Decision-making on the use of arable land considering the factors of field crops yield

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Abstract. The solutions of methodological problems arising in connection with the managerial decisions adoption on the arable land use at the level of agricultural organization management are proposed. In place of the existing economic-mathematical toolkit used for this purpose, a nonlinear specification of the stochastic two-stage ED-model of optimal use of arable land is proposed, in which yield is a variable depending on the properties of the plot, fertilizer application, the use of seeds of higher reproduction. The source data of the model are organized so that it can be solved at any moment in the season in order to dispose the released area or to resow the field occupied by the unprofitable culture due to changes in market conditions, as well as in the event of damage or loss of crops.

1 Introduction

The feasibility of applying mathematical programming for the purposes of planting planning was written about in the middle of the last century [1; 2], but from then to this day in the peer-reviewed issues there were almost no reports of restructuring field management systems on the basis of this method. A sceptical remark by J. Ranney [3] on the practical impossibility of full substitution of the traditional budgeting procedure in agriculture (we will add - including crop farming) with mathematical programming, made more than half a century ago, proved to be perfectly fair at that time. Methods of finding optimal solutions were used sporadically, usually in simplified settings.

In the few available works on this topic, not normative (managerial), but positive (explanatory) models are presented. The latter require specific methodological approaches that differ in the preparation of the baseline data (involving calibration procedures) and the architecture of the models [4] themselves. Among the models of positive mathematical programming (PMP models) describing the distribution of arable land between field cultures, we will highlight the one presented in the article [5]. The aim of that study is to assess the impacts of climate change on land use in the prairie pothole region of Western Canada, and to find ways to preserve the region's water resources.

Analytical applications occupy, in a sense, an intermediate position between normative and positive. Typically, they are used to compare different management options, including

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those affecting the use of arable land. So, [6] addresses (positively) the question whether corn grown for bioethanol production will stand up to compete against rice and cotton in the southern Mississippi Basin. [7] explores the effects of climate change on California agriculture. The subject of the article [8] is the impact of CO₂ emission quota trade on crop farming in the United States. The article [9] solves the problem of manure disposal by applying for irrigated crops. The amount of subsidies to ensure the disposal of all manure produced by feedlots in Eastern Colorado is determined, taking into account the optimal distribution of irrigated areas between silage crops and corn grain.

Among analytical applications are distinguished studies in which the optimal placement of crops is conditioned by the solution choice of a particular engineering problem. Research of this kind is presented in the article [10] on irrigation system planning and [11], which uses a system of two models, one of which (hydrological) forms the source data for a nonlinear programming problem describing, in particular, the use of arable land.

As far as normative models are concerned, until now they are based on methodological approaches of more than half a century ago, with almost no reports of achievements in this field in the scientific literature. Various modifications of mathematical models from [12, sec.8.1] and [12, ch. 10] are applied sporadically to make operational decisions on the placement of crops by fields, including taking into account crop rotation requirements.

At the same time, largely due to the progress of computing and software, agrarian management science is gradually expanding the possibilities of displacing traditional budgeting automated tools for constructing and solving problems of mathematical programming. In tracking this work, large agribusiness has shown a growing interest in the management applications of mathematical programming. This in particular has made it possible to carry out this study. The author hopes that the results outlined in this article will give the impulse for re-actualization of this problem on the methodological basis of the XXI century.

2 Materials and methods

The methodological approach, which is based on the mathematical model presented in this article, relies on a number of innovations in theory and practice of normative modeling. The first of them is a reinterpretation of foreign [13; 14, p. 161-168] and Russian [15, p. 83-107; 16] experience of reflecting factors of uncertainty in planning the placement of crops by fields. The basis for the reinterpretation is the emergence [17] and approbation [18] of the stochastic two-stage ED-models architecture. Thanks to the ED-architecture, procedures for reflection of uncertainty in mathematical programming problems become routine and are easily automated, the resulting plans are less risky, in addition to the meaning of the resulting solutions become clearer. The second is the development of an architecture that allows the model to be used to make decisions about changes in the use of arable land at any given time. The third is the abandonment of the crop rotation paradigm in favor of individual solutions for each plot based on data about its history, current market conditions and exogenous perspective plan of the crops structure, which set only the most important requirements for it.

The fourth innovation — using the approach [19] (formulas 1 and 2) to yield model, taking into account not only fertilizer application, but also the state of the specific plot and the quality of seeds — let us get into more details here.

Models that take into account the impact of fertilizer application levels on yields, which are reduced to linear programming, have been developed for a long time. They treat different levels of fertilization under the same crop as different processes that can be combined. Probably the earliest work to reflect this approach is [20]. A similar method is used in the above-mentioned source [12, sec.8.1]. Today, the processing power of even

personal computers and software capabilities allow solving the convex programming problems without difficulty, which allows a researcher to explicitly reflect in the model nonlinear dependence of yields on doses of fertilizer application together with factors of natural soil fertility. The proposed model is based on the study [19] and, in particular, gives the user a choice of one of three functional forms consistent with the theoretical concept adopted by the agronomic science on the impact on yield from fertilizer introduction doses. These forms are substantiated by S. O. Siptits, one of the authors of the article [19]. In addition to these, the model includes constraints that control the balanced application of individual active substances into the soil.

3 Results and Discussion

The full formulation of the proposed model (in GAMS language) is given in Annex 1 to the article posted on the Internet at <http://svetlov.timacad.ru/sci1/pl.pdf>. In the same file, Annex 2 contains a description of the test case, Annex 3 - the software code that generates analytical tables in CSV format, which allows a user to view and further edit them in a spreadsheet software.

