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D. T. Muhamediyeva, M. R. Raxmonova, "Application of a genetic algorithm for solving problems of optimization of placement and rotation of crops in cotton crops," Proc. SPIE 12564, 2nd International Conference on Computer Applications for Management and Sustainable Development of Production and Industry (CMSD-II-2022), 125640K (5 January 2023); doi: 10.1117/12.2669429

Event: Computer Applications for Management and Sustainable Development of Production and Industry (CMSD2022), 2022, Dushanbe, Tajikistan

Application of a genetic algorithm for solving problems of optimization of placement and rotation of crops in cotton crops

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ABSTRACT

Currently, the rational distribution of cotton and fodder crops with their combination in crop rotation fields is relevant. This task is solved in two stages. The first is the placement of cotton and other crops in the fields of crop rotation. The implementation allows determining in which field a particular crop should been sown. Such a task considers as a static one and its model develops taking into account the main natural and economic conditions of the economy. The second task considers as dynamic. It allows to determine in which years of rotation in which field a particular crop should been sown. The development model of the task bases on information obtained from the static task and from the crop rotation table in the crop rotation. The main purpose of the article is to solve the problems of optimizing the placement and rotation of crops in the cotton crop rotation. The genetic algorithm is used to solve this problem. The computational experiment was implemented

Keywords: genetic algorithm, optimization problem, mathematical seeding problem

1. INTRODUCTION

For the rational placement of cotton and fodder crops with their combination in the fields of crop rotation, several indicators are determined that characterize the suitability of fields for sowing a particular crop. In our opinion, the main one is the yield of a crop rotation crop in a particular field. Therefore, the forecast of crop yields by crop rotation of fields occupies a special place in the system of crop rotation optimization problems [1-3]. This task is implemented in two stages. At the first stage, the potential yield of crop rotation crops is determined for each field of the crop rotation. The calculation is performed according to the model of multiple correlation by soil types with a preliminary assessment of the soil suitability for sowing this type of crop. At the same time, the model includes a complex of natural and economic factors that characterize the state of the soil and other production conditions. The results of the forecast serve as the main information for the static model of the distribution of crops in the fields of crop rotation [2]. At the second stage, the problem of predicting crop yields of crop rotation fields is solved, taking into account the alternation of cotton and its predecessors for the rotation period. The experience of scientists and the practice of mastering crop rotations in farms show that in the first years of cotton sowing after ploughing alfalfa in crop rotation fields, high yields are obtained, starting from the 3rd and 4th years of sowing, the productivity of the fields decreases, respectively, the yield of cotton also decreases [3-5]. This should be taken into account in the model as the main phenomenon that occurs during the alternation of crops in a crop rotation. Thus, the dynamics of crop yields over the years serves as the main information in determining the rotation of crops. Considering the above, we have developed static and linear-dynamic models of the problem of placing crops in the fields of crop rotations and their alternation during the rotation period [6-11].

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2nd Intl. Conference on Computer Apps for Mgmt and Sustainable Dev. Production and Industry (CMSD-II-2022),
edited by Shahriyor Sadullozoda, Arthur Gibadullin, Proc. of SPIE Vol. 12564, 125640K

2. METHODS AND MODELS

To mathematical formalize the problem model, we introduce additional notation:

- P_r^k - the size of the r-th crop rotation field in the K-scheme of crop rotation.
- u_{rj}^k -yield of the j-th crop on the r-th field of crop rotation with K-scheme of crop rotation.
- t_{jz}^k -labor costs for I on the j-th culture.
- c_{jk}^k - the cost of gross output from the I hectare of the j-th crop.
- Z_{1j}^k - production costs for I on the j-th culture.
- $\alpha_1^k, \alpha_2^k, \alpha_3^k$ - number of fields in the K-th crop rotation scheme.
- T^{**} - labor resources.
- V_1 - total production costs.
- Q_i - the required volume of production of the i-th type of agricultural products.
- x_{zj} - coefficient that determines the share of the r-th field in the K-th crop rotation scheme for sowing the j-th crop.
- $J \in J_1, J_2, J_3$ - a set of indices of variables for crop rotation.

