agriculture”	0.2935	1.4233	0.8385

Table 3

The cognitive map of agricultural growth control: system indicators

Concepts	$\vec{C}_i$	$\overleftarrow{C}_j$	$\vec{P}_i$	$\overleftarrow{P}_i$
The structural block of parameters				
The basic growth of agricultural production	0.9579	0.9762	0.1766	0.1573
Gross value added in agriculture	0.9571	0.9770	0.1111	0.2227
Gross value added per employee in agriculture	0.9562	0.9778	0.0637	0.2477
The number of employees in agriculture	0.9949	0.9976	–0.3063	–0.1836
The share of employees in agriculture with vocational education	0.9950	0.9988	0.2407	0.0796
Planted area	0.9677	0.7330	0.1132	0.0697
Livestock and poultry	0.9833	0.7174	0.1057	0.0504
Agricultural fixed assets	0.9587	0.9011	0.0430	0.3137
Fixed capital investment	0.9677	0.9987	0.0671	0.2075
Innovations	0.7812	0.9870	0.1190	0.1382
Mineral fertilizer application	0.9677	0.9832	0.0492	0.1112
The concentration of agricultural production	0.8791	0.9795	0.3136	0.0421
The ratio of wages in agriculture to the national average	0.8671	0.9832	0.3186	0.0681
Budgetary support for agriculture	0.9554	0.9786	0.1882	0.0787
The dynamic block of parameters				
The basic growth of agricultural production	0.7921	0.6151	0.1631	0.0324
Gross value added in agriculture	0.7329	0.6743	0.1010	0.0947
Gross value added per employee in agriculture	0.7269	0.8300	0.0762	0.0579
Grain production	0.9105	0.5182	0.0947	0.0902
Meat production	0.8513	0.5559	0.0745	0.0355
Milk production	0.9105	0.9339	–0.1358	0.0306
Grain yields	0.9556	0.9560	0.1373	0.0722
Milk yield per cow	0.9589	0.9472	–0.0338	0.0726
Labor productivity	0.7277	0.9351	0.1305	0.0725
The exports of agricultural raw materials and foodstuffs	0.7486	0.9058	0.0336	0.0562
The ratio of average per capita monetary resources of the rural and urban population	0.9623	0.8539	0.0089	0.0444
The life expectancy of the rural population	0.8112	0.8479	0.1056	–0.0091
The number of highly productive jobs in agriculture	0.5756	0.8419	0.0547	0.0908
The unemployment rate of the rural population	0.8205	0.8419	–0.0937	–0.0337
Research costs in agriculture	0.7209	0.8360	0.1037	0.0475
Gross value added in the processing industry	0.7694	0.8817	0.0631	0.0889

influence are reliable. Considering the theoretical framework of agricultural growth control, the determinants of growth were treated as controlled concepts (see Fig. 4). Note that "Fixed capital investment" and "Mineral fertilizer application," the investment and technological determinants, do not almost influence agricultural growth. Meanwhile, the greatest influence on agricultural growth corresponds to the structural determinants: "The ratio of wages in agriculture to the national average" and "The concentration of agricultural production". Consider the system's influence on the target concepts as an indicator of its consistency. Obviously, these concepts are maintained by the system since the estimates of such an influence are commensurate or significantly exceed the estimates of the reverse influence.

Within the accepted framework, the concepts of generating dynamics in the dynamic block were treated as controlled ones (Fig. 4). "Life expectancy of the rural population" and "Research costs in agriculture" are the concepts with a significant influence on the system. Also, note an appreciable negative influence of the concept "Milk production" and a slight negative influence of the concept "Milk yield per cow" on the system: such influences contradict the objective content of these factors as quantitative and qualitative ones of agricultural growth. An increase in milk production and its efficiency should positively affect agriculture. Therefore, the negative influence of these concepts testifies to the limitations of agricultural growth in this AIC branch.

The negative value of the system influence on the concept "Life expectancy of the rural population" also indicates systemic problems reducing the potential of agricultural growth. (No doubt, it should have a positive effect.) Generally speaking, there is an insufficient level of system consistency: the influences of the system on the target concepts have smaller estimates compared to the reverse ones.

