Expert strategic management systems in precision farming

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Abstract. Evaluating the modern market of the Internet of things, one should consider equipment connected into a single network, solutions, applications along the entire chain of product creation, including the end user. In this paper, such a binding is based on cloud information technologies. Through these technologies, the intellectualization of agrotechnology management is implemented through the creation of expert management decision support systems (DSS). The aim of the work is to consider the methodology for constructing DSS of strategic management in precision farming systems, where this type of management has not been implemented to date. To this kind of management, the task of forming strategies for the application of mineral fertilizers and ameliorants of prolonged action for all the years of various types of crop rotations is included. To solve the problem, an algorithm for the formation of optimal strategies for the application of mineral fertilizers and ameliorants, which is implemented in an analytical automated control system of agricultural technologies, through which a knowledge base (KB) is transmitted from the cloud system to local DSS, is substantiated. To select the best option from the knowledge base, the pattern recognition method is used. The technique was tested on arbitrary initial conditions of local systems, including extreme combinations of initial conditions. Based on the analysis of the loss of optimality associated with the discrepancy of the initial conditions on the local DSS and the KB, a method for controlling the formation of the BR, aimed at reducing these losses, is substantiated.

1. Introduction

The concept of the digital economy appeared in the last decade of the last century. Nicholas Negroponte, an informatics specialist, founder of the Media Labs at the Massachusetts Institute of Technology (MIT), formulated the fundamental principles of the digital economy. Back in 1995, he spoke about the shortcomings of classic goods (weight, raw materials, transport) and the advantages of the new economy (lack of weight of goods, virtuality, instant global movement) [13].

Today, agriculture is on the verge of the Second Green Revolution. Experts believe that, thanks to the new information technologies based on the Internet of Things, a surge in yields of such magnitude that humanity did not see even at the time of the appearance of tractors, the invention of herbicides and genetically modified seeds, could follow. Technologies evolved, became cheaper and advanced to such a level that for the first time in the history of the industry it became possible to obtain data on each agricultural object and its environment, mathematically calculate the algorithm of actions and predict the result. Digitalization and automation of the maximum number of agricultural processes is included as a conscious need for a development strategy for this sector of the economy [1].

The task of informatization and digitalization is the maximum automation of all stages of the production cycle to reduce losses, increase business productivity, and optimal resource management.

Further automation represents a higher level of digital integration, which affects the most complex organizational changes in the business. However, their implementation can dramatically affect the profit and competitiveness of products and the company as a whole. Integrating data with various intelligent IT applications that process them in real time provides a revolutionary shift in decision making for the farmer, providing analysis of multiple factors and a rationale for subsequent actions. In this case, the more sensors, sensors and field controllers are connected to a single network and exchange data, the more intelligent the information system becomes and the more useful information for the user it can provide.

The initial base of digitization and intellectualization of agriculture was provided by the scientific and technical progress of the 20th and early 21st centuries, which provided new and unique possibilities for actually reducing the risk of agricultural production. They include new robotic machines, measuring devices, computing equipment and modern mathematical base. The rapid development of information technologies enables researchers and developers to combine measuring instruments of various physical natures with computer equipment and automated agricultural machines into a single, controlled complex. The natural response to such opportunities was the development of a new agrarian-technological direction, known as "precision farming" or "precision agriculture" (PA). At its core (PA), it implies the solution of the problem of increasing the manageability of crop production by solving a set of tasks for managing agrotechnologies [9].

At the same time, it should be borne in mind that a high scientific and technical level of agrotechnology management systems requires the availability of highly qualified personnel for their operation, which is a difficult problem to solve in conditions of agricultural production. This problem can be solved by switching to cloud computing technologies, when computer resources and capacities are provided to the user as an Internet service [7,8,10,14]. Cloud technologies have become possible due to the rapid development of hardware. Processor power is growing day by day, multi-core architecture is developing and hard drive volumes are increasing, and high-bandwidth Internet channels are widely used. The capabilities of cloud technologies allow implementing the full range of procedures necessary for making management decisions.