Taking into account the accepted notation, the static model of the problem of optimizing the placement of crops in the fields of crop rotation is as follows. It is required to find the optimal plan for the placement of crops in the fields of crop rotation, which allows obtaining the largest amount of net income, expressed as a linear function:

$$F(x) = \sum_{j=1}^{J}\sum_{K=1}^{K} P_r^K \left(c_{1j} - Z_{1j}\right) x_j^k \to \max,$$

When the following restrictions are met:

$$\sum_{j=1}^{J}\sum_{r=1}^{R} x_{rj}^k = 1 \tag{1}$$

$$x_{rj}^k = \begin{cases} 1, \text{If the } j\text{-th crop is sown on the } r\text{-th field in the } K\text{-th rotation scheme} \\ 0, \text{otherwise} \end{cases}$$

$$\sum_{j=\gamma+1}^{J_1}\sum_{r=1}^{R} u_{rj}^K x_j^k \geq \alpha_1^K u_j^K, \gamma = 0,3,6,9,.... \tag{2}$$

$$\sum_{j=\gamma+2}^{J_2}\sum_{r=1}^{R} u_{rj}^K x_j^k \leq \alpha_2^K u_j^K \tag{3}$$

$$\sum_{j=\gamma+3}^{J_3}\sum_{r=1}^{R}u_{rj}^{K}x_j^k \le \alpha_3^K u_j^K \tag{4}$$

$$\sum_{j=1}^{J}\left(\sum_{k=1}^{K}\sum_{r=1}^{R}P_r^k \cdot h_{rj}^k\right)\cdot x_j^k \le T^{**} \tag{5}$$

$$\sum_{j=1}^{J}\left(\sum_{k=1}^{K}\sum_{r=1}^{R}P_r^k c_{rj}^K\right)\cdot x_j^k \ge 0 \tag{6}$$

$$\sum_{j=1}^{J}\left(\sum_{k=1}^{K}\sum_{r=1}^{R}P_r^k 3_{rj}^K\right)\cdot x_j^k \le V_1 \tag{7}$$

$$\sum_{j=1}^{J}\left(\sum_{k=1}^{K}\sum_{r=1}^{R}P_r^k u_{rj}^K\right)\cdot x_j^k \ge Q \tag{8}$$

$$x_{rj}^k \ge 0 \tag{9}$$

The contents of the individual restrictions and conditions are as follows. Equality (1) reflects the conditions for choosing one and only one crop rotation field for sowing a given crop. Inequalities (2) - (4) implement the condition under which each crop must be sent where it produces the maximum yield.Such a restriction is introduced for each type of crop, which can be conditionally divided into three groups: the first is cotton, the second is forage crops, the third is corn, wheat and barley. Inequalities (5), (6) and (7) make it possible to evaluate crops and crop rotations in terms of their labour intensity (5), production costs (7) and the possibility of obtaining gross output (6) on a crop rotation field[12].

Inequality (8) implements the requirements for the obligatory fulfilment of the plan for the procurement of agricultural products; relation (9) is the condition for the non-negativity of the variables.

The solution of the problem according to this model makes it possible to determine in which fields one or another type of crop should been placed. This calculation is the basis for planning the rotation of crops in a crop rotation. To solve this optimization problem, a genetic algorithm is used. In the general case, the optimization procedure based on the usual sequential complex-method is as follows: it is required to find the maximum of some function $F(x)$ under conditions (1)-(9).

The operation of such an algorithm is formed by the sequence of the following steps [13]:

- Creation of the initial population.
- Operation crossing with population increase.
- Mutation operation.
- First selection (determination of the worst individuals) without population reduction.
- Selection operation, values are replaced by the best value in the entire population.

3. RESULTS

When solving problems using a static model, the numbers and sizes of crop rotation fields are determined, on which it is possible to place a particular crop according to the selected schemes. The main conditions included in the model were the values of crop yields in the same field, the volume of cotton production, production, labour costs and conditional net income. The criterion for the optimality of the problem was the minimization of production costs and the maximization of the conditional net income, calculated as the difference between the costs of gross output per 1ha and production costs per 1ha. All initial data were calculated based on long-term data of the collective farm. Information was prepared for each crop rotation scheme. This made it possible to evaluate all crop rotation schemes and fields in a complex, taking into account the main indicators of collective farm production. The tasks were solved according to the above two optimality criteria. By a comparative analysis of the final results and their effectiveness, the second variant of the results obtained with the criterion of minimizing production costs was chosen for further research. The main results of this option are shown in Tables 1 and 2. With the chosen placement of crops in the fields of crop rotation, the volume of cotton production will be 32.5 thousand per centner.