4. DESIGN OF AGRICULTURAL GROWTH CONTROL SCENARIOS

The parameters of the agricultural growth control system for the dynamic development of domestic agriculture were determined through the scenario analysis of the FCM using the pulse process technology (see formula (7)). At this stage of the study, the main task was to design agricultural growth scenarios for Russia as a set of parametric trends. Their parameters characterize the current situation, act as growth targets, form a set of control actions, and illustrate the level of agricultural dynamics. The choice of scenarios was determined by the current geopolitical situation and the agricultural policy of Russia. Modern challenges necessitate the effective use of the country's agricultural potential and ability to take a leading position in global agro-food markets.

Changes in the current agricultural policy are primarily connected with the new version of the Development Strategy for the Agro-industrial and Fishery Complexes of the Russian Federation for the period up to 2030 (hereinafter referred to as the Strategy); it was approved by RF Government Order No. 2567-r dated September 8, 2022. The Strategy focuses on a new economic development model to ensure the sustainable and dynamic growth of agriculture. Considering these two conditions, three scenarios were identified to test the theoretical concept of parametric control:

- Scenario 1 forecasts situation development within the newly adopted Strategy (The Acting Strategy).
- Scenario 2 forecasts situation development under a set of measures for the balanced and sustainable growth of agriculture within the available agricultural potential (The Complex Strategy).
- Scenario 3 synthesizes a set of measures to achieve breakthrough agricultural growth into a leading supplier of the global agro-food market (The Breakthrough Strategy).

Each scenario consists of two sets of parameters. The parameters of the structural block determine a set of control actions (means and tools) for agricultural dynamics. The parameters of the dynamic block reflect the resulting state of agriculture (agricultural growth processes) with long-term stable dynamics.

The values of the concepts were calculated as the ratio of the current level of indicators to their target level determined by the expert method in accordance with the best (foreign or domestic) practices. Following the cognitive technology, the resulting values were interpreted as the concept states on the uniform grading scale from 0 to 1 (Table 4). The initial states and values of the concepts are presented in Table 5.

Table 4

The grading scale for concepts

Value range	Interpretation
0.000–0.142	Very low
0.143–0.285	Low
0.286–0.428	Below medium
0.429–0.571	Medium
0.572–0.714	Above medium
0.715–0.857	High
0.858–1.000	Very high

Considering the specifics of cognitive modeling, the forecasting horizon was determined by the model time. The model and physical time scales were correlated according to the stages specified in the main regulatory documents for agriculture development: years 2020–2025 for the first stage and years 2025–2030 for the second stage. Table 6 presents the three scenarios of agricultural dynamics obtained by parameterization.

Table 5

The initial states and values of concepts of the cognitive agricultural growth control model

Concepts	The initial state of the concept	The initial value of the concept
The target block		
The basic growth of agricultural production	Low	0.21
Gross value added in agriculture	Low	0.28
Gross value added per employee in agriculture	Very low	0.14
The structural block		
The number of employees in agriculture	Above medium	0.7
The share of employees in agriculture with vocational education	Below medium	0.41
Planted area	Medium	0.49
Livestock and poultry	Below medium	0.39
Agricultural fixed assets	Low	0.24
Fixed capital investment	Low	0.28
Innovations	Very low	0.14
Mineral fertilizer application	Low	0.22
The concentration of agricultural production	Below medium	0.41
The ratio of wages in agriculture to the national average	Low	0.25
Budgetary support for agriculture	Low	0.28
The dynamic block		
Grain production	Above medium	0.65
Meat production	Above medium	0.61
Milk production	Low	0.28
Grain yields	Low	0.25
Milk yield per cow	Low	0.28
Labor productivity	Low	0.22
The exports of agricultural raw materials and foodstuffs	Low	0.24
The ratio of average per capita monetary resources of the rural and urban population	Low	0.25
The life expectancy of the rural population	Very low	0.1
The number of highly productive jobs in agriculture	Very low	0.12
The unemployment rate of the rural population	High	0.81
Research costs in agriculture	Very low	0.08
Gross value added in the processing industry	Low	0.2

