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A LINEAR SIMULATION MODEL FOR OPTIMIZING CROP STRUCTURE IN ORDER TO MAXIMIZE INCOME IN A VEGETAL AGRICULTURAL FARM

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Abstract

Agriculture, as the basic branch of the national economy, is placed among the priority areas of the application of informatics. The goal of the agricultural digitalization strategy is to incorporate computer technologies at the workplace of engineers, technicians, economists and farm managers. Emphasis is placed on the development of software products for the design and implementation of high-performance remote data processing systems and database management systems, along with a sustained concern for professional training of users and providing technical assistance to production units. In this context the paper aimed to set up a linear simulation model for optimizing crop structure in order to maximize income in a vegetal farm using linear programming and simplex method. The model included: the 8 unknown variables for the cultivated area with 8 crops: wheat, rye, barley, peas, rape, soybean, maize and sunflower, 14 restrictions regarding Diesel fuel, fertilizers, herbicides, total surface, expenditures, income, and area per each crop, and objective - function f(Max) Income. The data processing for the simulation model was assisted by Solver from MS Excel application. The results offered solutions for the basic primal and dual problems. For a surface of 760 ha entirely cultivated, the optimal area by crop was the following one: 120 ha wheat, 25 ha rye, 120 ha barley, 50 ha peas, 90 ha rape, 125 ha soybean, 170 ha maize, 60 ha sunflower. The maximum income obtained was Lei 2,210,750, while the consumed expenditures accounted for Lei 1,349,150 and profit for Lei 861,600. Average profit rate was Lei 0.64 per 1 Leu spent. The model also assured savings of Diesel and NPK. As a final conclusion, this simulation model proved that farmers have at their disposal an important IT tool which could help them to use linear programming and simplex method to find optimal solutions for their practical technical and economic problems and assure a high efficient agrobusiness.

Key words: *crop structure and income optimization, mathematical model, linear programming, simplex method*

INTRODUCTION

The modelling and simulation of economic processes is a discipline at the border of mathematics and computational techniques and aims to substantiate the managerial decisions in conditions of efficiency for the producer, with the help of economic-mathematical models.

The modelling of a decision-making process leads to specifying its elements: formulating the problem, specifying the objectives proposed by the decision-maker (minimizing/maximizing some technical-economic indicators), specifying the multitude of possible variants/alternatives that characterize a decision-making situation, specifying the multitude of anticipated consequences for each variant, specifying independent decision-making factors of a conjunctural type. From the multitude of calculated possible variants, the decision-maker is going to retain only one, namely the most convenient one. The solution that the decision-maker will choose depends on the data he is analyzing [22].

Optimization of the agricultural production is an attribute of farm manager who must look for new solutions for increasing yields, productions, incomes and profit or for decreasing production expenditures.

The mathematical modelling of the biological, technical and economic processes is deeply sustained by the increase of performance in computer science. Nowadays, computers are capable to simulate the structure and evolution of the mathematical models set up by the farm manager and the results of the simulation to be compared to the data of the modelling process. The main advantages of modelling and simulation are the opportunities to analyze and synthesize the modelled processes and their dynamics.

In agriculture, production processes could be analyzed and optimized both at the macro-economic level and at micro economic level, more exactly at the farm or agricultural holding level.

One of the most utilized tools in the manager's hand for optimizing agricultural processes is linear programming (LP).

The foundation of this mathematical method is recognized to belong to Leonid Kantorovich, a Russian mathematician who developed “linear programming problems” in 1939, then to George Bernard Dantzig, an American mathematician who is properly acclaimed as “the father of linear programming” and who published “simplex algorithm” in 1947 and further John von Neuman, a Hungarian-American mathematician who developed “the theory of the duality” also in 1947 [21].

Linear programming was created to be used in the “maximization or minimization of a linear function in which different variables are subject of restrictions” [8, 9, 10, 17].

The objective function of the linear programming is a linear expression which depends on the optimization variables, x_i, required to satisfy certain linear restrictions of equality and non-equality [11, 25, 27].

Linear programming is successfully applied in agriculture both in vegetal and animal production for various purposes.

For example, for establishing the optimal structure of agricultural crops, a mathematical model could be used, that considers the income and expenditure of crops per hectare. In this way, the area of each crop is determined and the maximum income or gross margin or profit level could be derived combining the areas of each crop. Therefore, applying the econometric model of linear programming, it is possible to optimize economic indicators such as income, gross margin and profit based on the optimization of crop and production structure [19, 21, 28, 29].

