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METHODOLOGICAL APPROACHES TO ECONOMIC AND MATHEMATICAL MODELLING OF CROP ROTATION IN THE DEVELOPMENT OF A LAND MANAGEMENT PROJECT THAT PROVIDES ECOLOGICAL AND ECONOMIC JUSTIFICATION FOR CROP ROTATION

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Abstract. *The proposed research paper systemises methodological approaches to optimisation and dynamic modelling of crop rotation in the development of land management projects that provide ecological and economic justification of crop rotation, since the crop rotation models proposed to date do not solve the task in general, but only in certain specific cases. In this regard, the need to develop full-fledged software products with a user interface integrated into existing information and accounting databases of agricultural formations is substantiated.*

It is proved that economic and mathematical modelling of crop rotations should be developed by improving the methodology of dynamic crop rotations, which will allow farmers to analyse the economic efficiency of various alternative options for crop rotation under specific natural and economic conditions and constraints, as it is a promising interactive tool for substantiating management production decisions based on optimisation algorithms and analysis of large amounts of accumulated retrospective data.

The approaches, criteria and limitations of the economic and mathematical model of crop rotation in the development of land management projects that provide ecological and economic justification of crop rotation are substantiated.

The proposed economic and mathematical model with its objective function, constraints and algorithms is aimed at a comprehensive solution of issues related to production planning and rational land use. The presented model provides ample opportunities for further optimisation of the system of making effective managerial decisions in the agricultural sector and can serve as a basis for solving the problems of investment justification and development of agricultural land use.

Key words: *crop rotation, land management project, economic and mathematical modelling of crop rotation, methodological approaches, dynamic modelling, software products with user interface, agricultural land use, land use, crops.*

Problem statement. Crop rotation is an important technology in agricultural production, which consists in alternating different crops on the same field for several years. This helps preserve soil fertility, reduce the negative impact of weeds, diseases and crop pests, increase crop yields, and reduce costs of plant protection products and other production inputs.

The Law of Ukraine "On Land Management" provides for the development of "... land management projects that provide ecological and economic substantiation of crop rotation and land management" [1] in accordance with point "e" of Article 25 of the Law. The development of such projects is aimed at "... the organization of agricultural production and the arrangement of agricultural lands within the boundaries of land ownership and land use for the effective management of agricultural production, rational use and protection of land, the creation of a favorable ecological environment and the improvement of natural landscapes" [2]. According to the provisions of Article 52 of the Law, this type of land management documentation provides - determination of the location of industrial buildings and structures; - organization of the territory of land holdings and land use with allocation of crop rotation based on ecological and economic factors, including the formation of infrastructure (engineering and social); - determination of the types and types of crop rotation planned for introduction on the basis of specialization of agricultural production; - design of crop rotation fields; - drawing up schemes for alternation of agricultural crops in crop rotation; - development of a transition plan to an acceptable crop rotation; - transfer of designed crop rotation fields to nature (in the area) [1, 2].

The task of economic-mathematical modelling of crop rotation includes a large number of factors and is extremely complex from a mathematical and algorithmic point of view, which to some extent explains the lack of distribution of its integrated solutions both in the literature and in practice.

The problem of developing an effective crop rotation cannot be solved without a proper modelling methodology, which should include interrelated blocks: land resources; technologies for growing agricultural crops; crop yield programming models; specialization and scale of the economy; restrictions on available material and technical, financial, personnel, informational, organizational and other resources of the economy; market conditions and economic environment of the enterprise; spatial modelling of crop placement on crop rotation fields (based on GIS technologies); optimization of the composition of the machine-tractor fleet and execution of technological processes; investment justification of project decisions; comprehensive consideration of economic and ecological criteria of optimality of the model, etc.

Currently, Ukrainian and foreign scientists have developed numerous economic and mathematical models for building crop rotations [3, 4, 5]. The most common today are the models of linear programming of the structure of cultivated areas of agricultural enterprises according to the criteria of the maximum net income.

Unfortunately, the crop rotation models proposed to date do not solve the task in general, but only in certain specific cases or its components: designing soil-protective crop rotations or crop rotations on eroded or heavily washed lands; considering economic standards in linear models of the production structure; taking into account environmental restrictions. At the same time, there is no general methodology for complex programming and design of the crop rotation system, considering all its separate subtasks. However, in practice, not only effective optimization and search algorithms are needed to solve the specified problems with appropriate data structures, but also full-fledged software products with a user interface integrated into existing information and accounting databases of agricultural formations.

We should also note that the lack of crop rotation in agricultural enterprises in modern conditions is connected with the complexity of long-term production planning: today the economic, organizational, legal and institutional foundations of management are changing rapidly; logistics processes in the industry are accelerating and changing, market fluctuations occur every year; As a result of the land reform in Ukraine, there has been a fragmentation of land ownership and land use, and most agricultural land is under short- and medium-term leases, which complicates the development of long-term land use plans.