The situation is greatly simplified in the transition to expert systems in which control decisions are made directly from the input information, bypassing complex multi-step computational procedures. The main information core of expert systems is knowledge bases (KB), which are the source of information for making management decisions. To form a KB, the principle of coding the knowledge of a human expert cannot be used, no matter how highly qualified he may be. An expert system with such a KB is not a modern breakthrough information technology and does not allow optimizing the control decisions made. However, the high efficiency of expert systems can be ensured if, instead of a human expert, the source of information will be software and hardware complexes of analytical systems for managing agrotechnologies. Through such complexes, a large number of optimal solutions are formed for various soil and climatic conditions of growing crops. Each such case is an element of the knowledge base and is the optimal control solution for the given conditions, ensuring the maximization of the result in a controlled system.

The formation of the KB optimal solutions for the given conditions is a serious foundation that provides a high scientific and technical level of the management process. But it remains unclear how the user himself can make management decisions on the KB and the signals of his information-measuring system. One of the most effective means of making such decisions is the pattern recognition method, when the current situation is searched for the best option, taken as a class or image [6]. Considering the fact that there are many such images in the knowledge base, the recognition algorithm can be constructed based on the methods of conditional probabilities of classes or the “nearest neighbor”.

The purpose of this work is to present the methodology for constructing expert systems for strategic management in TK systems. To this level of management, we include the task of optimizing the doses of application of mineral fertilizers of prolonged action in crop rotations of various types. Currently, there is no theory for building such systems, and the results are presented for the first time [3-5].

2. Algorithm Strategic Management

The problem to be solved is formulated as follows: for the sequence of crops in the adopted crop rotation, denoted by the indices j = 1,2,3 ..., N, it is necessary to find a strategy for introducing the main nutrients and ameliorants in a given field, ensuring the achievement of the management goal, namely: minimizing the yield losses of all crop rotation, with minimal consumption of resources and given technological constraints.

To formalize the problem, we introduce into consideration a vector of parameters of the chemical condition of the soil of a given field that is averaged over the area of the field: V = [3x1], with components: $v_1 = pH, v_2 = P, v_3 = K$; *pH*- acidity, P - phosphorus, K - potassium. We will also need a vector of crop cultivation conditions unregulated by this strategy: F = [4x1], with components: f_1 - is the seasonal sum of temperatures; f_2 - is the seasonal total precipitation; f_3 - is the total flux of Phyto active radiation; f_4 - is the annual consumption of available forms of nitrogen.

We accept the assumption that for each crop of the used crop rotation the optimum content of the main nutrients and the optimum value of soil acidity are known. Any deviation from these optimal values will lead to yield losses [5]. Taking into account the fact that all the above indicators of the chemical state of the soil act simultaneously, we will consider the following forms of yield loss patterns for each j-th crop in crop rotation

$$\Delta \mathrm{u}_j(\mathrm{T}) = \mathrm{k}_{1j}^{\mathrm{T}}(\mathrm{V}_j^* - \mathrm{V}(\mathrm{T})) + (\mathrm{V}_j^* - \mathrm{V}(\mathrm{T}))^{\mathrm{T}} \mathrm{K}_{2j}(\mathrm{V}_j^* - \mathrm{V}(\mathrm{T})) \tag{1}$$

where: V* is the optimal value of the vector of the chemical state of the soil in a given field for the j-th crop of the crop rotation; $\Delta u_j(T)$ - yield losses for the j-th crop rotation due to the deviation of the vector of the chemical state of the soil from the optimal value;

$\mathrm{k}_{1j}^{\mathrm{T}} = \begin{bmatrix} k_1 & k_2 & k_3 \end{bmatrix}_j$ – matrix-row parameters of the linear part of the model,

$\mathrm{K}_{2j} = \begin{bmatrix} k_4 & k_5 & k_6 \\ 0 & k_7 & k_8 \\ 0 & 0 & k_9 \end{bmatrix}_j$ – matrix of parameters of the quadratic part of the model.