Also, linear programming is used for the optimization of the cultivated area and crop structure in order to identify the feasible optimal crop combination and rotation which could led to production maximization [5, 15, 26].

In animal farms, linear programming is an important tool for optimizing feed rations in order to minimize ration cost, for optimizing forage balance in relationship with the livestock structure, for optimizing livestock structure in order to increase production [2, 4, 15, 23, 24].

Also, linear programming could be used for optimizing profit in pasture grazing with beef cattle and sheep [1].

Moreover, transport expenditures could be optimized in relation to the need to buy farm inputs from various suppliers etc. [12].

Also, linear programming is often used in agriculture for economizing water, labor, energy, fertilizer and other resources [6, 7].

In order to enhance the importance of Linear Programming in agriculture, Alotaibi and Nadeem (2020) developed LP applications concerning: feed mix, crop pattern and rotation plan, irrigation water, and product transformation [3].

In this context, the purpose of this research study is to set up a mathematical linear model for obtaining a maximum income under the conditions of limited expenditures, which involves linear programming and simplex method for carrying out the solutions regarding the optimized crop structure. For attaining this goal, the IT analysis was made using the Solver from MS Excel application [13].

MATERIALS AND METHODS

The optimization model consists of the following components:

(a) The unknown variables of the model symbolized as: $x_1,\ldots\ldots\ldots\ldots,x_n$ which are positive real numbers which has to be determined or positive whole numbers or even binary values.

(b) The restrictions of the mathematical model which are m equations which contain the unknowns $x_1,\ldots\ldots\ldots\ldots,x_n$. Each restriction regards the limits of the resource to whom it is referred.

(c)The objective-function of the model which could be counted as “p” and contains the unknowns $x_1, \ldots, x_n$ which are going to be optimized (maximized or minimized) [15].

The linear model simulation proposed in this study will consider the history of an agricultural farm for test data, which will represent the support for a manager of an agricultural holding [16].

It is considered that the farm has an agricultural cultivated area of 760 ha which must be cultivated with the following crops: wheat, rye, barley, peas, rapeseed, soybean, corn and sunflower.

The purpose of the research is to obtain a variant of the distribution of the surface of each crop under the conditions of limited expenses in the amount of Lei 1,349,150.

The mathematical model developed in this research is represented by:

(a) The unknown variables of the model which are going to be calculated

They are 8 unknown variables represented by x_1, x_2, x_3, x_4, x_5, x_6, x_7, x_8, the cultivated areas which are going to be determined: wheat, rye, barley, peas, rape, soybean, maize and sunflower [14].

(b)The restrictions of the model

The 14 restrictions proposed in the model regard: Diesel fuel, Herbicides, Chemical fertilizers, The total area, The minimum areas required for each culture, Expenditures and Income, as follows:

-Diesel fuel <= 158,000
-Herbicides <= 55,000
-Fertilizers <= 162,000
-Limited expenditures <= 1,349,150
- Total cultivated surface = 760 ha
- Min area for wheat x_1 >=120 ha
-Min area for rye x_2>=25 ha
-Min area for barley x_3 >=35 ha
-Min area for peas x_4>=50 ha
-Min area for rape x_5>=90 ha
-Min area for soybean x_6>=70 ha
-Min area for maize x_7>=170 ha
-Min area for sunflower x_8>=60 ha
Total Income $\geq$ 1,842,000 Lei.

(c)The objective function

The objective-function aims to maximize income and has the form given below:

$F_{(MAX)}$ Income= $C_1x_1 + C_1x_2 + C_3x_3 + C_4x_4 + C_5x_5 + C_6x_6 + C_7x_7 + C_8x_8$ ....(1)

where:

$C_1, \ldots, C_8$ are the coefficients of the objective-function represented by maximum income desired for each crop cultivated on unknown surfaces $x_1, \ldots, x_n$ which are going to be optimized.

The data were processed using SOLVER from MS Excel Application and the results and tables are correspondingly commented.