The problem of production planning is aggravated in connection with the losses of agriculture because of Russia's armed aggression, the role of external factors is increasing.

Economic-mathematical modelling of crop rotations, in our opinion, must be developed by improving the methodology of dynamic crop rotations, which will enable farmers to analyse the economic efficiency of various alternative options for crop rotation in specific natural and economic conditions and limitations, because it is a promising interactive tool for substantiating managerial production decisions based on optimization algorithms and analysis of large volumes of accumulated retrospective data.

The purpose of the study is to substantiate the approaches, criteria and limitations of the economic-mathematical model of crop rotation (crop rotation) in the development of a land management project, which provide ecological and economic justification of crop rotation and land management.

Methodical approaches. Based on our research, for economic and mathematical modelling of crop rotation, we suggest using linear programming (linear optimization) with the formation of a system of variables in the form of an oriented graph.

Let's outline the main groups of factors that should be considered in the crop rotation model. These factors must be formalized through the establishment of appropriate standards, restrictions, and optimality criteria for crop rotation modelling. These factors include:

1) agronomic factors, including the analysis of soils, climatic conditions, hydrology and other physical factors that affect the cultivation of agricultural plants. The nature of the influence of these factors depends on the compliance of specific conditions with the needs of individual crops, for example, on indicators of the level of humidity, pH of the soil, the availability of necessary nutrients, relief, soil fertility, the influence of predecessor crops on the yield level of subsequent crops, the development of negative phenomena and processes related to clogging weeds, pests, diseases, etc.;

2) economic factors, including the analysis of production costs for growing crops, yield of crops depending on the level of intensity of cultivation technology, expected net income (profits), minimum and maximum economically justified volumes

of production of agricultural products by their types, available production resources by their types;

3) environmental factors, including environmental impact assessment, soil conservation and humus balance, biodiversity, land and water pollution;

4) social factors, including analysis of the needs of the local population and social aspects, ensuring food security of the region, jobs for the local population;

5) engineering and technical factors, taking into account the analysis of the availability and efficiency of the use of energy machines, agricultural machinery, machine-tractor units, engineering systems and networks, sources of electricity, land reclamation;

6) spatial and transport-storage factors, including spatial analysis of land resources and routes of movement of equipment through crop rotation fields, location of production resources, warehouses, available motor transport capabilities.

All indicators calculated in the crop rotation model characterize the economic efficiency of current production activities and do not consider capital investments or long-term investments.

Based on spatial analysis, it is necessary to determine the boundaries of agricultural land massifs and the boundaries and areas of fields within them. For each field, a probable pool of possible options for their further use for the cultivation of certain agricultural crops will be determined.

To do this, it is necessary to build an oriented graph of possible options for alternation of agricultural crops on crop rotation fields. A graph is a collection of vertices (nodes) and connections (edges) between them. In our case, the vertices of the graph are the areas of specific crops (from among those included in the simulation), and the edges are the ecological and economic effect (net income), which is caused by growing a given crop on a given field, considering its predecessors. The task of modelling crop rotation is related to another scientific problem - modelling the productivity of each agricultural crop depending on many factors.

At the vertices of the graph, we will place the variables that determine the area of the i-th crop in the j-th harvest year for *the* h-th field. The edges of the graph will be the vectors of alternating crops, and their values will characterize the net income due to the change of crops from one year to the next.

Of course, the graph is oriented, and after the culture of the 2nd year, only the culture of the 3rd year can go, and so on. This allows you to first form a graph for all possible rotation options for all crops in all fields for all planned years. And then discard those vertices and edges of the graph that do not meet the constraints that we must form. The tighter the constraints, the smaller the graph becomes and the fewer options remain. On the other hand, the restrictions should not be too strict to leave room for a sufficient number of crop rotation options.

The algorithm searches for the "longest" path along the crop rotation graph, that is, the largest amount of net income, considering all economic, ecological, technological and other restrictions:

$$\sum_{n=1}^{N} E_{n(n-1)} \to \max ,$$

where: $E_{n(n-1)}$ is the net income of culture *n* after culture *(n-1).*

In the classical problem, the areas of all fields are approximately the same, and the determination of the total area of crop rotation is calculated by the sum of the areas of all fields. The variable acquires only natural (Boolean) values, and there is either one field (several fields) for a given crop per year, or none (Fig. 1). Next year, the set of crops remains, only their location on the fields’ changes.

