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A Set of Economic and Mathematical Models for Assessment of Agricultural Crop Cultivation Technologies

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Abstract**:** ***Research objectives. The paper describes the process of development of a set of mathematical models for assessment of agricultural production technologies to be used as the basis of a software complex module for managing technological processes in crop farming. The reported study was funded by RFBR according to the research project № 18-37-00148. Methods. Given the specifics of management in agriculture, it is worth noting that the lack of objective information across the production cycle in crop farming and the subsequent misalignment with an optimum technology results in overshooting labour and material costs, lost profits for the enterprise or even losses. These issues have to be addressed through advanced studies of economic and mathematical models and methods for analysis and assessment of economic efficiency of agricultural crop cultivation technologies and the development of a comprehensive automated information support system for decision-making in crop farming management. Results. A methodology is proposed for selecting economically efficient technological processes in crop farming, involving the sequential application of results obtained through the analysis of technological process criteria by the methods of binary decision matrices, cobweb diagrams and the matrix assessment model, taking into account their orientation at the economic performance of crop farming. Practical significance and applicability of results. The authors developed a complex of software and information support and assessment of technological processes in crop farming, with experimental trials showing improved efficiency of crop farming production through the well-reasoned selection of agricultural crop cultivation technologies.***

Index Terms**:** ***crop farming management, mathematical modelling, software, technology, agricultural crop, assessment, economic efficiency.***

I. INTRODUCTION

The agricultural production system operates as a complex dynamic system comprising numerous subsystems [1]. Ensuring its stable operation amid changing uncertain economic environment requires a scientifically grounded approach for efficient managerial decision-making. This creates the need to develop appropriate models and methods for decision-making support in managing the economic parameters of production systems in the agroindustrial complex [2-5].

Therefore, the development of mathematical models for assessment of agricultural crop cultivation technologies has now become quite relevant along with the integration of the model-based decision-making support system into the production management processes [6-8].

As part of the research, an objective was set consisting in the development of a set of mathematical models and a multicriterion methodology for the assessment of agricultural crop cultivation technologies under a range of indicators using the modern information technology and software development tools.

II. METHODS

A. Algorithm

Field crop cultivation is a complicated production process requiring clear-cut management.

The first stage of agricultural production involves preplant (preparatory) measures including the development and optimisation of planting rotation, agricultural production plans and various forecasts, as well as the development and calculation of flow process charts and assessment and selection of technological approaches to cultivation.

The next stage consists in managing and supervising fieldwork. The third conclusive stage involves agricultural production performance analysis [9].

Ideally, decision-making in crop farming includes the following steps: problem analysis, developing and approving planting rotation, generating possible options of agricultural crop cultivation technologies, describing each of them, assessment of individual technologies under economic, bioenergetic and agroecological indicators, selecting technological approaches, calculating the economic efficiency of production, summarising the cumulative practice [10]. In a market economy, agricultural production efficiency is considerably related to product competitiveness. Efficient and competitive production largely depends on the choice of crop cultivation technologies and process management [11].

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The unstable economic environment in Russia, Western sanctions and fluctuating oil market may mean possible sharp and unexpected price changes in fuel, seeds, fertilizers and crop protecting agents [12]. This complicates the choice of technology, cost calculation and profit forecasting [13].

The issues of crop farming management and managerial decision-making support at agroindustrial enterprises have not become any less relevant. Research and development of mathematical methods and models for production management, particularly, in agriculture, was chosen as the subject of the works by V. I. Loiko, A. G. Burda, etc. [14-15].

However, despite the abundance of research concerning crop farming management at an agroindustrial enterprise, the aspects of application of mathematical models, methods and information support tools to analyse and assess the economic efficiency of processes in crop farming has been under-researched. The relevance of the above issues has suggested the topic and problem-setting of this paper.

B. Flow Chart

To select the best technology from available alternatives, a three-stage sequence methodology is proposed for the identification of efficient technological processes in crop farming. The first stage consists in selecting a set of technologies using the binary decision matrices. The next stage involves a comparison of the selected technologies using a multicriterion economic and mathematical model and a cobweb chart visualisation. The conclusive stage involves the analysis and choice of an economically efficient technology using a matrix model [16-18].