RESULTS AND DISCUSSIONS

The mathematical model developed in this research is represented by:

(a) The unknown variables of the model which are going to be calculated

These are:
x_1- cultivated area with wheat
x_2- cultivated area with rye
x_3- cultivated area with barley
x_4- cultivated area with peas
x_5- cultivated area with rape
x_6- cultivated area with soybean
x_7- cultivated area with maize
x_8- cultivated area with sunflower

(b)The restriction of the model

There are 14 restrictions of the mathematical model, as following:

Diesel fuel

$170x_1+130x_2+150x_3+160x_4+170x_5+165x_6+220x_7+190x_8 \leq 158,000$ ....(2)

Herbicides

$70x_1+65x_2+60x_3+65x_4+70x_5+65x_6+90x_7+80x_8 \leq 55,000$ ....(3)

Fertilizers

$200x_1+160x_2+140x_3+170x_4+190x_5+150x_6+200x_7+180x_8 \leq 162,000$ ....(4)

Expenditures limits

$1,850x_1+1,400x_2+1,260x_3+1,450x_4+1,980x_5+1,850x_6+2,100x_7+1,700x_8 \leq 1,349,150$ ....(5)

Total Income $\geq$ 1,842,000 Lei

Total cultivated area=

$x_1+x_2+x_3+x_4+x_5+x_6+x_7+x_8 = 760$ ...(6)

Minimum cultivated area by crop:

$x_1>=120$ (MIN area for wheat)
$x_2>=25$ (MIN area for rye)
$x_3>=35$ (MIN area for barley)
$x_4>=50$ (MIN area for peas)
$x_5>=90$ (MIN area for rape)

$x_6>=70$ (MIN area for soybean)
$x_7>=170$ (MIN area for maize)
$x_8>=60$ (MIN area for sunflower)

Expenditures were calculated summing all the costs belonging to each technological stage starting from plowing to harvesting, transportation and storage.

Incomes were determined based on the obtained grain production multiplied by market price.

Profit is given by the difference between incomes and expenditures per crop and farm.

The limits and the coefficients corresponding to each restriction are presented in Table 1.

Table 1. The matrix of the limits and coefficients corresponding to each restriction of the linear optimization model with limited expenditure and maximum income

Crops / Resources	Wheat	Rye	Barley	Peas	Rape	Soybean	Maize	Sunflower	Restrictions - limits
Diesel fuel (liters/ha)	170	130	150	160	170	165	220	190	158,000 litres
Herbicides etc. (lei/ha)	70	65	60	65	70	65	90	80	55,000 lei
Chemical fertilizers (kg/ha)	200	160	140	170	190	150	200	180	162,000 kg
MIN area (ha)	120	25	35	50	90	70	170	60	Total area = 760 ha
Expenditures (lei/ha)	1,850	1,400	1,260	1,450	1,980	1,850	2,100	1,700	Total ≤ 1,349,150 lei
Income (lei/ha)	3,200	2,350	1,940	2,420	3,270	3,200	3,190	2,960	Total ≥ 1,842,000 lei

Source: Author's own conception of the simulation data and thresholds.

(c)The objective-function

The objective-function aims to maximize income and has the form given below:

$F_{(MAX)}Income=$
$3,200x_1+2,350x_2+1,940x_3+2,420x_4+3,270x_5+3,200x_6+3,190x_7+2,960x_8$ ....(7)

After the presentation of the mathematical model, Table 2 presents the data prepared to be introduced into an Excel spreadsheet [18].

In Table 3 it is shown the data written in the Excel spreadsheet.

We start from the initial solution:

$x_1 = x_2 = x_3 = x_4 = x_5 = x_6 = x_7 = x_8 = 0.$

In A11 cell the formula for the objective function will be written: =SUMPRODUCT(A4:H4,A7:H7).

In the column TOTAL, the formula for each restriction corresponding to each line will be written: =SUMPRODUCT(A4:H4,A14:H14), the last one being: =SUMPRODUCT(A4:H4,A26:H26).

The mouse cursor is then positioned in the cell (the easiest) and then the Solver add-in is called, from the top Ribbon, Data group, Analyze subgroup. Enabling Solver in MS Excel can be done from File, Options, Add-ins, select Solver Add-in, click on Go, select Solver-Add-in to enable it and confirm with OK.

Next, in Figure 1, we complete the required information in accordance with the data presented in Table 3.

There are set the 3 reports: Answer, Sensitivity and Limits which provide details about the solutions of the primary and respectively dual problems, useful for interpretations and forecasts.