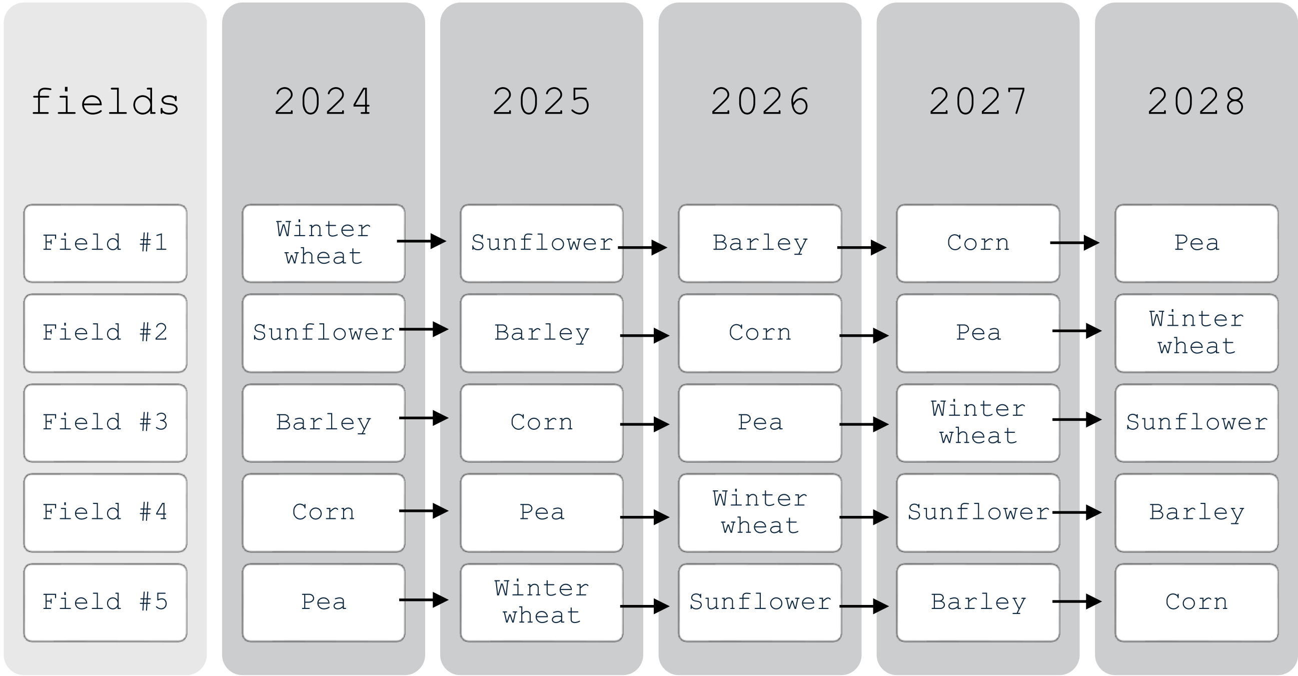

Figure 1 – Conventional scheme of the traditional form of crop rotation of five agricultural crops on five fields for five years

In the crop rotation model we propose, the number of variables increases in progression with the increase in planning duration and the number of fields and crops (Fig. 2). And if you calculate such variables for each field, considering its soil and agroecological features, then the rotation of crops can be individual for each year and each field. That is, every year the set of crops can be different, which allows taking into account the dynamics of changes in the external and internal environment of the agricultural enterprise.

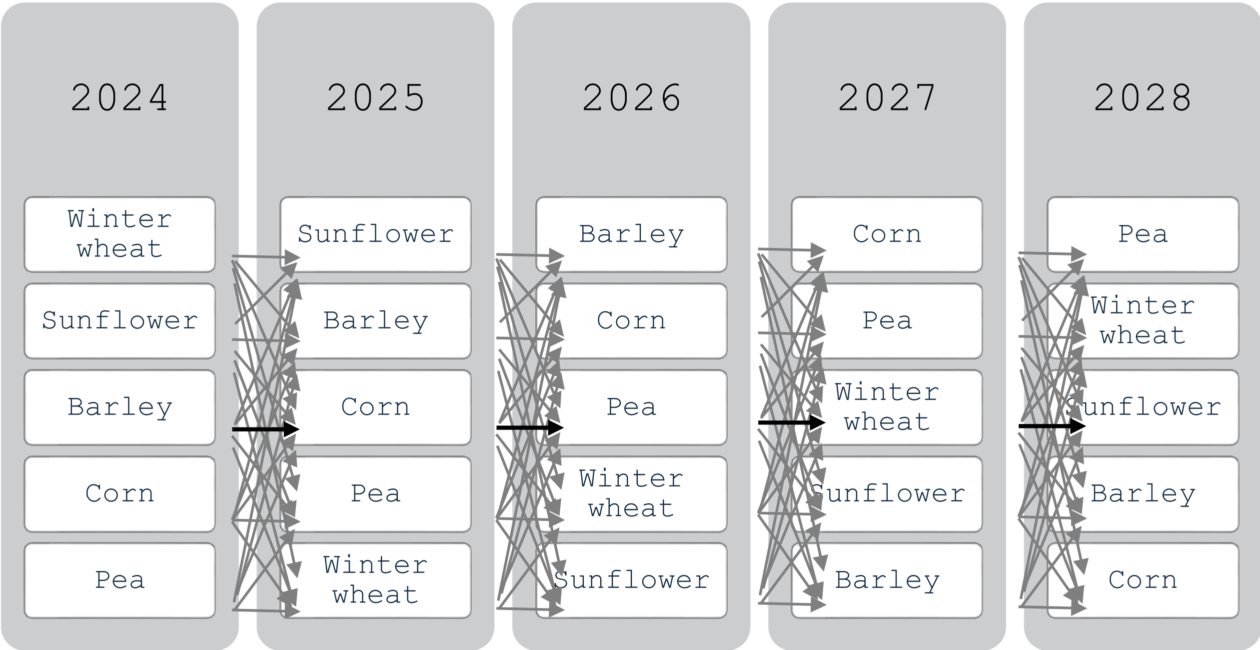

Figure 2 – Conditional scheme of all possible variants of the crop rotation model of five agricultural crops for five years for one field