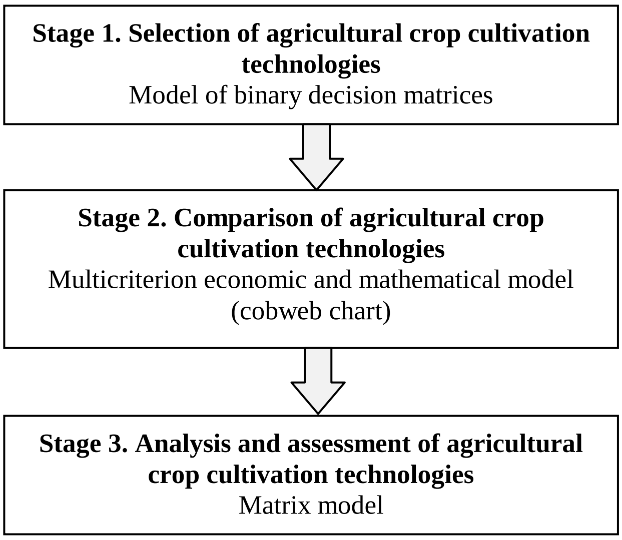

Fig. 1: Model composition of a comprehensive multicriterion assessment of technological processes in crop farming

III. RESULTS

An adaptation of the binary decision matrix method was rendered to complete the first stage in the methodology of analysis and assessment of technological processes in crop farming. Presumably, a database of more than a hundred technology options for each crop is to be available in the selection of agricultural crop cultivation technology. The task is to use specific criteria to identify a suitable option for the respective climate zone and soil (1).

The objective function is finding the maximum sum of binary values of the technology $a_{i,j}$.

$$D_j = \sum a_{i,j} \rightarrow \max \qquad (1)$$

where i is the assessment criterion, j is the discussed technology.

$$A = \begin{pmatrix} a_{1,1} & a_{1,2} & \cdots & a_{1,j} & \cdots & a_{1,m} \\ a_{2,1} & a_{2,2} & \cdots & a_{2,j} & \cdots & a_{2,m} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{i,1} & a_{i,2} & \cdots & a_{i,j} & \cdots & a_{i,m} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ a_{k,1} & a_{k,2} & \cdots & a_{k,j} & \cdots & a_{k,m} \end{pmatrix}; \quad i = \overline{1,k};\ j = \overline{1,m}; \qquad (2)$$

$$a_{i,j} = \begin{cases} 1, \text{satisfies the condition} \\ 0, \text{doesn't satisfy the condition} \end{cases}$$

where A is a binary decision matrix, k is the number of assessment criteria, m is the number of technology options.

A fragment of the binary decision matrix is laid out in Table 1.

Legend:

- the first digit factor A is soil fertility;
- the second digit factor B is fertilizer system;
- the third digit factor C is plant protection system;
- the fourth digit factor D is the primary soil cultivation system.

Table 1: A fragment of the binary matrix to select winter wheat cultivation technology

Criteria	Agricultural crop cultivation technologies						
	0113	1113	0330	2222	3132	2132	2232
Yield							
51-60 hundred kilograms per hectare	1	1	0	0	0	0	0
61-70 hundred kilograms per hectare	0	0	1	1	0	0	0
71-80 hundred kilograms per hectare	0	0	0	0	1	1	0
81-90 hundred kilograms per hectare	0	0	0	0	0	0	1
Profitability:							
0-20%	0	0	0	0	0	0	0
21-30%	0	0	1	0	0	0	0
…	…	…	…	…	…	…	…

The decision-maker sets requirements for each criterion of the sought technology.

Rows of the binary matrix are further selected and the binary criterion values for each technology are added up to calculate the sums. The best technology is the one with the maximum total.

The advantage of this selection approach is that decision matrices accommodate the majority of the existing technologies and criteria and this model is easily rendered as a database (1).