In Table 4 the obtained results are presented: the values of the variables, that are: the surfaces allotted by the model in this variant in the field A4:H4 and, respectively, the value of the objective-function, that is the maximum income in the cell A11.

Table 2. The data prepared to be introduced into the Excel spreadsheet for solving the problem using Simplex Method with the SOLVER add-in from MS Excel Application

Restrictions	**Wheat** X_1(ha)	**Rye** X_2(ha)	**Barley** X_3(ha)	**Peas** X_4(ha)	**Rape** X_5(ha)	**Soybean** X_6 (ha)	**Maize** X_7 (ha)	**Sunflower** X_8 (ha)	**Sign**	**Limits**
1.Diesel fuel (liters/ha)	170	130	150	160	170	165	220	190	≤	158,000 liters
2.Herbicides (Lei/ha)	70	65	60	65	70	65	90	80	≤	55,000 Lei
3.Chemical fertilizers (Kg/ha)	200	160	140	170	190	150	200	180	≤	162,000 kg
4.Expenditures (C) (Lei/ha)	1,850	1,400	1,260	1,450	1,980	1,850	2,100	1,700	≤	1,349,150 Lei
5.Surface (ha)	1	1	1	1	1	1	1	1	=	760 ha
6.MIN area wheat	1	0	0	0	0	0	0	0	≥	120 ha
7.MIN area rye	0	1	0	0	0	0	0	0	≥	25 ha
8.MIN area barley	0	0	1	0	0	0	0	0	≥	35 ha
9.MIN area peas	0	0	0	1	0	0	0	0	≥	50 ha
10.MIN area rape	0	0	0	0	1	0	0	0	≥	90 ha
11.MIN area soybean	0	0	0	0	0	1	0	0	≥	70 ha
12.MIN area maize	0	0	0	0	0	0	1	0	≥	170 ha
13.MIN area sunflower	0	0	0	0	0	0	0	1	≥	60 ha
Income (V)(Lei/ha)	3,200	2,350	1,940	2,420	3,270	3,200	3,190	2,960	**MAX**	

Source: Own work based on [20].

Table 3. The data entered in the Excel spreadsheet

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	SOLUTION											
3	X1	X2	X3	X4	X5	X6	X7	X8				
4	0	0	0	0	0	0	0	0				
5	OBJECTIVE FUNCTION COEFFICIENTS											
6	C1	C2	C3	C4	C5	C6	C7	C8				
7	3200	2350	1940	2420	3270	3200	3190	2960				
8												
9	OBJECTIVE FUNCTION:											
10	FO											
11	0											
12												
13	MATRIX A								SIGN	B (limits - for restrictions of the model)	TOTAL	Resources consumed
14	170	130	150	160	170	165	220	190	<=	158000	0	
15	70	65	60	65	70	65	90	80	<=	55000	0	←
16	200	160	140	170	190	150	200	180	<=	162000	0	
17	1850	1400	1260	1450	1980	1850	2100	1700	<=	1349150	0	←
18	1	1	1	1	1	1	1	1	=	760	0	←
19	1	0	0	0	0	0	0	0	>=	120	0	←
20	0	1	0	0	0	0	0	0	>=	25	0	←
21	0	0	1	0	0	0	0	0	>=	35	0	
22	0	0	0	1	0	0	0	0	>=	50	0	←
23	0	0	0	0	1	0	0	0	>=	90	0	←
24	0	0	0	0	0	1	0	0	>=	70	0	
25	0	0	0	0	0	0	1	0	>=	170	0	←
26	0	0	0	0	0	0	0	1	>=	60	0	←

Source: Own research work results.