Based on the above scheme, it is possible to represent how the variables are formed in such a model, which are the areas for each crop for each year after each predecessor (Fig. 3). For simulation purposes, you can choose a Boolean variable that can take two values: 0 (zero) or 1 (one). So, if a zero value was obtained for some variable as a result of the model calculation, then the crop that corresponds to this variable does not enter the crop rotation on this field in a certain year after a certain crop. Conversely, a variable whose value is equal to 1 will be included in crop rotation.

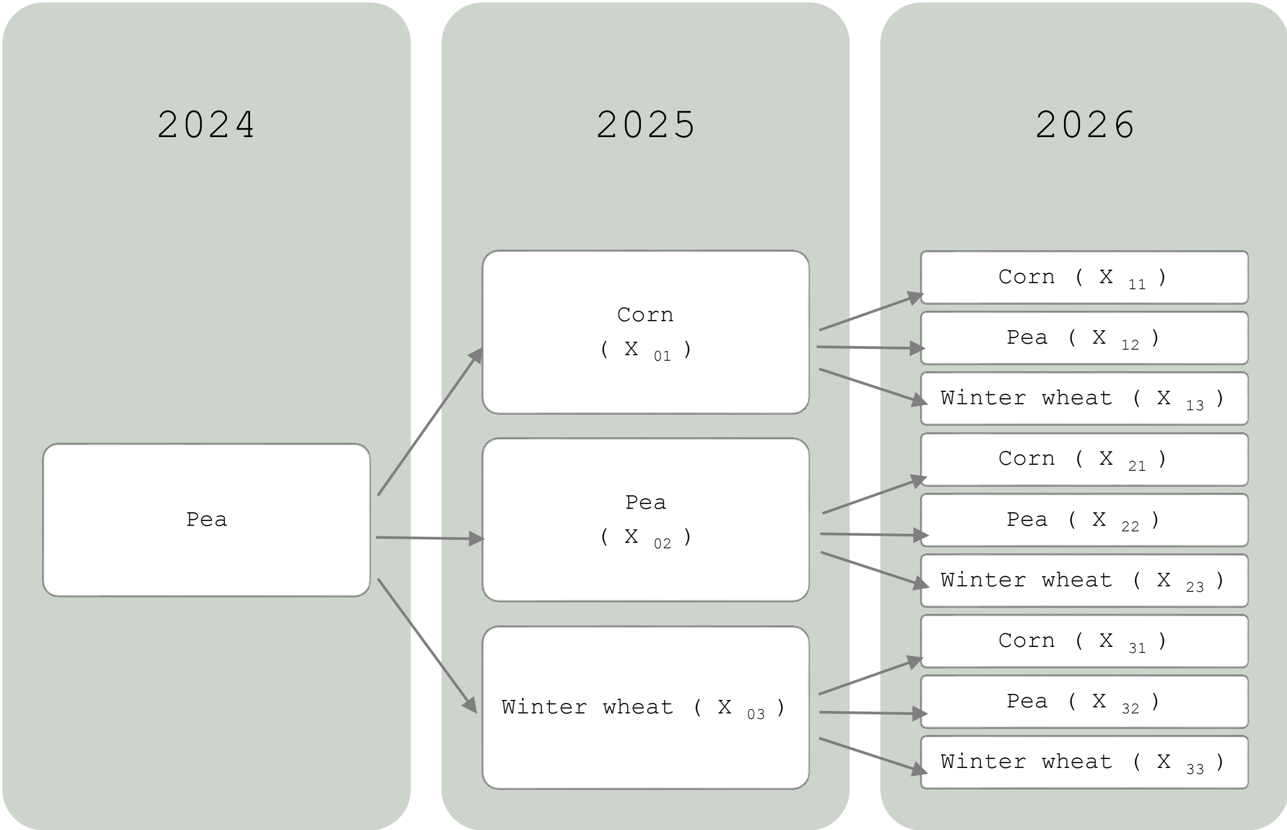

Figure 3 – Conditional diagram of the formation of variables of the crop rotation model on the example of three agricultural crops for two years for one field

If it is necessary to plan rotation for 10 crops and 7 fields, then the number of variables of the combinatorial problem for 10 years will be 77.8 billion. This can be calculated using the following formula:

$$y = \sum_{n=0}^{N} a_n c^n ,$$

where: *y* is the total number of variables (all variants of crops by their areas);

n – year of crop rotation, *N* – duration of crop rotation (for example, 10 years);

a_n – the number of fields in the *nth* year (for example, 7 fields every year);

c - a list of agricultural crops (for example, 10 crops each year).