At the same time, in order to identify model (1), we need its observed yield - the amount of yield loss due to the deviation of the chemical state parameters from the optimal values - $\Delta u_j(T)$, which is formed by comparing the potential yield for the j-th crop for given cultivation conditions determined by the F vector and the real or projected yield $u_j(T)$ for the same conditions

$$\Delta u_j(T) = \mathrm{B}_{\mathrm{j}}^{\mathrm{T}} \mathrm{F}(T) - u_j(T) \tag{2}$$

$\mathrm{B}_j^{\mathrm{T}} = \begin{bmatrix} b_1 & b_2 & b_3 & b_4 \end{bmatrix}_j$ – vector of parameters of a linear model of potential yield.

Optimization of strategies for the introduction of agrochemicals and ameliorants is possible only if there are predictions of the chemical state of the soil, by which it is possible to estimate the total yield loss in crop rotation. For this purpose, a dynamic model of all components of the chemical state of the soil of the following type is proposed

$$\begin{aligned} \dot{v}_{1j} &= a_{11} v_{1j}(T) + b_1 d_{Ca}(T) + c_1 f_2(T), \\ \dot{v}_{2j} &= a_{22} v_{2j}(T) + b_2 d_P(T) + c_2 f_2(T) + d_2 \hat{u}_j(T), \\ \dot{v}_{3j} &= a_{33} v_{3j}(T) + b_3 d_K(T) + c_3 f_2(T) + d_3 \hat{u}_j(T), \end{aligned} \tag{3}$$

where: $\hat{u}_j(T) = \mathrm{B}_{\mathrm{j}}^{\mathrm{T}} \mathrm{F}(T) - \Delta u_j(T)$ – crop yield taking into account losses; $d_P(T)$, $d_K(T)$, $d_{Ca}(T)$ – doses of nutrients and improver for years of crop rotation (elements of strategy); a_{11}–a_{33}, b_1–b_3, c_1–c_3 – model parameters.

The scalar form of the model (5) is convenient for its line-by-line identification, but to form an optimal strategy for introducing agrochemicals and ameliorants, the canonical vector-matrix form expanded

$$\begin{bmatrix} \dot{v}_1 \\ \dot{v}_2 \\ \dot{v}_3 \end{bmatrix} = \begin{bmatrix} a_{11} & 0 & 0 \\ 0 & a_{22} & 0 \\ 0 & 0 & a_{33} \end{bmatrix} \begin{bmatrix} v_1(T) \\ v_2(T) \\ v_3(T) \end{bmatrix} +$$

$$+ \begin{bmatrix} b_1 & 0 & 0 \\ 0 & b_2 & 0 \\ 0 & 0 & b_3 \end{bmatrix} \begin{bmatrix} d_P(T) \\ d_K(T) \\ d_C(T) \end{bmatrix} + \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} f_2(T) + \begin{bmatrix} 0 \\ d_2 \\ d_3 \end{bmatrix} u(T); \tag{4}$$

and compact character

$$\dot{\mathrm{V}} = \mathrm{AV(T) + BD(T) + cf_2\,(T) + du(t)} \tag{5}$$

The introduced designations and models allow us to form an optimal solution criterion for the problem, adequate to the goal

$$\mathrm{I = M\{\sum_{\mathit{T}=1}^{\mathit{N}}[(V^* - V(T))^T\, G(V^* - V(T)) + c_{Tu}\,\Delta u_T(T) + C_d^T D(T)]\}} \tag{6}$$

where: M - the operation of the mathematical expectation of the area of the field; G – matrix of weight coefficients, by which the ratio of the parameters of the chemical state of the soil varies; $\mathrm{c_{Tu}}$ - crop unit price in the T-year of crop rotation, $\mathrm{C_d^T}$ - the vector of prices for mineral fertilizers for each nutrient.

Criterion (6) has the meaning of the average risk of crop underperformance in crop rotation and over-consumption of fertilizers spent on its production [5,11,12].