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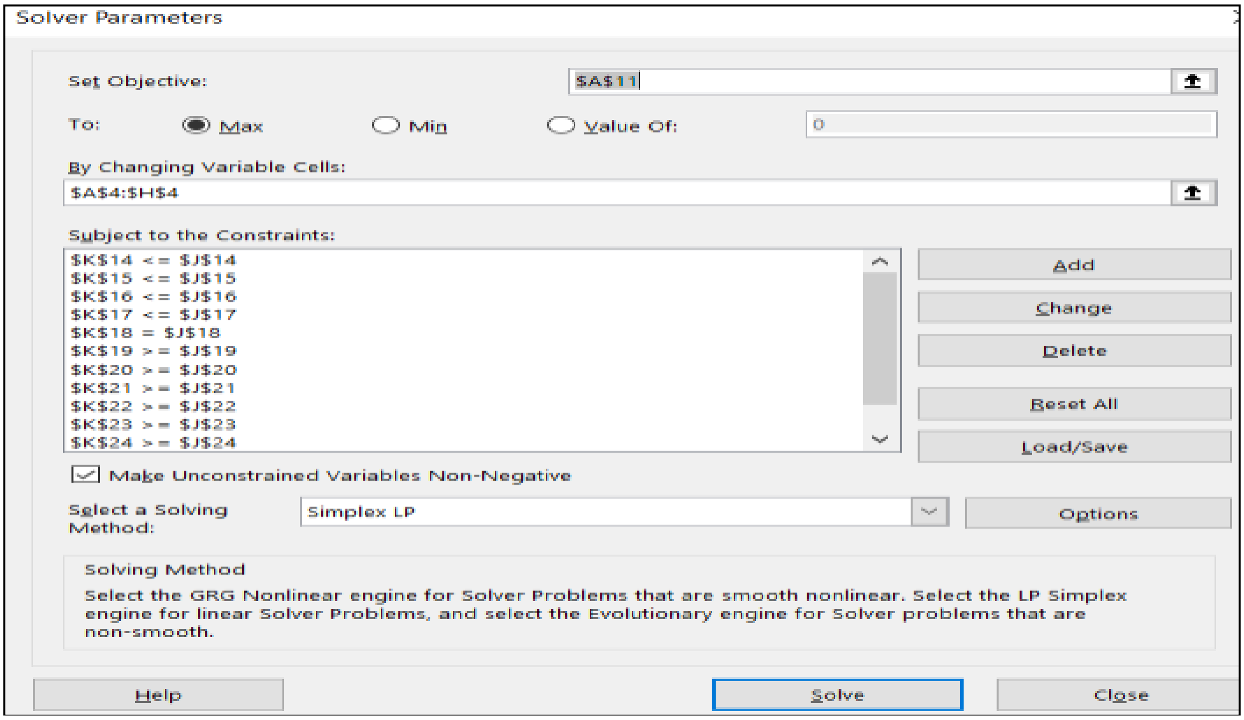

Fig. 1. Completing the information for Solver
Source: Own research work results.

Table 4. The obtained results for the surfaces allocated to each crop and the optimum income value

	A	B	C	D	E	F	G	H	I	J	K	L
1												
2	SOLUTION											
3	X1	X2	X3	X4	X5	X6	X7	X8				
4	120	25	120	50	90	125	170	60				
5	OBJECTIVE FUNCTION COEFFICIENTS											
6	C1	C2	C3	C4	C5	C6	C7	C8				
7	3200	2350	1940	2420	3270	3200	3190	2960				
8												
9	OBJECTIVE FUNCTION:											
10	FO											
11	2210750											
12												
13				MATRIX A					SIGN	B (limits - for restrictions of the model)	TOTAL	Resources consumed
14	170	130	150	160	170	165	220	190	<=	158000	134375	
15	70	65	60	65	70	65	90	80	<=	55000	55000	←
16	200	160	140	170	190	150	200	180	<=	162000	133950	
17	1850	1400	1260	1450	1980	1850	2100	1700	<=	1349150	1349150	←
18	1	1	1	1	1	1	1	1	=	760	760	←
19	1	0	0	0	0	0	0	0	>=	120	120	←
20	0	1	0	0	0	0	0	0	>=	25	25	←
21	0	0	1	0	0	0	0	0	>=	35	120	
22	0	0	0	1	0	0	0	0	>=	50	50	←
23	0	0	0	0	1	0	0	0	>=	90	90	←
24	0	0	0	0	0	1	0	0	>=	70	125	
25	0	0	0	0	0	0	1	0	>=	170	170	←
26	0	0	0	0	0	0	0	1	>=	60	60	←

Source: Own research work results.

In Table 4 are presented the obtained results: the values of the variables, that are the surfaces allotted by the model in this variant in the field A4:H4 and, respectively, the value of the objective-function, that is the maximum income in the cell A11.