The calculation of the total number of variables of such a model according to the above formula is shown in Table 1.

Table 1 – Calculation of the total number of model variables according to the combinatorial problem for 10 crops and 7 fields for 10 years

Model year	**The number of variables in this year**
0	7
1	70
2	700
3	7,000
4	70,000
5	700,000
6	7,000,000
7	70,000,000
8	700,000,000
9	7,000,000,000
10	70,000,000,000
In total	**77,777,777,777**

Thus, even a small task turns into one that cannot be formed or calculated according to the modern computing capabilities of personal computers or servers. In practice, the number of fields and crops is much larger, which further complicates the model. Therefore, when forming an oriented graph of the crop rotation model in each field for each year, it is necessary to introduce restrictions that will allow to significantly reduce all possible combinations of crops. But first, let's define the objective function, or optimality criterion.

The goal function of this task (or *the optimality criterion* for solving the crop rotation problem), as was justified above, it is proposed to determine the maximum amount of net income for the entire period for which crop rotation is planned:

$$\sum_{k=1}^{m}\sum_{i=1}^{n}\sum_{y=1}^{t}\sum_{j=1}^{l}(U_i B_{ji} V_{ki} K_{ji} P_{iy} - C_{iy}) X_{kiyj} \rightarrow max$$

where: U_i – estimated yield *of* i-th crop under the most optimal conditions (on the best soils with the best predecessor), t/ha;

B_{ji} – land assessment score (for example, soil quality score) on *the* j-th field for *the* i-th crop , $B \in [0.0; 1.0]$;

V_{ki} is the coefficient of influence of *the* k-th predecessor crop on the productivity *of the* k-th successor crop, $V \in [0.0; 1.0]$;

K_{ji} is the coefficient of the possibility of placing *the* i-th crop on the j-th field, taking into account the biological characteristics of the crop, the ecological state of the soil, and other restrictions. In particular, soil differences and natural and agricultural conditions determine the level of suitability of the soil of a land plot for the cultivation of certain crops , $K \in [0.0; 1.0]$;

P_{iy} – estimated price of products for *the* i-th crop in the y-th year, hryvnias/t;

X_{kiyj} – the area of the i-th crop on the j-th field in the y-th year after *the* k-th predecessor, ha;

k – the number of the predecessor culture (k = 1, 2, ..., m);

i – the current culture number (i = 1, 2, …, n);

y is the year of crop cultivation (y = 1, 2, ..., t);

j is the current number of the field (j = 1, 2, ..., l).

In this formula, the crop area (X_{kiyj}) is the unknown, model variable that must be calculated . The crop area according to this variable is determined by the field area.

The limitations of the model consist of the following elements.

1. Initial limitations of the available area for each field (S_j) under crops, that is, as of year zero of the model:

$$X_{kK_0 0j} = S_j,$$

where: K_0 – initial crops in year zero, which are predecessors for crops of the first year, $K_0 \in \{1 , 2, ... , m\}$;

k – there are no predecessors for crops of zero year, $k = \emptyset$;

0 – zero year indicator;

j – field number;

S_j is the area of the j-th field in year zero.

2. Restrictions on the total area of fields between predecessor and successor crops:

$$\sum_{k=K}^{K}\sum_{i=1}^{n}\sum_{y=Y}^{Y}\sum_{j=1}^{l}X_{kiyj}=\sum_{k=1}^{m}\sum_{i=1}^{K}\sum_{y=Y-1}^{Y-1}\sum_{j=1}^{l}X_{kiyj}$$

where: K is the predecessor culture, $K \in \{1, 2, \dots, m\}$;

Y is the current year. Accordingly, $(Y-1)$ is the previous year, $Y \in \{1, 2, \dots, t\}$.

According to this limitation, the area of each culture will be equal to the area of its immediate predecessor.

3. Limitation of production volumes of crop production for each crop in planned years:

$$\sum_{k=1}^{m}\sum_{i=1}^{n}\sum_{y=1}^{t}\sum_{j=1}^{l}U_iB_{ji}V_{ki}K_{ji}X_{kiyj}\geq W_{iy}$$

where: $U_iB_{ji}V_{ki}K_{ji}X_{kiyj}$– the estimated production volume of crop production by *the* i-th crop in the y-th planning year, tons;

W_{iy} is the minimum amount of crop production for *the* i-th crop in the y-th year, which must be obtained to ensure the production program, in tons. For example, these minimum requirements may be stipulated by long-term contracts, necessary feed production needs for livestock industries, etc.