This selection method is used at the first stage helping to arrive at 6-8 most suitable technological approaches.

A multicriterion economic and mathematical model for a comprehensive assessment of agricultural crop cultivation technologies is further introduced at the second stage of the proposed methodology to expand the model of binary decision matrices. The model is remarkable in terms of the combined use of mathematical and graphical methods of modelling.

In contrast to diagrams plotted in the Cartesian orthogonal coordinate system, a cobweb chart is rendered in a polar coordinate system. The axes used to plot criterion values are radial lines drawn from the pole to the outer part. Figure 2 provides an example to illustrate this method.

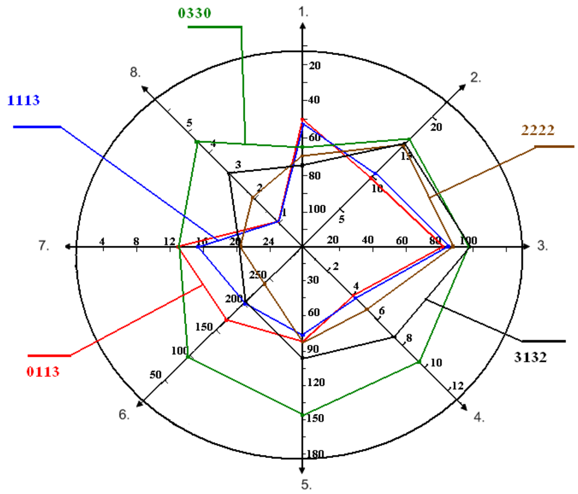

Fig. 2: Comparison of technology options of cultivating winter wheat in a cobweb chart

1. Yield, hundred kilograms per hectare; 2. Labour input per hectare, man-hours; 3. Fuel consumption per hectare, kg; 4. Direct costs, thousand rubles; 5. Production costs of hundred kilograms, rubles; 6. Profitability, %; 7. Profit per hectare, thousand rubles; 8. Cost of fertilizers and chemicals, thousand rubles.

These eight criteria are further rendered in a circle with eight radial scales featuring the quantitative values of the criteria so that the best readings are closer to the pole and the worst values further from it toward the outer circles. According to the assessment rule of the cobweb chart, the cobweb enclosing the smallest area inside corresponds to the best option.

Such a comparison of several technologies helps to easily isolate their respective drawbacks and shows the level of positive effects in the overall picture from improvements in particular parameters (the area within the cobweb).

However, there are some drawbacks to this approach:

1) the number of objects or options in the cobweb comparison should not exceed four, otherwise, it might impair its illustrative visibility;

2) in case of minor differences in the values of the criteria, the cobweb chart will not provide good visibility as well.

Due to the above-mentioned drawbacks, the methodology proposed to refine this approach through the development of a mathematical model, which helped to transform the originally graphical method as a mathematical method.

The objective function of the model relates to minimising the area of the cobweb chart:

$$M_j \to extr; \quad extr \in \{\min, \max\}; \qquad (3)$$

where M_j is the area of the resulting cobweb chart corresponding to one of the options, j is the number of technology. The most advantageous technology in terms of the discussed criteria will be the one corresponding to the cobweb chart enclosing the smallest area.

To calculate the area of the cobweb, the following adjustments need to be introduced: the angles between the axes should be equal and calculated by the equation $l = 360 / i$, where l is the angle between the axes, i is the number of assessment criteria.

Next, the segment length is measured from the pole of the radial scale to the plotted value, for which all criteria, both quantitative and qualitative (descriptive, verbal) are transformed into abstract non-dimensional items using the developed scale.

Following such transformations, the area is calculated for each n-gon figure, which is made up of the areas of constituent triangles shaped by pairs of criteria plotted on adjacent axes.

$$M_j = \sum_{i=1}^{k} S_i; \quad i = \overline{1,k}; \quad j = \overline{1,m}; \qquad (4)$$

where i is assessment criteria, m is the number of technologies in the comparison, S_i is the area of a triangle shaped by pairs of axes (criteria).