In Table 5 are presented the solutions offered by Solver for the primal and dual problems and for three economic indicators: Average profit rate, Marginal profit rate and profit elasticity rate [16].
Also, there are presented:
1.VPP - the values of the variables, that is of the surfaces which are going to be cultivated, proposed as a variant;
2.VPE - the differences between the consumed resources and their limits, named: „spreads*”*;
3.VDE - the additional income in Lei/ha for each crop;
4.VDP - Marginal incomes.

Maximum obtained income = **2,210,750** Lei;
Available and consumed Expenditures = **1,349,150** Lei;
Profit = Income - Expenditures = **861,600** Lei.
Economic efficiency indicators:
Average profit rate, RMP = Profit/ Expenditures = **0.64** Lei profit/1 leu spent
Marginal profit rate, RDP = y_4 -1 **= -1 leu** increased profit / 1 leu increased expenditures
Elasticity of the profit rate, ERP= RDP/ RMP = **-1.56 %** profit growth /1 % expenditures growth
Changes could be done directly in the dialog box in Solver (see Figure 1) like: variable additions/deletions/restrictions, data changes.

Table 5. Solutions for the primal problem (column 1) and for the dual problem (column 2)

Solution for the basic optimal primal	**Solution for the basic optimal dual**
1)VPP (Cultivated areas) x_1= 120 ha wheat x_2= 25 ha rye x_3= 120 ha barley x_4= 50 ha peas x_5= 90 ha rape x_6= 125 ha soybean x_7= 170 ha maize x_8= 60 ha sunflower	3)VDE (Additional income Lei/ha crop) ye_1= 0 Lei additional income/ha wheat ye_2= 0 Lei additional income/ha rye →ye_3= 7.66 Lei additional income/ha barley ye_4= 0 Lei additional income/ha peas ye_5= 0 Lei additional income/ha rape →ye_6= 595 lei additional income/ha soybean ye_7= 0 Lei additional income/ha maize ye_8= 0 Lei additional income/ha sunflower
2)VPE -Differences between the consumed resources and their limits- “*spreads*” xe_1= 23,625 liters non consumed Diesel fuel →xe_2= 0 lei unspent on herbicides xe_3= 28,050 Kg non consumed NPK **→xe_4= 0 Lei unspent money** →xe_5= 0 ha non cultivated land →xe_6= 0 ha wheat surplus →xe_7= 0 ha rye surplus xe_8= 85 ha barley surplus →xe_9= 0 ha beans surplus →xe_{10}= 0 ha rape surplus xe_{11}= 55 ha soybean surplus →xe_{12}= 0 ha maize surplus →xe_{13}= 0 ha sunflower surplus	4)VDP (Marginal incomes) y_1= 0 Lei income growth/ one more Diesel fuel liter →y_2= 252 Lei income growth/one more Leu for expenditures with herbicides y_3= 0 Lei income growth/ one more kg NPK **y_4= 0 Lei income growth/one more Leu spent** →y_5= - 13,180 Lei income growth/one more ha land →y_6= - 1,260 Lei income growth/for the 181st ha with wheat →y_7= - 850 Lei income growth/for the 84th ha with rye y_8= 0 Lei income growth/for the 41st ha with barley →y_9= - 780 Lei income growth /for the 61st ha with peas →y_{10}= - 1,190 Lei income surplus/for the 131st ha with rape y_{11}= 0 Lei income surplus/ for the 101st ha with soybean →y_{12}= - 6,310 Lei income surplus /for the 201st ha with maize →y_{13}= - 4,020 lei income surplus/for the 91st ha sunflower
FO Maxim (Income) = **2,210,750** Lei	

Source: Own results.

CONCLUSIONS

Digitalization in agriculture using new IT technologies could significantly contribute to the development of agricultural production and its economic efficiency.
In this article, a mathematical method from the field of “Operational Research” was combined to obtain the optimal economic variants in an agricultural vegetal farm.
The mathematical model method, accompanied by linear programming and simplex method and using the Solver tool from MS Excel Application, have quickly offered options for a farm manager to maximize the income under the optimization of the crop structure.

The result variants obtained could help the manager to forecast the possibilities of structuring the arable land for several crops chosen to be cultivated, considering the soil and local climate conditions.

The developed model has offered a possible solution through which all the restrictions were fulfilled with an optimal value of the objective function - Maximum net income. It should be noted that the entire arable surface was fully used.

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