4. Restrictions on the volume of production resources by year:

$$\sum_{s=1}^{r}\sum_{k=1}^{m}\sum_{i=1}^{n}\sum_{y=1}^{t}\sum_{j=1}^{l}A_{siyj}X_{kiyj}\leq R_{sy}$$

where: A_{siyj} is the consumption rate *of the* s-th type of production resources on *the* j-th field for the i-th culture in the y-th year, calculated per 1 ha (UAH/ha, man-hours/ha, um.ha/ha, kg d.r./ha, etc.). These can be critically important types of resources, for which there are possible restrictions on the power of tractors, machines and combines, the amount of labour, fertilizers, seeds, plant protection products, fuel, electricity, etc. The consumption norms of the specified resources are oriented towards achieving the estimated yield U_i.

R_{sy} is the maximum volume of *the* s-th type of production resources that can be used in the economy in the y-th year (UAH, man-hours, um.ha, kg d.r., etc.).

5. Restriction of non-negativity of variables:

$$X_{kiyj} \geq 0.$$

This limitation is due to the chosen method for solving the given problem – linear programming, for which the variables must have a non-negative value.

6. Limitation of the model by the sum of areas: the area under all crops each year should be equal to the total area of available land resources:

$$\sum_{j=1}^{n} X_{ijy} = S_{iy}$$

where: X_{ijy} is the area i-th culture for the j-th plot (field) in year y (n – number of plots);

S_{iy} - the area of the j-th field.

Therefore, for the formation of an economic-mathematical model of crop rotation, it is advisable to use a set of restrictions on agricultural production planning, including the factors of productivity programming and the economic efficiency of the use of production resources.

We highlight the following limitations of the crop rotation model: compliance with the total land area; not exceeding the number of available resources (regarding labor costs, monetary and material costs, mechanized and transport works); optimal dimensions and configuration of fields; years of return (rotation) of each culture; non-negativity of variables; the total number of variables (no more than 500,000).

The practical application of the above model showed that, even considering the limitations of the task, the method of full lexical search often turns out to be irrational for a large number of cultures, since its calculation takes a lot of time [6, 7, 8]. As the number of crop variants increases, the complexity of the model grows exponentially. Taking into account other parameters of the model, the duration of the planning period, the number of fields, the calculation of the optimal plan can take many hours or even weeks. Sometimes the solution cannot be obtained due to the great complexity of the model.

Therefore, to optimize the formation and solution of the model, we suggest using model modifiers related to the formation of the graph of variables, as they will allow you to reject wrong solutions known in advance (branches of the graph). The number of agricultural crops, fields, predecessors, other parameters of the model should be limited based on specialization, farm needs, available resources, etc.

We offer the following directions for modification and reduction of the graph of variables:

1. Unpromising branches of the graph should be weeded out for cases where a specific crop is unsuitable for growing on a specific field for the corresponding agro-production group of soils. This is the first thing that will make it possible to significantly reduce the number of non-optimal directions for finding a solution.

2. Unpromising branches of the graph should be screened out for cases where a specific crop does not have acceptable predecessors for a given field in a given planning year. This will also allow further reduction of the model by discarding suboptimal options.

3. Unpromising branches of the graph should be screened out for cases where a particular crop should not return to this field earlier than after a certain number of years of rotation. This has both economic and environmental reasons. So, for winter rye and barley, spring barley, oats, buckwheat, the standard of frequency of crop cultivation on the same field is not less than one year. Winter wheat, potatoes, and millet should return to this field no earlier than in two years. For corn in crop rotation or in a field temporarily removed from crop rotation, the frequency of rotation is two to three years in a row. For sunflower, return is recommended no earlier than after seven years. Similarly, rotation restrictions should be set for all crops that are included in the model [9, 10, 11].

Due to the introduction of these graph modifiers, the stiffness of which can be adjusted by certain coefficients, it is possible to obtain a model size that fully characterizes the research object and at the same time is suitable for calculation on modern computers or servers.

Another limitation of the model can take into account the norms of the optimal ratio of crops in crop rotations in different natural and agricultural regions [12, 13, 14]. This is stipulated by the current Resolution of the CMU dated February 11, 2010 No. 164 , according to which it is necessary to take into account the recommended ratios of crops in crop rotations by species cultures For example, the share of the area of grain and leguminous crops each year in the farm in Polissia should be limited in the range from 35% to 80% [15]. And such restrictions fit well into our model from a formal point of view. This is an additional important criterion that will help ensure the optimization of crop rotation and their structure in crop rotation.

To speed up the search for a model solution, you can additionally use heuristic methods that do not guarantee finding the most optimal "path", but such methods allow you to set the desired value and the permissible deviation from it, which will significantly reduce the duration of the search for a solution, without significantly affecting the result.

Also, heuristic methods are used to optimize existing "paths" with the possibility of finding a more optimal replacement for certain links, rather than the "path" as a whole, which will allow it to be optimized to the desired result, while spending significantly less time. Such methods include the genetic (evolutionary) algorithm, simulation modelling, etc.

