Artículo de investigación

Planning algorithm for efficient and sustainable crop production

Алгоритм планирования эффективного и устойчивого производства сельскохозяйственных культур

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Abstract

The process of agricultural production is associated with a complex of factors of a different nature: systemic, technological, biological, socio-economic, climatic, reproductive, environmental. All of them influence the size and stability of economic and financial results. There is a threshold level of enterprise management complexity, the excess of which motivates agribusiness to switch to computerized methods. Management of an agricultural enterprise should be based on planning results, updated in a rolling mode. When developing the annual plan, it is necessary to take into account a lot of heterogeneous information and tend to the optimal solution – the achievement of the target indicators with the minimum expenditure of resources. As the basis of the optimal annual planning system, the article proposes an economic-mathematical model for optimizing the production and industry structure of an agricultural enterprise, which includes the following modules: assessment of the parameters of the yield production functions based on field history, the formation of a fertilizer application

Аннотация

Процесс производства продукции сельского хозяйства сопряжен с комплексом факторов разной природы: системных, технологических, биологических, социально-экономических, природно-климатических, воспроизводственных, экологических. Все они оказывают свое влияние на величину и устойчивость хозяйственно-финансовых результатов. Существует пороговый уровень сложности управления предприятием, превышение которого мотивирует агробизнес к переходу на компьютеризированные методы. Управление сельскохозяйственным предприятием должно базироваться на результатах планирования, актуализируемых в скользящем режиме. При разработке годового плана приходится учитывать множество разнородной информации и стремиться к оптимальному решению: достижению целевых показателей при минимальной затрате ресурсов. В качестве основы системы оптимального годового планирования в статье предлагается экономико-математическая модель

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plan with justification of economically feasible yield levels, solving the problem of optimizing the sectoral structure of crop production, taking into account the forecrop influence in the crop rotation. The algorithm for finding an effective and stable production structure under various combinations of environmental conditions implements the following sequence of procedures: generation of parameter combinations of the economic-mathematical model; obtaining the optimal solution for each combination of these parameters; assessment of the mathematical expectation of the efficiency criterion and variance for each optimal solution on a variety of parameter combinations; choice of a highly effective solution with a low dispersion of this efficiency. To implement this algorithm, the method of simulation experiments in the space of system parameters is used. The optimal solution is chosen by minimizing the distance to the “ideal point” (maximum efficiency, minimum dispersion).

Keywords: Agricultural enterprise, computerized plan, economic and mathematical model, efficiency dispersion, planning.

оптимизации производственно-отраслевой структуры сельскохозяйственного предприятия, в составе которой выделяются следующие модули: оценка параметров производственных функций урожайностей на основании истории полей, формирование плана применения удобрений с обоснованием экономически целесообразных уровней урожайности, решение задачи оптимизации отраслевой структуры растениеводства с учетом влияния предшественников в звеньях севооборота. Алгоритм нахождения эффективной и устойчивой производственной структуры при различных сочетаниях условий внешней среды реализует следующую последовательность процедур: генерацию сочетаний параметров экономико-математической модели; получение оптимального решения на каждом варианте сочетаний указанных параметров; оценку математического ожидания критерия эффективности и дисперсии для каждого оптимального решения на множестве сочетаний параметров; выбор высокоэффективного решения с низкой дисперсией этой эффективности. Для реализации данного алгоритма применяется метод имитационных экспериментов в пространстве параметров системы. Выбор оптимального решения осуществляется путем минимизации расстояния до «идеальной точки» (максимум эффективности, минимум дисперсии).

Ключевые слова: дисперсия эффективности, компьютеризированный план, планирование, сельскохозяйственное предприятие, экономико-математическая модель.

Introduction

There is a threshold level of complexity in managing a business in the agricultural sector, the excess of which significantly motivates the producer to switch to computerized management methods and systems (this is not about accounting systems). This level depends on the size of the enterprise, industry structure, organization of production processes, the availability of relevant competencies for decision-makers, the quality and availability of consulting, and a number of other circumstances, for example, the ability to use the necessary Internet resources (market information system, trading platforms, forecasts of yields of agricultural crops, prices for agricultural raw materials and food, demand through distribution channels, etc.). Thus, we can assume a whole range of configurations of agricultural management systems for enterprises with various combinations of the above features. However, in the process of their economic and financial activities, the need for solving well-known problems remains:

- Implementation of operational management of production and marketing of products, and more generally – the functioning of agricultural enterprises during the agricultural year.

- Development of an annual plan of economic and financial activities.
- Development of a production program for the development of the enterprise for several years.