Scenario 1. It was designed in accordance with the Strategy approved on September 8, 2022. In the structural block of parameters, “Fixed capital investment,” “Mineral fertilizer application,” and “Budgetary support for agriculture” were considered the main control actions. In the dynamic block of parameters, control actions were “The unemployment rate of the rural population,” “Research costs in agriculture,” “Gross value added in the processing industry” and “The ratio of average per capita monetary resources of the rural and urban population.” The pulse value, time, and duration were determined according to the target indicators of the Strategy.

The simulation results for the structural block of parameters generally proved the potential efficiency of the control actions to achieve the target values of the agricultural growth parameters. It is possible to achieve the gross value added in agriculture established by the Strategy (6.55 trillion RUB) by 2030. As expected, gross value added per employee in agriculture will increase 2.8 times but with reducing the number of employees to 2.5 million. However, it will be difficult to achieve the average growth of agricultural output at a level of 102.9% specified in the Strategy (the baseline growth is 129.7%). The simulation results for the structural block of parameters indicate a lower value of 102.4% (the baseline growth is 123.9%). But, even this level of growth can be limited when considering the simulation data for the dynamic block of parameters.

The state of agriculture due to quantitative, qualitative, and generating variations shows that, on average, growth can be ensured at a level no higher than 102% (the baseline growth is 119.95%). Gross value added may increase 1.2 times (reaching 5.2 trillion RUB), which will not satisfy the target of the adopted Strategy. The parameter "Gross value added per employee in agriculture" will be unstable and its value will remain invariable on average.

Scenario 2. The agricultural growth control strategy in this scenario was based on available opportunities and assumed the complex action of all control concepts to maximize the use of the national agricultural potential. In the structural block of parameters, the control action was formed through step-by-step variations of all the determinants of growth and strengthening their influence by two levels to the initial value. The exception was the concept "The concentration of agricultural production": considering the diverse forms of economic control in the AIC, the value of this indicator was increased by one level.