The mathematical programming problem from Annex 1 provides to find the maximum mathematical expectation of short-term profit from the sale of field crops products by selecting:

- the areas of their crops on the available plots whose parameters, along with other model parameters, are defined in the baseline database (Annex 2 contains the test case data);
- volumes of fertilizer application;
- the use of seed (planting) material of two different quality levels.

Variable values shall meet the requirement of sufficient production resources, the list of which in Annex 1 may be revised according to the specific agricultural organization. Resource sufficiency is ensured under any of the user-defined random conditions outcomes. It is recommended to set at least five options for these conditions.

Unlike other such developments, the model takes into account the impact of fertilizer application and seed quality on yield in order to optimize their consumption, as well as the condition and field history of each plot, allowing to make decisions about seeding only those fields (plots) that are currently free. In addition, the model is able to identify the feasibility of changing the plan for the use of plots prepared for planting other crops and even re-planting already growing cultures — for example, in case of their partial death leading to loss of yield, or market collapse of any field product without the hope of recovery by the time of harvest. The source database of the model allows a user to correctly and fully reflect the costs and losses associated with changing the plan of the site use or re-planting the crop growing on it, and to obtain the optimal plan, taking into account the balance of expected gains and losses caused by such changes. Previously, mathematical models with such capabilities were not created.

A new level of model functionality has been achieved thanks to the development of an architectural solution that allows the model to be used for planning (or forced change of the seeding plan) as of on any date, taking into account the current state of each field (free to sow, occupied with a certain culture, under fallow), the history of each field and the need to create conditions for a sustainable production process in the future (e.g. planting of perennial field crops due to the need for them in the future).

The model allows a specialist to study a large enough set of alternatives of arable usage in terms of conditions in which a specific alternative appears to be the best. It secures taking the reasonable risk with an understanding of the possible consequences when making a final decision on crops. It is not designed to anticipate the future or to predict. Its task is to draw a clear boundary between results achievable in the scenario conditions

described by the baseline data and results that cannot be achieved in any way under such conditions.

Among the parameter values specified by the model user may be those that differ significantly from the actual values. Because of this, it may turn out that some other plan could prove to be more profitable than the plan proposed by the model. However, there is little chance that such a better plan could be found by a competitor. Even less chance of a competitor to prove this advantage. Therefore, competitive positions in the market of field products, achievable with the help of the model, are very difficult to surpass, having lands of similar quality, similar natural conditions and the same technologies of field farming, but not using a similar model.

In the test example, the model selects field crops so that resources can be used as fully as possible (labor, land, capital, fertilizers, seeds — the list of resources can be expanded or detailed if necessary) and also to provide the largest short-term profit without harming the interests of livestock production. Only available labor, land and fixed capital are taken into account — their acquisition or lease is not considered. The model takes into account that one year is better and the other is worse, and takes care that under any of the five preceding years the resources for the planned cultures will suffice. The mathematical programming method ensures that, assuming the supplied baseline data are absolutely correct, it is absolutely impossible to achieve greater short-term profit with available resources — but does not guarantee the workability of the plan due to the possible lack of other resources that are not accounted for in the model, inaccuracies in the data, or due to the outcome of random conditions that are worse than introduced in the model.

Practice shows that the increase in short-term profit due to these models is usually not too large compared to normal decision-making practices based on the identification of the increase efficiency provisions of field crop cultivation and finding ways to utilize them. Revenue can be increased by a few percent (usually no more than 2 -3%); costs may be also reduced by a few percent. The main benefit of the model is that it allows more reliable (than other planning approaches) to protect against the risk of lack of resources when seeking to create a maximum strenuous plan with the goal of earning as much as possible.

According to the results of the test case according to Annex 2, from the area of 3400 hectares the application of fertilizers provides added value of 31.1 million rubles in comparison with gross yield formation solely due to soil fertility and quality of seed material. Per hectare, this is 9,15 thousand rub. The results of the decision obtained are detailed in Annex 4.

4 Conclusions

As a result of the conducted research, the economic-mathematical model of optimal planning of field crops has been created, taking into account, firstly, the uncertainty that takes place in the production process and on the market, and secondly, the impact of field conditions (including their history) on crop yields, fertilizer application and seed use. With this combination of factors, the use of the traditional approach [20] to reflect their impact on yield in models of optimal field planning becomes impractical. Using it, each combination of factors for each site would have to be considered and incorporated into the model as a separate process and the yield for each such process would have to be calculated. In this regard, the choice is made in favor of convex programming instead of linear, which allowed the use of nonlinear multifactor dependencies of yield on factors.

The model provides computational support for decision-making on the use of arable land, taking into account crop yield factors at the level of agricultural organization or association of agricultural organizations. The source database of the model is designed so

that it is possible to update the planting plan at any time, not just on the eve of the spring or autumn sowing campaign.

The model is accompanied by a software code generating a basic set of analytical tables, configurable according to a set of crops, sites, random conditions outcomes and types of fertilizers. The code is open for the development of other forms of analytical tables if necessary.

Lists of resources taken into account in solving the model, field plots, crops from which the plan is formed are also open for extension. Machine-readable format of the source database allows forming it by unloading the required parameters from the operational planning module of the corporate information system. Capabilities of the GAMS tool used as a software platform for model development and operation and the CONOPT non-linear optimization computing module allow a user to automatically form and solve this model, including hundreds of crops, thousands of plots and types of resources. These properties of this development practically eliminate the obstacles to management system restructuring on the base of mathematical programming described in [3].

The only obstacle that still needs to be overcome is the training of specialists in competent operation of the model, the skill of conducting scenario experiments with its use and clear understanding of the meaning of the results it produces.

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