Let us consider the Hamiltonian of the system (7), (8) [2]

$$\begin{aligned} &\mathrm{H(T) = [(V^* - V(T))^T\, G(V^* - V(T)) + c_u[K^T(V^* - V(T)) +} \\ &\mathrm{+(V^* - V(T))^T\, H(V^* - V(T))] +} \\ &\mathrm{+C_d^T D(T)] + \lambda^T[AV(T) + BD(T) + cw(T) + du(t)],} \end{aligned} \tag{7}$$

where λ = is the vector of conjugate variables associated with the vector of the chemical state as follows:

$$\begin{aligned} &\dot{\lambda} = \frac{\partial H(T)}{\partial V} = [\mathrm{G+H}](\mathrm{V}^* - \mathrm{V}(T) + c_u\,\mathrm{K} + \mathbf{A}^{\mathrm{T}}\lambda(T), \\ &T \in (N,0),\ \lambda(N) = 0. \end{aligned} \tag{8}$$

The partial derivative of the Hamiltonian in the vector of doses of agrochemicals

$$\mathrm{g}(T) = \frac{\partial H(T)}{\partial D} = C_d\ + \mathrm{B^T}\,\lambda(T). \tag{9}$$

The optimal strategy for introducing agrochemicals for all years of crop rotation is a sequence of dose vectors D (T) and is found by performing the following computational procedure:

$$\mathrm{D}_n^*(T) = \mathrm{D}_{n-1}^*(T) - \Delta_n[C_d + \mathrm{B^T}\,\lambda_n(T)],\ \mathrm{D_1} \le \mathrm{D}_n^*(T) < \mathrm{D_2} \tag{10}$$

if $\mathrm{D}_n^*(T) < \mathrm{D_1}$, that $\mathrm{D}_n^*(T) = 0$, if $\mathrm{D}_n^*(T) > \mathrm{D_2}$, that $\mathrm{D}_n^*(T) = \mathrm{D_2}$.

3. Expert Strategic Management System

Figure 1 shows a block diagram of an automated agrotechnology management system with training from a data center for use in cloud information technologies. Here in the information cloud is the data center of the automated control system, which implements the above-described algorithm of strategic management. Through this algorithm, a knowledge base (KB) is formed, in which for different variants of the initial values of the parameters of the chemical state of the soil and different climatic conditions for each type of crop rotation, optimal strategies for the application of mineral fertilizers and ameliorants are formed.

The approbation of the system consisted in presenting a local expert DPRS of an arbitrary version of the initial conditions for choosing the optimal strategy from the BK. When using the pattern recognition approach, it is advisable to use the "nearest neighbor" method, when class membership is estimated by the minimum distance between the vectors

$$\rho_i(T) = \sqrt{\sum_{j=1}^{n} (z_{ji}(T) - y_j(T))^2}, \ j = \overline{1, J}, \tag{11}$$

where: i=1,2,…I – record numbers in the BK, y_j ,z_j - factors for making decisions on the local DSS and on KB, j=1,2...J – indices and the total number of components of the combined vector of decision-making factors.

The choice of the best variant of the optimal strategy from the BR for a local DSS is taken according to the condition

$$I^* = \arg\min_i \rho_i(T) \tag{12}$$

Were chosen arbitrary initial conditions for the formation of optimal strategies are shown in Table 1.

Table 1. Initial conditions of local DSS.

Initial conditions	Acidity kg·ha^{-1}	Phosphorus kg·ha^{-1}	Potassium kg·ha^{-1}
	4,30	30,40	41,80

To assess the possible loss of optimality for these conditions, an optimal strategy has been formed for ameliorating and mineral fertilizers, shown in Fig. 2. The effectiveness of such a strategy is characterized by the value of the optimality criterion of 534.55 rub.·ha^{-1}.

In accordance with rule (13), the closest variant of the strategy was chosen in the BK, which is characterized by the following initial conditions.

Table 2. The closest initial conditions from the BK.

Initial conditions	Acidity kg·ha^{-1}	Phosphorus kg·ha^{-1}	Potassium kg·ha^{-1}
	5,10	40,20	42,40

This option corresponds to the optimal strategy shown in Fig. 3, the effectiveness of which is estimated at 492.44 rub.·ha^{-1}. Comparison of the results shows that the discrepancy between the initial conditions in the KB and the local DSS leads to a loss of optimality of the strategy by 8.5%.