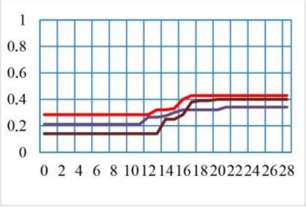
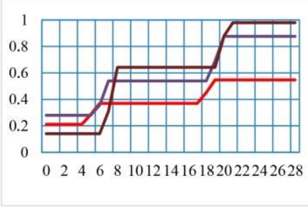
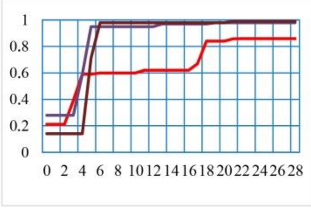
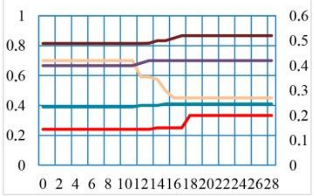
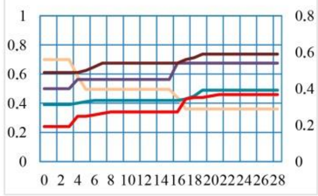
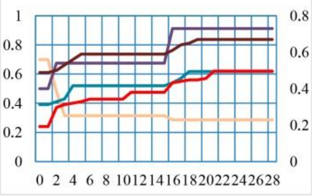
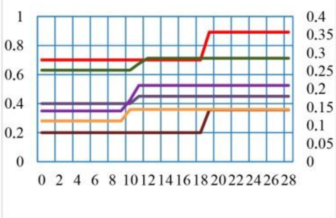
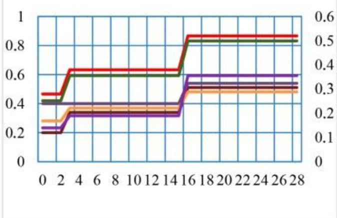
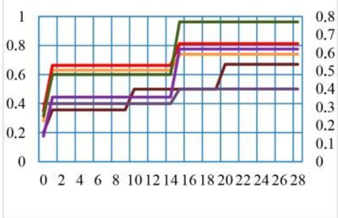
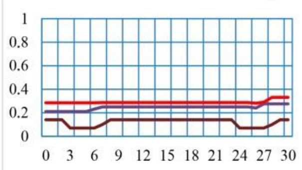
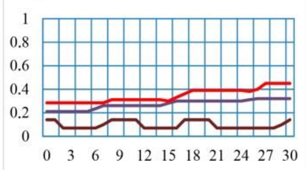
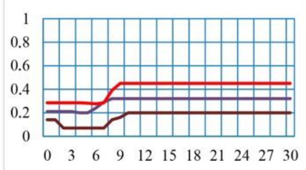
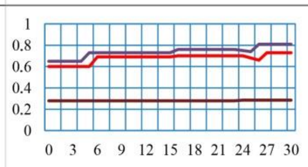
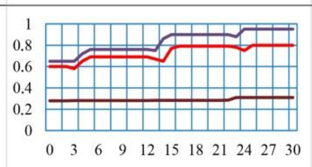
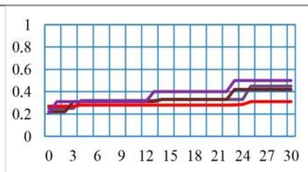
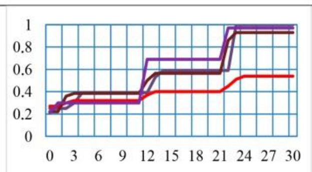
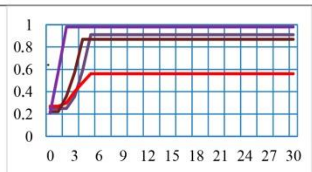
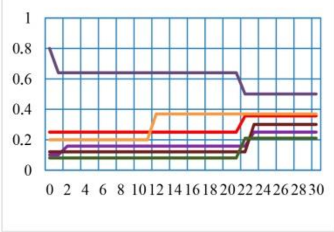
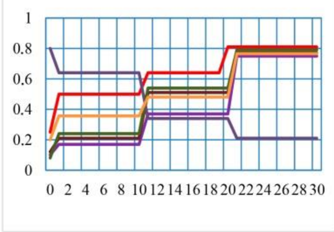
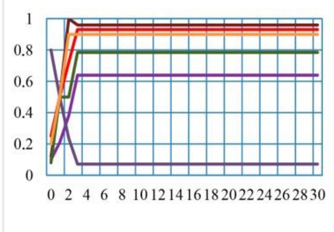
The forecasting results were as follows: the average growth of agricultural production will be at a level of 103.8% (the baseline growth is 138.3%) and gross value added will increase more than 3 times. The concept "Gross value added per employee in agriculture" can increase significantly, almost 7 times, with reducing the number of employees to 2 million. In the dynamic block of parameters, simulation within the integrated approach was implemented through the stage-by-stage strengthening of the concepts of the generating group of factors. Each concept was strengthened depending on its economic content and real national opportunities to make such changes. The resulting situation was similar to the previous scenario. As it was discovered, rather efficient control actions for agricultural dynamics within the structural block of parameters cannot form the appropriate internal potential of agricultural growth within the dynamic block of parameters. The average growth of production was forecasted at a level of 102.2% (the baseline growth is 122.4%); the increase of gross value added, at a level of 1.6 times. The parameter "Gross value added per employee in agriculture" will be more unstable and its value will also remain almost invariable.