The essence of these problems has been discussed many times in the specialized literature, as well as the informational interaction of these stages of the production cycle with parameters changing during evolution (Csaki, 1988; Glen, 1987; Kardash, 1981; Krylatykh, 1979; Ognivtsev, 1994).

The difficulty of tasks quickly grows from top to bottom. The operational management of production and marketing of products uses (should use) the annual plan indicators (possibly updated in the rolling planning mode) as the basis, and the target setting is to provide technologies with the necessary resources within the organizational structure formed at the enterprise and taking into account disturbances and unforeseen situations.

When developing an annual plan, one has to take into account a lot of heterogeneous information and tend to the optimal solution.

The procedure for developing an annual plan is aimed at solving the following main tasks facing a commodity producer: substantiating the nomenclature and volumes of manufactured products, providing all the technologies involved with labour, technical means, consumed resources, substantiating distribution channels and distributing commodity mass along with them.

The natural desire of the manufacturer should be the implementation of the annual plan at minimal cost, which increases its profitability and current competitiveness indicators. The actual behaviour of the manufacturer, as a rule, differs from the optimal. One of the reasons is the lack of opportunities provided by appropriate computer technologies and optimal annual planning systems. This resource for increasing the efficiency of agricultural production, is still not very widespread, is produced on a commercial basis, it is expensive and its creation is not supported by the state.

When substantiating the nomenclature and volumes of agricultural production, the “do as I did before” strategy cannot be winning, although it can be acceptable (not leading to loss of solvency in the medium term).

The functioning of the optimal annual planning system can be based on the well-known economic-mathematical model for optimizing the production and industry structure of an agricultural enterprise (AE) (Braslavets & Kravchenko, 1978; Ognivtsev & Siptits, 2002). As a criterion, such models consider the minimum cost for a given volume of production or the maximum profit (net income, gross output, marketable products in value terms) with restrictions on the resources used. In developing the model, a variety of specific characteristics are used, calculated from past information for this AE. Also, for the planning period, crop yields, sales prices, and prices of inputs must be predicted.

Such a procedure can be implemented:

1) By the producer himself if he has a database with historical information;
2) in the market information system (MIS), which does not know how to do it yet;
3) as a public service of the regional Ministry of Agriculture (not yet implemented). The choice between these options is a technical and economic problem that should be solved when developing a project for digitalization of the agricultural sector in each region.

It should be noted that the presence of forecast values of prices and yields, which can vary within certain limits, in the task of optimizing the sectoral structure of crops will require multivariate solutions from the user with various combinations of the mentioned parameters. At the same time, depending on the tendency of the user to risks of one or another degree, he will choose a solution in the interval “guaranteed result – the maximum possible result”.

The annual planning system should be activated as necessary, that is, 1) in the preparation and implementation of a business decision; 2) when updating forecast information if business decisions that may affect it have not yet been taken; 3) at the end of the planning period for adjustment regulatory information in the database of AE.

Finding the optimal plan is carried out by linear programming methods, an integral part of which is the analysis of dual estimates (Bellman & Drejfus, 1965; Khedi & Kandler, 1965; Zubanov, 2001). This allows us to identify the presence of active restrictions for the further development of the economic system, to assess the significance of each of them and, thereby, indicate a promising direction for its future changes.

The implementation of such changes is usually associated with the implementation of relevant investment projects. In addition, the agricultural development program may be associated with the emergence of new activities that did not exist before and which could not be included in the optimal annual management plan. Thus, the program for the development of agricultural production over a long-term interval with some simplifications can be imagined in the form of an agreed set of investment projects that should be provided with funding sources, working capital, labour, and other resources. At the same time, since money is limited for the implementation of projects, the moments of their start must meet the phasing conditions, that is, the previous ones that have already recouped costs and entered the net profit regime should take part in financing the next project.

Investment design technologies are currently quite well developed (Ognivtsev, 2001; Romanenko, 2007; Siptits, 2016). For their implementation, there are a variety of software products. However, it should be noted that all these funds do not protect against risks by 100%, are quite difficult to master and, if necessary, rely on long-term forecasts of prices, tariffs, salary rates, inflation, bank interest, etc. Now the development of investment projects in the interests of agricultural enterprises is carried out on a commercial basis. Examples of the development of multi-project programs for the development of agricultural production for the perspective of 10-15 years are very rare. The development of investment projects by AE is possible if there are no borrowed funds in the financing structure. Otherwise, with the complex structure of borrowed capital, competencies and authority of specialized firms come second; the first is the availability of liquid collateral assets.