The low level of loss of optimality in the considered example indicates that arbitrary initial data in the local DSS is chosen from the range of possible values close to optimal. Of interest are cases far from this area. Such a case is presented in table 3.

Table 3. The case of extreme initial conditions.

Initial conditions	Acidity $kg \cdot ha^{-1}$	Phosphorus $kg \cdot ha^{-1}$	Potassium $kg \cdot ha^{-1}$
	4,10	20,00	25,00

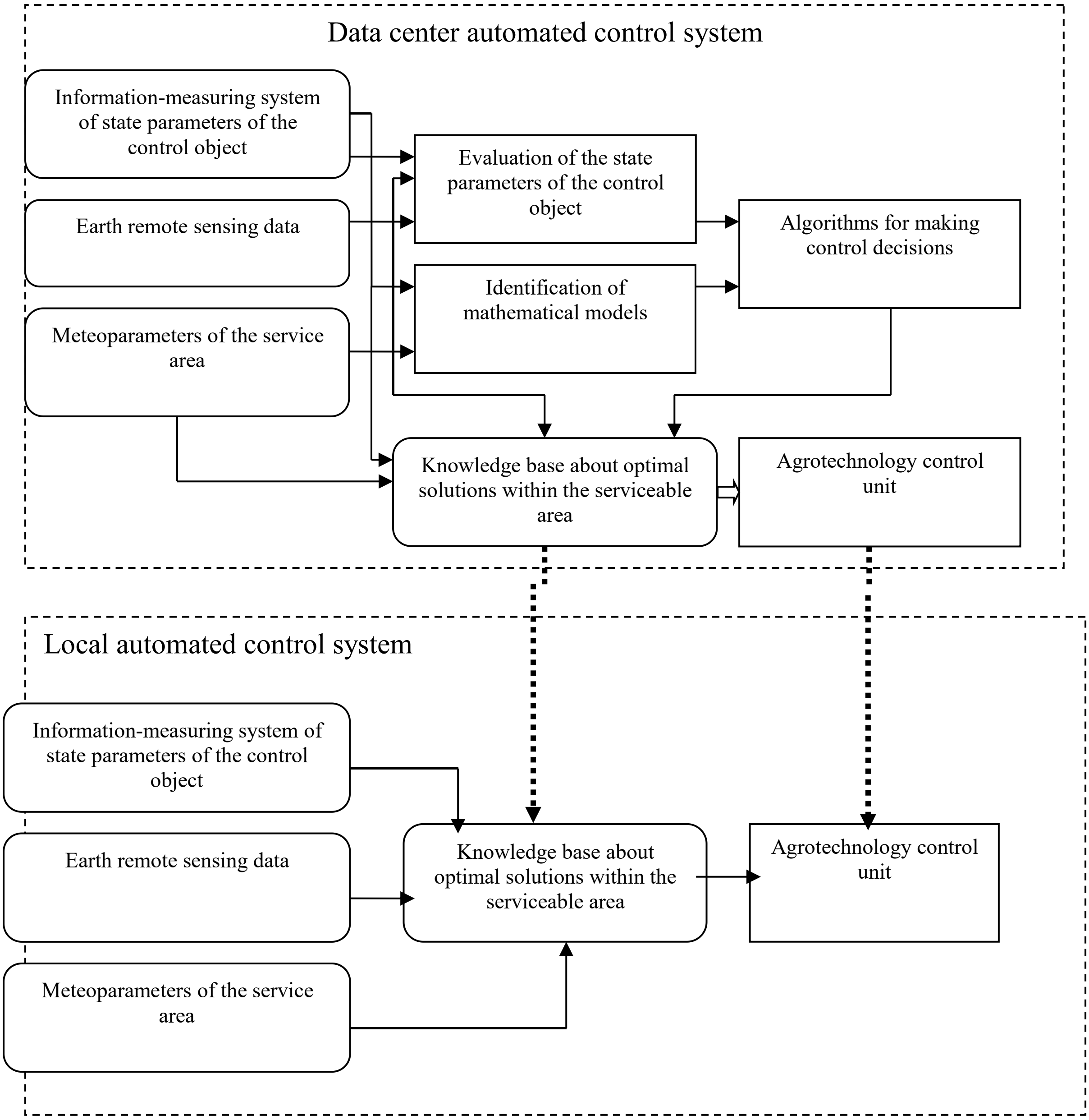

Figure 1. Block diagram of the automated process control system with training from the data center.