Scenario 3. In this scenario, the agricultural growth control strategy was assigned a breakthrough nature. Intensive variations of the controlled concepts were assumed at the initial stages, which do not always correspond to the real possibilities of the modern agricultural economy of the country. However, this scenario was intended to test the possibility to level the contradiction between agricultural growth and lack of conditions for expanded reproduction in agriculture based on the existing economic experience. In the structural block of parameters, fixed capital investment was increased 2.3 times, the innovations of agricultural organizations increased by 30%, and mineral fertilizer application was set at the level of developed countries (increase by 3.4 times). Considering the current changes in the budgetary policy for agriculture and the additional 900 billion RUB announced by the RF Government for agriculture, the concept "The budgetary support of agriculture" was increased 2.7 times. In the author's opinion, social justice is an important factor ensuring agricultural growth in the country. Therefore, the controlled concept "The ratio of wages in agriculture to the national average" was increased to 84%. As in the previous scenario, the value of the concept "The concentration of agricultural production" was increased by one level. According to the simulation results, it is possible to achieve the average growth of agricultural production at a level of 106%. Gross value added in agriculture can be increased by 3.5 times (significantly). It is possible to reach a high level of gross value added per employee in agriculture (more than seven times) at a faster pace compared to the Complex Strategy. Furthermore, the number of employees in agriculture will be further reduced to 1.6 million. The simulation results for the dynamic block of parameters indicated the following: even with a sufficiently intensive variation of the controlled concepts (starting from the first steps), the internal growth potential of agriculture will not correspond to the potential of external control action.

The maximum possible average growth will remain at 102.2%, and gross value added will not increase as well. However, a more stable character and growth of 1.4 times will be observed for the target concept "Gross value added per employee in agriculture," which is much lower than the forecasted value in the structural block of parameters.

Table 6

Parameterization of agriculture in different agricultural growth scenarios

Concepts	Dynamics and parameter values		
	Scenario 1 (The Acting Strategy)	Scenario 2 (The Complex Strategy)	Scenario 3 (The Breakthrough Strategy)
The structural block of parameters			
Target concepts The basic growth of agricultural production Gross value added in agriculture Gross value added per employee in agriculture			
The factors of growth The number of employees in agriculture The share of employees in agriculture with vocational education (right scale) Planted area (right scale) Livestock and poultry Fixed capital			
The determinants of growth Fixed capital investment (right scale) Innovations (right scale) Mineral fertilizer application The concentration of agricultural production The ratio of wages in agriculture to the national average (right scale) Budgetary support for agriculture			
The dynamic block of parameters			
Target concepts The basic growth of agricultural production Gross value added in agriculture Gross value added per employee in agriculture			
Quantitative dynamics Grain production Meat production Milk production			
Qualitative dynamics Grain yields Milk yield per cow Labor productivity The exports of agricultural raw materials and foodstuffs			
Generating dynamics The ratio of average per capita monetary resources of the rural and urban population The life expectancy of the rural population The number of highly productive jobs in agriculture The unemployment rate of the rural population Research costs in agriculture Gross value added in the processing industry			

Thus, the parameters of agricultural growth have been forecasted using the parametric control methodology as a theoretical framework and cognitive technologies as a toolkit. According to the simulation results, there is a contradiction between the growth of agricultural production in Russia and the lack of conditions for expanded reproduction under the existing management approaches in the AIC. This situation acts as a significant barrier to the strategic development of the domestic agricultural economy. The structural-target and scenario analysis of the cognitive model shows that the main reason for this contradiction is the inconsistent parametric content of the agricultural growth control system.

A complex agricultural growth control strategy has been proposed to achieve target indicators and bring agricultural production to a new level using the cognitive modeling methodology. This strategy takes into account the current trends of political, economic, technological, environmental, and social character. The agricultural growth control toolkit proposed in this paper includes a set of tools and methods to apply control actions to agricultural dynamics and a set of indicators to monitor its compliance with specified targets [4].

CONCLUSIONS

In this study, the hypothesis about a contradiction between agricultural growth and the lack of conditions for expanded reproduction in the AIC has been proved using the concept of parametric control. Russian agriculture has been parameterized as a controlled object based on expert assessments and statistical data for the past 20 years. A set of consistent and balanced indicators has been identified, and an analytical cognitive modeling framework has been formed for agricultural growth scenarios.

According to the scenario simulation results, in modern management practice, the potential of control actions for agriculture as an object of agricultural growth control exceeds the internal potential of agricultural growth itself. Therefore, it is necessary to change management approaches in the AIC in order to achieve high indicators of agricultural growth and ensure its long-term sustainability and balancedness.

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