Materials and methods

During the study, system functions were determined that should be implemented by the producer regularly. These features are discussed below.

Each producer of crop products annually faces the task of forming a production plan that provides the maximum possible profit with acceptable risks. The solution to this problem necessitates the adoption of informed decisions on the following issues, which can be represented in the form of the following algorithm:

1. Select a list of marketable crops.
2. Set the forecast prices for crop products, production factors that are part of the production cost.
3. Based on the information of the "History of Fields" database (the applied doses of mineral and organic fertilizers and the corresponding yields obtained in previous years), construct the appropriate empirical relationships, in the form:

$y = y_{max}(1 - e^{-\alpha V})$, (1)

where $V = \sum_i k_i v_i + k_U D_U + k_H H$,

(2)

$k_i v_i$, $k_U D_U$, $k_H H$ - the utilization factor of the i^{th} element from soil reserves and the actual reserves of the i^{th} element, the utilization rate of mineral fertilizers and the dose of mineral fertilizers. The same for organic fertilizers;

y_{max} - the value set by the user to the maximum possible yield in the given soil and climatic conditions;

α - dependence parameter estimated by the least squares method, which determines the response form of a given crop to changes in mineral nutrition conditions.

1. To determine the values of economically feasible crop yields and the corresponding plan for the use of mineral fertilizers, based on the obtained dependences of yields on doses of mineral fertilizers. The criterion is net income, the result of the decision is yield levels, doses of mineral fertilizers for each crop, the mass of fertilizers purchased by type and brand. To assess the production costs corresponding to this decision, the technological map selected by the user from the database "Technologies for the cultivation and harvesting of crops" is used, the total costs of which are reduced to:

$s = a_0 + \Sigma c_k z_k + c_U D_U$, (3)

where s, a_0, c_k, z_k, c_U - specific (per unit of sown area) production costs, conditionally fixed costs, price of the k^{th} production factor, technologically determined consumption of this factor, price per unit mass of the dose of mineral fertilizers ($N+P_2O_5+K_2O$) in proportions balanced for a given crop. The determination of doses of organic fertilizers and their distribution over crop rotation fields in this version of the algorithm is outside the scope of optimization procedures. It is assumed that this problem will be solved based on well-known agronomic recommendations. Nevertheless, information on the introduction of organic matter will be taken into account when assessing the size of yields (see (1) - (2))

2. To solve the problem of optimizing the sectoral structure of crop production, that is, to find the distribution of the entire cultivated area for cultivated crops from the condition of maximizing net income, taking into account the existing restrictions of the resources: labour and working capital allocated for the purchase of production factors, as well as production volumes. At the same time, it is possible to use two technologies for the production of one type of crop production: with the use of elite seed material and without it. These technologies differ from each other by at least one parameter – y_{max}, which in this case the user should determine expertly (usually by 15–20% more than in the second case).
3. Based on assessments of the forecrop quality in the links of crop rotation, to give recommendations on the distribution of cultivated areas of forecrops for crops planned for production.

The solution to the problem of crop rotation optimization is based on information about the positive or, conversely, the negative impact of the forecrop on the yield of the subsequent crop. This information is contained in the matrix (square if the list of forecrops matches the list of crops planned for production and rectangular otherwise). The criterion for the quality of crop rotation is also the value of the total net income from the cultivation and sale of cash crops.

Results and discussion

We describe the procedures that make up the core of the algorithm for planning crop production.

- The user chooses the composition of crops – applicants for inclusion in the production program based on the cultivation practice and the profitability indicators averaged over the last 3 years (the ratio of sales to the total cost in cost terms). Sources of information can be the “History of Fields” database, annual reports of the producer, anonymized data of other producers, available to all users of the digital platform (DP) and located in similar soil and climatic conditions.
- Planning of crop yields is based on the approximation of the economic activities results of the producer, recorded in the database “Field History”. At the regional level, information sources are aggregated reports of business entities, as well as statistical reporting forms with data on mineral and organic fertilizers applied for certain crops.
- To predict the prices of sales of crop products and the acquisition prices of factors of production, the user is provided with two options: an intuitive forecast made by himself, and a short-term forecast for the available time series using exponential smoothing:

$$p(t+1) = \beta c(t) + (1-\beta)\, p(t) \qquad (4)$$

$$\beta = \frac{2}{n+1};\; p(0) = \frac{1}{n}\sum_{t=0}^{n} c(t) \qquad (5)$$

where *n* – the length of a series of previous price forecasts,

p(t) – projected price.