Figure 4 presents the optimal strategy for the application of improver and mineral fertilizers for extreme initial conditions. The effectiveness of this variant of the strategy is characterized by the value of the optimality criterion of 1,158.10 rub.$\cdot ha^{-1}$.

In accordance with rule (13), the closest variant of the strategy was chosen in the BR, which is characterized by the following initial conditions:

Table 4. The closest initial conditions from the BR.

Initial conditions	Acidity $kg \cdot ha^{-1}$	Phosphorus $kg \cdot ha^{-1}$	Potassium $kg \cdot ha^{-1}$
	4,40	33,30	29,60

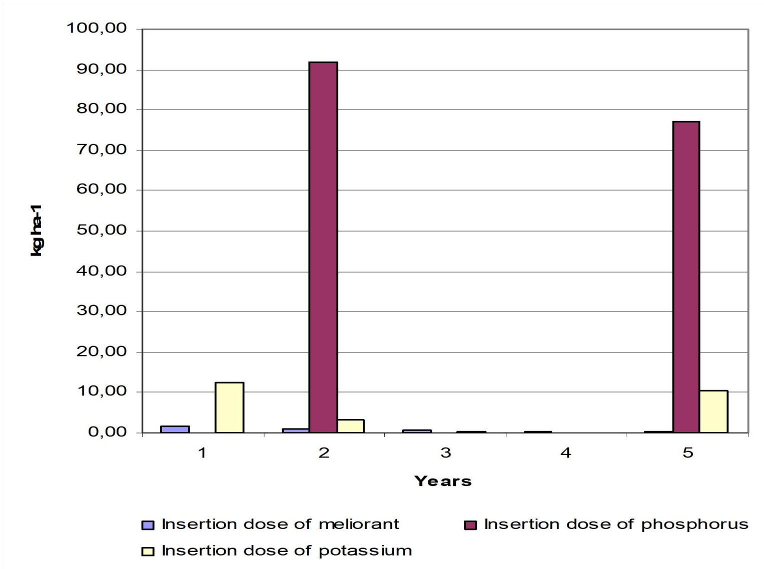

Figure 2. The optimal strategy for the introduction of improver and mineral fertilizers for arbitrary initial conditions of the DSS.

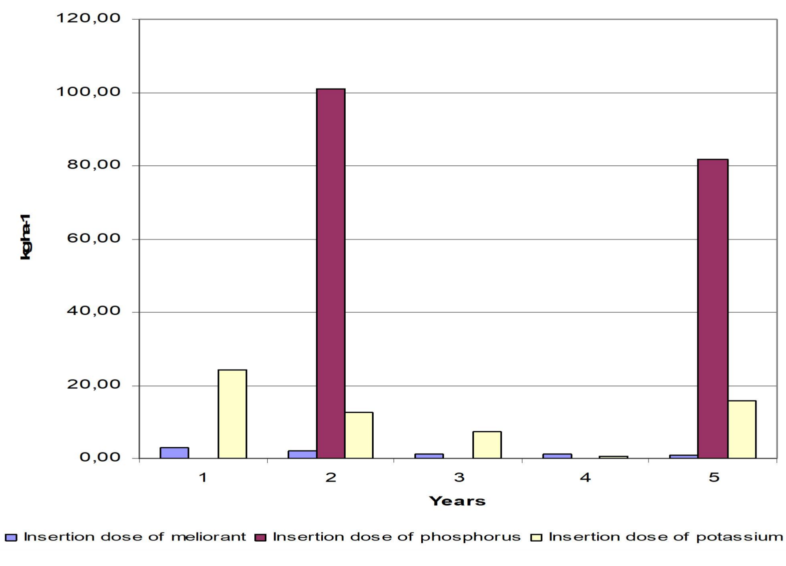

Figure 3. The optimal strategy for the application of improver and mineral fertilizers for the closest case of the BK.