The formula of the area of a triangle is applied for the model as follows:

$$M_j = \sum_{i=1}^{k} \frac{b_i \times b_{i+1} \times \sin\beta}{2} \qquad (5)$$

where b_i is the segment length corresponding to a particular criterion of a discussed option transformed as an abstract non-dimensional item; b_{i+1} is the length of the segment of the next criterion.

The developed mathematical model (5) enables a more precise assessment of agricultural crop cultivation technologies even where the cobweb chart provides no visibility. That said, the model allows to simultaneously compare options with relatively close criteria values, and the number of technologies discussed can be above five (2).

Next comes the third and conclusive stage of the methodology of analysis and assessment of processes in crop farming.

In fact, the assessment criteria have different relative priority levels in selecting an approach to agricultural crop cultivation.

Due to this, a matrix model of technology assessment was developed and tested. The well-known Assessment Scoring Table method was used as the basic principle.

The objective function of the model is finding the maximum score D of the j-th technology.

The above example suggests that the objective function of the model relates to finding a maximum value of the technology score assessment.

$$D_j \to MAX \qquad (6)$$

where D_j is the final score of each of the discussed technologies.

The Assessment Scoring Table model is easily represented as a multiplication of two matrices, A and B, in line with a certain algorithm:

$$A = \begin{pmatrix} a_1 \\ a_2 \\ a_3 \\ \vdots \\ a_n \end{pmatrix}, \quad (7) \qquad B = \begin{pmatrix} b_{1.1} & b_{1.2} & \cdots & b_{1.j} \\ b_{2.1} & b_{2.2} & \cdots & b_{2.j} \\ \vdots & \vdots & \vdots & \vdots \\ b_{i.1} & b_{i.2} & \cdots & b_{i.j} \end{pmatrix} \quad (8)$$

where matrix A stands for the coefficients of the relevance of the criteria and matrix B represents the values of the criteria for each technology, where i is the assessment criterion and j is the discussed technology.

The assessment scoring table for economic efficiency of the processes (matrix C) is derived by multiplication of the criteria weight a_i and the respective elements in the rows of matrix B.

$$A \times B = C = \begin{pmatrix} a_1 \times b_{1.1} & a_1 \times b_{1.2} & \cdots & a_1 \times b_{1.j} \\ a_2 \times b_{2.1} & a_2 \times b_{2.2} & \cdots & a_2 \times b_{2.j} \\ \vdots & \vdots & \vdots & \vdots \\ a_n \times b_{i.1} & a_n \times b_{i.2} & \cdots & a_n \times b_{i.j} \end{pmatrix} \quad (9)$$

By simplifying this expression, the mathematical model of the assessment scoring table method is built.

$$D_j = \sum a_n \times b_{i,j} \quad (10)$$

It is worth noting that this model accommodates qualitative criteria as well as quantitative criteria (e. g., grades of grain, environmental or agrotechnical parameters).

Variable b_{ij} represents the values of the assessment criteria for each technology transformed in accordance with the transition scale as relative score items.

The product of multiplication of vector A and matrix B provides the score of the criteria for each technology. The scores in columns are then added up. Thus, the economically efficient crop farming production technology is determined.

IV. CONCLUSION

The research led to the following results and findings:

1) a background review showed that an improvement of agricultural development levels in Russia requires the identification of ways and tools to improve agricultural production efficiency. Efficient use of the existing technical capacity and the development of regional investment strategy are potential economic levers of stable agricultural production growth;

2) a multicriterion methodology was developed for comprehensive assessment and identification of economically efficient technological processes in crop farming, involving the sequential application of results obtained through the analysis of technological process criteria by the methods of binary decision matrices, cobweb diagrams and matrix assessment model.

Such labour-intensive processes as the development of flow process charts and assessment and selection of agricultural production technologies under the models of the proposed methodology involve a significant risk of errors by a specialist (the so-called human factor). That is what brings about the need in the automation of such labour-intensive processes. This problem has to be addressed through the development of an information system for managing crop farming of the entity as a whole, which is the objective of further research.

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