Formulas (4) - (5) are applicable for time series with equally spaced values of indicators, for example, average annual prices. Otherwise, if the user has non-equally spaced price data with a monthly step, it is advisable to highlight a trend using an approximation of the form: $c(t) = a + bLn(t)$ using a subset of data corresponding to the selected month as a data array.

It should be noted that any predicted indicator does not have a normative character for the user; the final choice and the associated risks always remain with him.

- Production yield functions describing the dependence of this indicator on the funds of mineral nutrients available for the plant. The latter is determined in accordance with (2), taking into account the aftereffect of organic and mineral fertilizers applied earlier (in the

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previous three years). Doses of N, P and K are calculated taking into account the ratio of these elements in plant tissues, that is, they are introduced into the soil in a balanced form.

– The determination of economically feasible crop yields occurs on the basis of solving the problem of optimizing the plan for the use of mineral fertilizers with a limited budget to cover the production costs of the user. A feature of the formulation is the nonlinear nature of the maximized criterion.

If it is supposed to use elite seeds, this leads to the introduction of the corresponding production functions of productivity into the task.

– The task of optimizing the sectoral structure of crop production practically does not differ from the classical settings. A feature is the finding of rational distribution of sown areas of given crops by technological methods of production. The user has the opportunity to determine the technological method of production by setting the yield increase of the corresponding crop, caused by the use of seed of the highest standards. The choice of energy-saving technologies (mini-till, no-till) is also possible and should be carried out at the second step of the algorithm by introducing the corresponding production functions into the circuit, the parameters of which, in the absence of a history of the use of such technologies, the user will have to set expertly.
– Optimization of the relations of crops in the links of crop rotation is the final procedure of the algorithm of annual planning of production and sale of crop products. At the same time, we proceed from the assumption that the influence of the forecrop on the yield of the planned crop is realized at a qualitative level and is evaluated in ordinal scales. This assumption makes it possible not to use iterative procedures in which the parameters of the production functions of crop yields are adjusted.

It should be noted that the results of the annual planning algorithm are potentially influenced by a sufficiently large number of parameters that arise at different stages of its operation (short-term price forecasts, expertly set maximum possible yields, soil characteristics, etc.). To obtain a sustainable solution, it is necessary to place this algorithm in a simulation system that implements the experimental design in the space of the parameters mentioned above.

Figure 1 shows a block diagram of such a system. The user makes the final choice of the planned option by comparing the indicators of the net income received by him in one or another variant and the variance of this indicator, the estimate of which is obtained in a series of simulation experiments.