This option corresponds to the strategy presented in Figure 5, the effectiveness of which is estimated by the value of the optimality criterion of 587.81 rub./ha. In this case, the loss of optimality due to the inconsistency of the initial conditions is 99%.

Such a high loss of optimality of the strategies for amelioration and mineral fertilizers makes it necessary to pay serious attention to the formation of the BR, which uniformly covers the entire multidimensional region of possible values of the initial conditions for rotation of crops. To replenish the BR can use two sources. In the first case, new variants of optimal strategies are generated through the above-described strategic management algorithm, and in the second case, real data from local DSS can be used during their centralized service in the cloud information system.

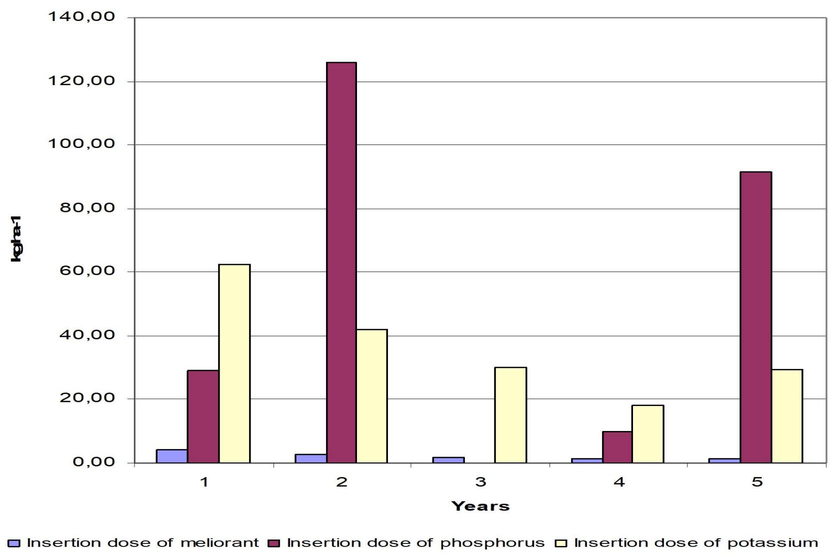

Figure 4. The optimal strategy for applying improver and mineral fertilizers for extreme initial conditions.

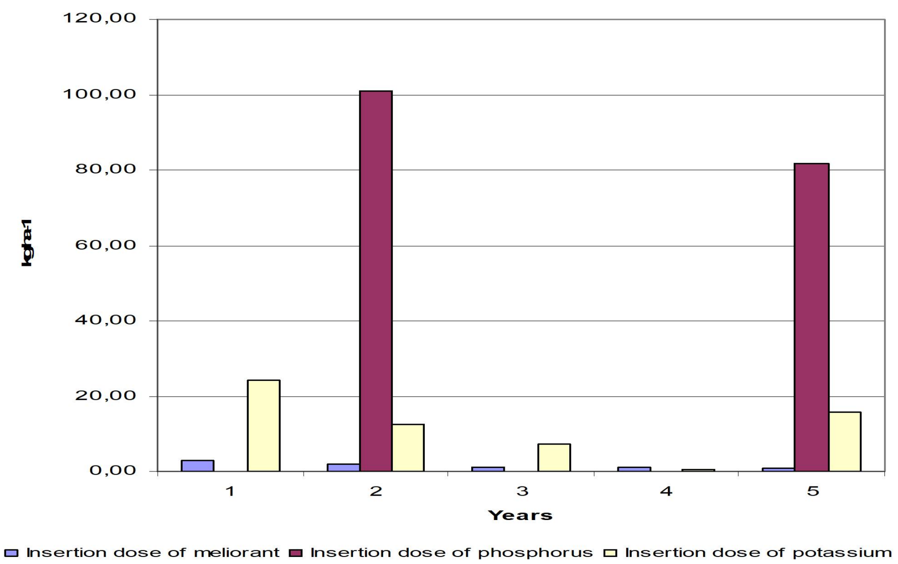

Figure 5. The optimal strategy for the introduction of improver and mineral fertilizers for the closest case of KB and extreme initial conditions.