Table 1. Placement of crops in the fields of crop rotation.

Crop rotation field	Crop rotation scheme			
	1:2:7	1:4:1:4	2:4:1:3	2:8
I	C 26.0	C 36.2	C 21.5	C 34.6
II	K + R 24.0	C 38.0	I+ B 21; 7	C 35.4
III	C 24.6	C 38.2	I+ B 22.0	C 32.1
IV	C 24.0	C 36.2	C 22.0	C 32.3
V	I+ B 22.5	C 38.9	C 22.4	C 35.6
VI	C 25.0	K + K 37.2	C 22.2	C 34.4
VII	C 25.6	K 37.8	K + R 22. 6	C 31.5

Table 2. Placement of crops in the fields of crop rotation.

Crop rotation field	Crop rotation scheme			
	1:2:7	1:4:1:4	2:4:1:3	2:8
VIII	C 24.0	C 37.3	C 22.6	I +B 34.8
IX	C 24.0	C 37.5	C 22.0	I +B 35.8
X	I+W 24.6	C 35.2	C 22.0	C 34.2

Here: in the numerator - the type of crop rotation, in the denominator - the size of the crop rotation field.

C - cotton; K - corn; R - root crops;

I - alfalfa; B- barley; W – wheat.

Table 3. Crop yields according to crop rotation schemes on average.

Crop rotation	Product type	Crop yield according to schemes			
		2:8	2:4:1:3	1:4:1:4	1:2:7
Alfalfa + barley	Hay	76.0	74.5	—	74.5
	Corn	32.0	31.6	—	31.6
	Straw	32.0	31.6	—	31.6
Alfalfa (2 years)	Hay	157.0	152.0	—	152.0
Grain + wheat	Hay	75.2	74.5	—	74.5
	Corn	32.0	30.0	—	30.2
	Straw	32.0	30.2	—	30.2
Alfalfa (2 years)	Hay	157.0	152.0	—	152.0
Corn	Corn	—	90.0	93.0	90.0
	Silage	—	492.8	492.8	492.8
Corn + root crops	Corn	—	87.5	87.5	87.5
	Silage	—	482.2	482.2	482.2
	green fodder	—	490.0	490.0	490.0
	Beet	—	411.0	411.0	411.0
Corn +alfalfa	green fodder	—	390.0	390.0	390.0
Cotton	Cotton	35.8	37.0	35.0	37.15

With the chosen placement of crops in the fields of crop rotation, the volume of cotton production will be 32.5 thousand per centner, alfalfa hay - 11.3 thousand per centner, corn grain - 10.2 thousand per centner. The yields of crops at which such a volume of production is achieved are shown in Table 3. As the data in Tables 1 and 2 show, fodder crops are sown in combination with cereals in 10 fields according to the indicated schemes, and cotton is sown in the remaining 30 fields. So, according to the 1:2:7 scheme, cotton is sown in the first year of rotation on fields I, III IV, VI-IX. Such placement of crops in the fields of crop rotation allows, according to all schemes, to move to the organization of alternation of crops for the future. The results of the static problem (numbers of fields and their sizes) serve as the initial information and starting point for solving the problem of placing and alternating crops for the entire rotation period. This problem is solvedby using a linear dynamic model.

4. DISCUSSION

A static model can developed based on a transport linear programming problem. However, it is impossible to take into account various options for sowing crops in a particular field with the condition that harvesting plans are fulfilled. The work [1] describes a model for the placement of cotton and fodder crops in crop rotation fields, taking into account their prospective alternation. The problem model allows you to determine in statics the placement of crops in the fields of crop rotation without taking into account the potential yield of the fields. In [2], the author notes: "... for each rotation period, a separate matrix of the problem is formed, which is solved independently". As is known, with this approach, the dependence of cotton alternation on predecessors is violated and a multiple solution of the same problem arises. At the same time, it is somewhat difficult to compare the results of one year of rotation with another, and the complexity of the calculation is violated.

5. CONCLUSION

The use of new approaches based on evolutionary methods to optimize fuzzy rule bases will significantly reduce the time of decision formation and increase the reliability of its adoption in intelligent systems. The problem of optimizing the placement and alternation of crops in the cotton crop rotation has been solved based on the use of a genetic algorithm with artificial selection, and software has been created to solve this task based on the use of a genetic algorithm with artificial selection.

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