It should be noted that the problem of substantiation of crop rotations can and should be solved in conjunction with other planning tasks regarding the economic justification of technological processes in crop production and drawing up a system of operational and financial budgets of the enterprise (Fig. 4).

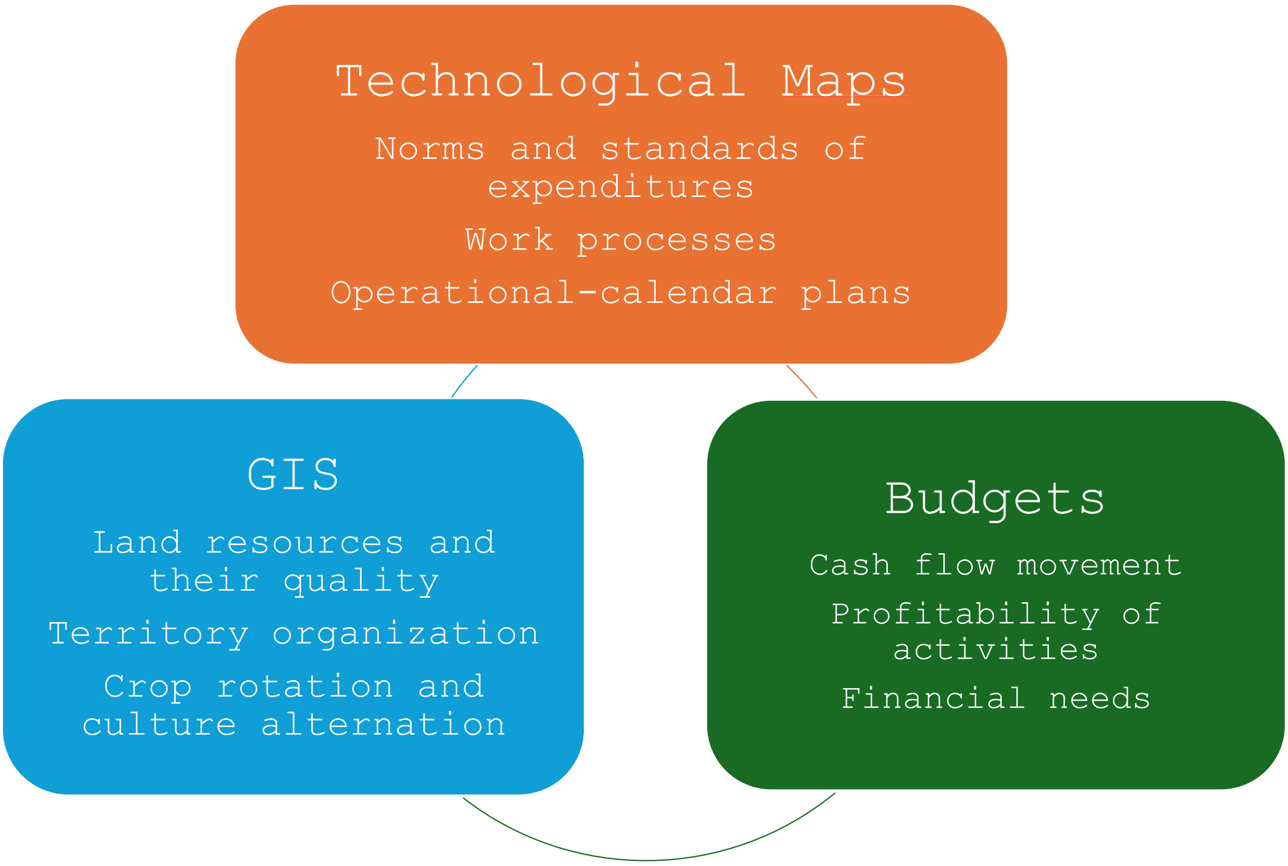

Figure 4 – Interrelated tasks of production and economic planning in crop production

Therefore, the information system for supporting management decision-making regarding the placement of agricultural crops, their rotation and planning directions for effective land use should be based on the data of the accounting system of the enterprise, including spatial data in dynamics: boundaries and areas of fields and crops, the history of each field in relation to crops, agrochemical soil analysis , applied crop cultivation technologies, the actual yield of each crop in the field, rates of applied fertilizers and other data on land use and its ecological and economic parameters.

We believe that today it is impractical to create a single system of static crop rotations, but it is necessary to form dynamic crop rotations that will constantly ensure a high economic effect in the volatile socio-economic environment in which today's agricultural producers operate. Accordingly, flexible tools of integrated management solutions are needed for the levels of strategic, tactical and operational-calendar planning, and the system of alternating cultures should become their integral component.

Crop rotation should not be a problem, the solution of which is separated from the problems of integrated production management. Along with crop rotation, it is necessary to plan and consider a large number of other parameters, both endogenous and exogenous in relation to the agricultural enterprise.