At the same time, to decide on the inclusion of the next variant of the optimal strategy in the BR, the same criterion of proximity of options (12) can be used, for which its threshold value Δ is established, and the decision rule is applied:

a new option is included in the BK, if $\min\rho \geq \Delta$,

a new option is not included in the BK, if $\min\rho < \Delta$.

A significant method of increasing the reliability of expert DSS with centralized maintenance of local systems is the segmentation of KBs by soil and climatic conditions and crop varieties.

When forming KB segments according to above rule, only differences in the parameters of mathematical models (1) - (7) used in the strategic control algorithm will remain the main source of optimality losses. Losses from such differences do not exceed 20-25%, and their elimination is possible only by adapting models according to the operational monitoring of the state of crops in analytical ASMCs tied to specific control objects.

4. Conclusion

The method of building expert management decision support systems (DSS) in precision agriculture is proposed. The method involves the use of cloud information technologies, in which a knowledge base (KB) is transmitted from the cloud to local DSS, by means of which the closest optimal strategies for applying mineral fertilizers and ameliorants in various types of crop rotations are selected. An algorithm for the formation of optimal strategies has been developed for the formation of the cloud BS, minimizing the risk of yield losses for all crops of crop rotation and over-expenditure of mineral fertilizers and ameliorants. Based on the results of testing the methodology, a methodology for managing the formation of a KB, aimed at reducing the loss of optimality of strategies associated with a mismatch of initial conditions on local DSS and knowledge base of an information cloud, is substantiated.

Acknowledgments

The work was carried out with the partial support of the Russian Foundation for Basic Research (project No. 18-016-00008).

References

[1] Averyanov M A, Evtushenko S N, Kochetkova E Yu 2016 Digital Society: New Challenges *Economic Strategies* **7** (141): 90-91
[2] Kazakov I Ye 1987 *Optimization Methods for Stochastic Systems*. Moscow: Nauka p 354
[3] Mikhaylenko I M, Timoshin V N 2016 Optimization of soil chemical parameters in field crop rotations *Agrochemistry* **3** p 3-10
[4] Mikhaylenko I M, Timoshin V N 2018 Soil chemical state management based on Earth remote sensing data *Tavrichesky herald of agricultural science* 1 (13): 65-76
[5] Mikhaylenko I M 2017 *Theoretical foundations and technical implementation of agrotechnology management*. Ed. St. Petersburg State Technical University p 250
[6] Mikhaylenko I M 2019 Intellectualization of agrotechnology management *Bulletin of Russian agricultural science* **2** p 24-28
[7] Orlov S 2012 Cloud computing *Journal of Network Decisions* No. 01 [Electronic resource] http://www.osp.ru/lan/2012/01/13012475/
[8] Razumnikov S V 2014 Risk assessment modeling using cloud IT services *Basic research* **5** (1): 39-43
[9] Zakharenko A V, Yakushev V P 2009 *Precision Agriculture* ed. D. Shpaar, SPb. VIZR p 397
[10] Shirokova E A 2011 Cloud technologies *Int. Conf. on Modern trends in technical sciences: materials* (Ufa, October 2011) p 30-33
[11] Roudier P, Tisseyre B, Poilve H and Roger J M 2011 A technical opportunity index adapted to zone-specific management *Precision Agriculture* **12** p 130-145
[12] Kim K, Chavas J P 2003 Technological change and risk management: An application to the economics of corn production *Agricultural Economics* **29** p 125-142
[13] Neogronte N 1995 New York: Alfred A. Knopf (Paper edition 1996, Vintage Books)
[14] Gillam. Lee 2010 Cloud Computing: Principles, Systems and Applications *Nick Antonopoulos* (Computer Communications and Networks) p 379