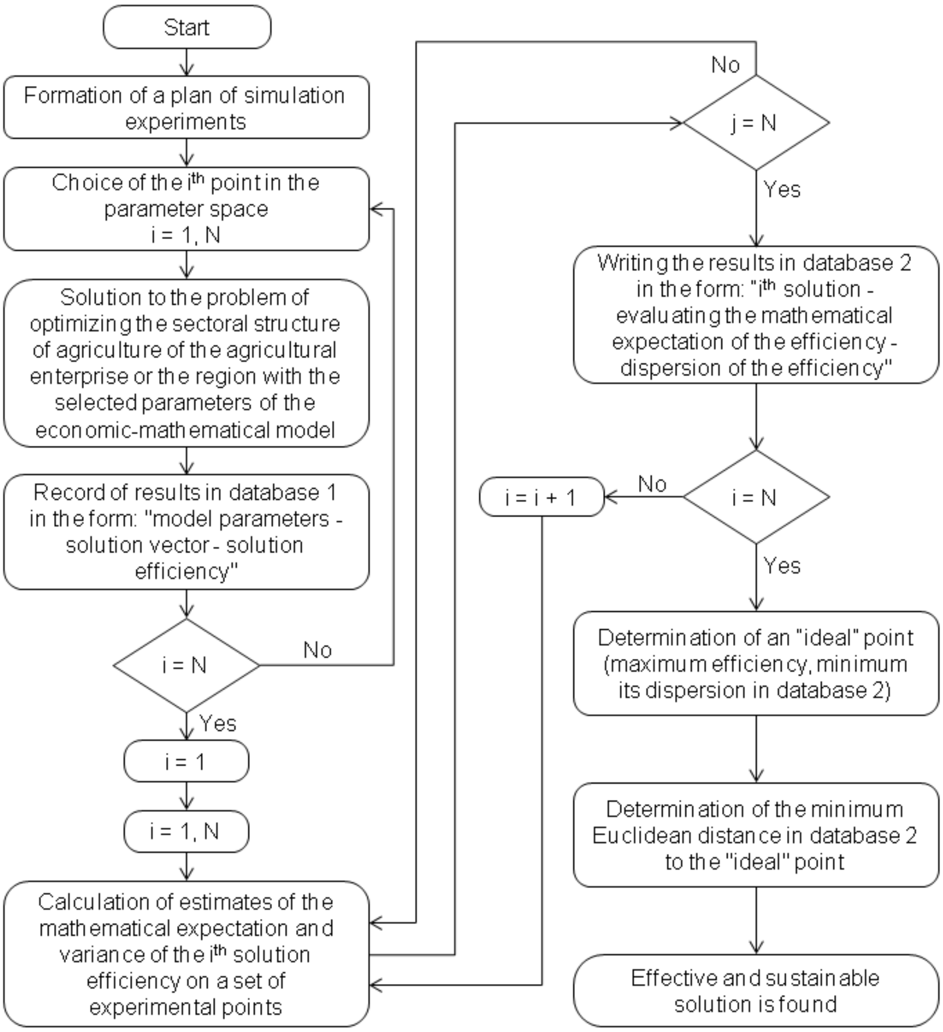

Figure. Block diagram of the system of statistical tests to assess the sustainability of decisions in the planning of crop production in agricultural organizations, as well as at the regional level.

As a result of the studies carried out according to this scheme, the directions of changes in crop production for the agricultural regions of the country were determined.

Table, as an example, presents the changes required in the production of corn for grain.

Table. Corn for grain

Direction of changes	Regions
111. The increase in sown areas, accompanied by an increase in doses of mineral fertilizers and the use of elite sowing material.	
112. The increase in sown areas, accompanied by an increase in doses of mineral fertilizers; the use of elite seed is not provided.	Belgorod region, Bryansk region, Voronezh region, Kursk region, Lipetsk region, Moscow region, Oryol region, Ryazan region, Smolensk region, Tambov region, Republic of Dagestan, Karachay-Cherkess Republic, Republic of North Ossetia-Alania, Republic of Mordovia, Orenburg region, Altai region

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121. The increase in sown areas, accompanied by a decrease in doses of mineral fertilizers with the use of elite sowing material.	
122. The increase in sown areas, accompanied by a decrease in doses of mineral fertilizers, the use of elite seed is not provided.	Kaliningrad region, Republic of Kalmykia, Astrakhan region, Chechen Republic, Republic of Bashkortostan, Penza region, Omsk region, Primorsky Territory, Amur region, Jewish Autonomous region
211. The decrease in sown areas, accompanied by an increase in doses of mineral fertilizers and the use of elite sowing material.	
212. The decrease in sown areas, accompanied by an increase in doses of mineral fertilizers; the use of elite seed is not provided.	Republic of Adygea, Krasnodar Territory, Kabardino-Balkarian Republic, Stavropol Territory, Perm Territory
221. The decrease in sown area, accompanied by a decrease in doses of mineral fertilizers with the use of elite sowing material.	
222. The decrease in sown areas, accompanied by a decrease in doses of mineral fertilizers; the use of elite seed is not provided.	Tula region, Volgograd region, Rostov region, Republic of Ingushetia, Republic of Tatarstan, Chuvash Republic, Nizhny Novgorod region, Samara region, Saratov region, Ulyanovsk region, Kurgan region, Sverdlovsk region, Chelyabinsk region, Krasnoyarsk Territory, Novosibirsk region, Khabarovsk Territory

Conclusion

Due to a large number of factors affecting the results of economic activity, the adaptation of the agri-food system by trial and error is not a satisfactory strategy for moving to a cost-effective state. The application of the methods of economic and mathematical modelling for these purposes, in principle, removes this problem, but gives rise to another – the problem of the stability of effective solutions, understood in this work as the ability of an agri-food system to minimize efficiency losses with random combinations of factors of different nature, and having a positive or, on the contrary, a negative effect on the results.

The algorithm for finding an effective and stable production structure under various combinations of environmental conditions implements the following sequence of procedures: 1) generation of combinations of parameters of the economic-mathematical model; 2) obtaining the optimal solution for each option combinations of these parameters; 3) assessment of the mathematical expectation of the criterion of efficiency and variance for each optimal solution on a variety of combinations of parameters; 4) the choice of a highly effective solution with a low dispersion of this efficiency. To implement this algorithm, the method of simulation experiments in the space of system parameters is used. The optimal solution is chosen by minimizing the distance to the "ideal point" (maximum efficiency, minimum dispersion). The algorithm discussed in the paper is free from the assumption of the linearity of the economic-mathematical model for optimizing the branch structure of the regional agri-food system.

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