Determination of all aspects of crop rotation should be implemented in all types of production and management planning, accounting, control, analysis, which are carried out in information support systems for making management decisions. Production structure and crop rotation ultimately have a direct impact on economic efficiency and cash flows in both the short and long term.

Thus, the economic-mathematical model proposed by us with its objective function, limitations and algorithms is aimed not only at determining the composition of agricultural crops and the order of their rotation in the planning period. We believe that in such a model, other aspects of production planning and rational land use should be comprehensively addressed. It is about strategic and tactical planning and normalization of the optimal structure of production, including modelling of relevant production processes and the use of production resources.

The presented model provides ample opportunities for further optimization of the system of making effective management decisions in the agricultural sphere and can serve as a basis for solving the problems of substantiating investments and developing agricultural land use.

Conclusions. Methodological approaches to optimization and dynamic modelling of crop rotation (crop rotation) were systematized in the study when developing a land management project that provides ecological and economic substantiation of crop rotation and land management.

The problems of organizing the structure of cultivated areas today are aggravated by the need to balance the export of agricultural products in the conditions of partially blocked seaports and other checkpoints for the export of products lost due to armed aggression of granaries and elevators, as well as the availability of food for domestic consumption in Ukraine. The structure is also affected by the uncertainty of agrarian business and the reduction of its material and technical base, significant fluctuations in prices on domestic and foreign agricultural markets, and the distribution of land between land users.

Crop rotation should not be a problem, the solution of which is separated from the problems of complex production management, together with crop rotation, it is necessary to plan and consider a large number of other parameters - both endogenous and exogenous in relation to the agricultural enterprise.

Determination of all aspects of crop rotation should be implemented in all types of production and management planning, accounting, control, analysis, which are carried out in information support systems for making management decisions. Production structure and crop rotation ultimately directly affect economic efficiency and cash flows in both the short and long term.

Thus, the economic-mathematical model proposed by us with its objective function, limitations and algorithms is aimed not only at determining the composition of agricultural crops and the order of their rotation in the planning period. We believe that in such a model, other aspects of production planning and rational land use should be comprehensively addressed. We are talking about strategic and tactical planning of the structure of production, crop yield, economic efficiency of production, as well as modeling of relevant production processes and the use of production resources.

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МЕТОДИЧНІ ПІДХОДИ ДО ЕКОНОМІКО-МАТЕМАТИЧНОГО МОДЕЛЮВАННЯ ЧЕРГУВАННЯ СІЛЬСЬКОГОСПОДАРСЬКИХ КУЛЬТУР (СІВОЗМІН) ПРИ РОЗРОБЦІ ПРОЕКТУ ЗЕМЛЕУСТРОЮ, ЩО ЗАБЕЗПЕЧУЄ ЕКОЛОГО-ЕКОНОМІЧНЕ ОБҐРУНТУВАННЯ СІВОЗМІНИ ТА ВПОРЯДКУВАННЯ УГІДЬ

Анотація. *У пропонованій науковій праці здійснено систематизацію методичних підходів до оптимізаційного та динамічного моделювання чергування сільськогосподарських культур (сівозмін) при розробленні проектів землеустрою, що забезпечують еколого-економічне обґрунтування сівозміни та впорядкування угідь, позаяк запропоновані до сьогодні моделі сівозмін вирішують поставлену задачу не в загальному вигляді, а лише у певних конкретних випадках або її складових. У цій відповідності обґрунтовано потребу в розробленні повноцінних програмних продуктів із користувацьким інтерфейсом, інтегрованих до існуючих інформаційно-облікових баз даних сільськогосподарських формувань.*

Доведено, що економіко-математичне моделювання сівозмін необхідно розвивати шляхом удосконалення методології динамічних сівозмін, які дадуть змогу аграріям аналізувати економічну ефективність різних альтернативних варіантів чергування культур у конкретних природно-господарських умовах та обмеженнях, адже це перспективний інтерактивний інструмент обґрунтування управлінських виробничих рішень на основі оптимізаційних алгоритмів та аналізу великих обсягів накопичених ретроспективних даних.

Обґрунтовано підходи, критерій та обмеження економіко-математичної моделі чергування сільськогосподарських культур (сівозмін) при розробці

проектів землеустрою, що забезпечують еколого-економічне обґрунтування сівозміни та впорядкування угідь.

Запропонована економіко-математична модель з її функцією мети, обмеженнями та алгоритмами спрямована на комплексне вирішення питань, пов'язаних із виробничим плануванням і раціональним землекористуванням. Представлена модель надає широкі можливості для подальшої оптимізації системи прийняття ефективних управлінських рішень в аграрній сфері та може слугувати базисом при вирішенні задач обґрунтування інвестицій і розвитку сільськогосподарського землекористування.

Ключові слова: *сівозміна, проект землеустрою, економіко-математичне моделювання сівозмін, методичні підходи, динамічне моделювання, програмні продукти із користувацьким інтерфейсом, сільськогосподарське землекористування, землекористування, сільськогосподарські культури.*