ITM Web of Conferences **59**, 01017 (2024) https://doi.org/10.1051/itmconf/20245901017
HMMOCS-II 2023

Solving problems of optimizing crop rotation using genetic and ant algorithms

Dilnoz Muxamediyeva[1*], *Nilufar* Niyozmatova[1], and *Boymirzo* Samijonov[2]

[1]Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, National Research University, Tashkent, Uzbekistan
[2]Sejong University, South Korea, Seoul, Korea

Abstract. Issues of optimizing crop rotations are becoming key to increasing production efficiency and ensuring sustainable development of agriculture. Crop rotation is the systematic rotation of different crops in the fields over several years, which helps maintain soil fertility, reduce the risk of diseases and pests, and optimize the use of resources. The goal of the study is to develop effective strategies for managing crop rotations in order to optimize the use of resources and increase productivity. The paper presents strategies for managing a crop rotation system aimed at optimal distribution of areas for different crops, rational use of resources and emergency management. A genetic and ant algorithm is proposed for solving problems. The model is calibrated and validated using available data, followed by scenario analysis to evaluate different options.

1 Introduction

Agriculture is the most important sector of the economy, playing a key role in ensuring food security and sustainable development of society. In the context of a changing climate, scarcity of natural resources and growing needs of the population, there is an urgent task of optimizing agricultural production processes. One of the important tools aimed at improving the efficiency of agricultural land use is a crop rotation system. This work is devoted to optimal modeling of crop rotation systems in the context of agriculture. The purpose of the research is to develop effective mathematical models aimed at optimizing the selection and distribution of agricultural crops in the fields, taking into account various factors such as climatic conditions, soil resources and demand for products [1, 2].

The work includes analysis of the impact of different scenarios of climate and resource changes on the efficiency of crop rotations. The results obtained provide agricultural enterprises with the tools to make informed decisions to optimize crop rotations, improve production sustainability and rational use of agricultural land. The study aims to identify optimal sowing and crop rotation strategies, taking into account a variety of factors, such as the climatic characteristics of the region, soil fertility, agrotechnical requirements and market needs [3, 4].

* Corresponding author: m_narzullo@mail.ru

2 Methods

The problem of optimizing the placement of crops in fields within the cotton-alfalfa crop rotation is an important problem in agricultural economics. The goal of this optimization is to maximize profit while taking into account restrictions on the number of fields, budget constraints and other factors [5, 6].

A mathematical optimization model has been developed to determine the optimal placement of crops in the fields. When developing the mathematical model, the following notations were used [7,8]:

x_{ij} - binary variable, where $x_{ij} = 1$, if the field i contains a culture j, and $x_{ij} = 0$ and otherwise.

Y_j - the total number of fields allocated for the culture$j$.

c_{ij} - the cost of growing a crop j on a field i.

p_{ij}- profit from culture j on the field i.

B - total budget.

The objective function is to maximize income:

$$F(x) = \left(\sum_{i=1}^{N} \sum_{j=1}^{M} p_{ij} \cdot x_{ij} - \sum_{i=1}^{N} \sum_{j=1}^{M} c_{ij} \cdot x_{ij} \right) \rightarrow max,$$

Restrictions:

Each crop must be placed on a certain number of fields:

$$\sum_{i=1}^{N} x_{ij} = Y_j, \forall j \in \{1,2, \dots M\}$$

The total number of fields allocated for all crops should not exceed the total number of fields:

$$\sum_{j=1}^{M} Y_j \leq N.$$

The budget should not be exceeded:

$$\sum_{i=1}^{N} \sum_{j=1}^{M} c_{ij} \cdot x_{ij} \leq B$$

Binary restrictions:

$$x_{ij} \in \{0,1\}$$

Solving this optimization problem will allow us to determine the optimal placement of crops in the fields while taking into account profits, growing costs and budget constraints [9-13].

To solve the problem of optimizing crop rotations in agriculture, a genetic algorithm was used, which consists of the following stages:

1. 1.Initialize the population size, that is, the number of potential solutions, the number of fields, the number of different crops that can be grown in each field. We generate random combinations of crops in each field to create an initial population.
2. 2.Calculation using cost matrices, which represents the costs of growing each crop in each field, supply restrictions for each field, and demand restrictions for each crop. It is checked whether the given solution satisfies the supply and demand constraints. If yes, the cost will be refunded. Otherwise, infinity returns to punish bad decisions.
3. Crossing A random separation point between the parents is selected and two offspring are created by combining parts of the parents to the right and left of the separation point.

4. Mutation. The solution undergoes mutation. A mutation mask with mutation probability for each bit is created and applied to the solution.
5. Calculate the fitness for each solution in the population.

To solve the problem of optimizing crop rotations, an ant algorithm was also used, which consists of the following stages:

1. Initialization of pheromones. Creation of a pheromone matrix of size (number of fields) x (number of crops). Initialize all matrix elements to 1.
2. Calculation of probabilities. For each ant, the initial field is chosen randomly. The ant moves to the next field according to probabilities based on pheromones and visibility. The probability of choosing the next field is calculated as the product of pheromones and visibility, taken to the alpha and beta powers, respectively. Pheromones are updated as the ant passes through.
3. Pheromone update. After each passage of the ant, pheromones are deposited on the edges, proportional to the inverse value of the cost of passage.
4. Completion and output of the best solution. Repeat steps 2-3 a specified number of times. Selecting the best solution among all ants at the end of execution.
5. Problem solving. Specifying a matrix of costs and algorithm parameters. Obtaining the optimal solution and its cost.

The algorithm uses the idea of modeling the behavior of ants following the tracks of other ants, finding optimal routes. This makes it possible to find the optimal distribution of crops across fields, taking into account cost factors and crop rotation restrictions in agriculture.

3 Results and discussion

The crop rotation optimization model has practical application in agriculture, allowing you to optimize the use of fields, increase the profitability of crop rotation and the efficiency of agricultural production. Consider a farm with 10 fields. There are two crops: cotton (crop 1) and alfalfa (crop 2). We have a budget, say $50,000, and the cost of cultivation and profit for each crop in each field. The task is to determine how many fields to allocate for each crop to maximize profits.

The following solutions were obtained using the genetic algorithm.

Optimal solution:

[[1. 0. 1. 0. 1. 1. 1. 1. 1. -0.]
[0. 1. 0. 1. 0. 0. 0. 0. 0. 1.]]

In this solution, the "Optimal solution" is a 2x10 matrix, where each row represents a crop and the columns represent crop rotation fields. The values in the matrix indicate whether a particular crop is grown (1) in a particular field or not (0) (Figure 1).

The first row of the matrix corresponds to the first culture.

The second row of the matrix corresponds to the second culture.

In this case:

This means that the optimal crop rotation program involves sowing on field 1 in the following years: 1, 3, 5, 6, 7, 8, 9. The optimal crop rotation program involves sowing on field 2 in the following years: 2, 4, and 10.

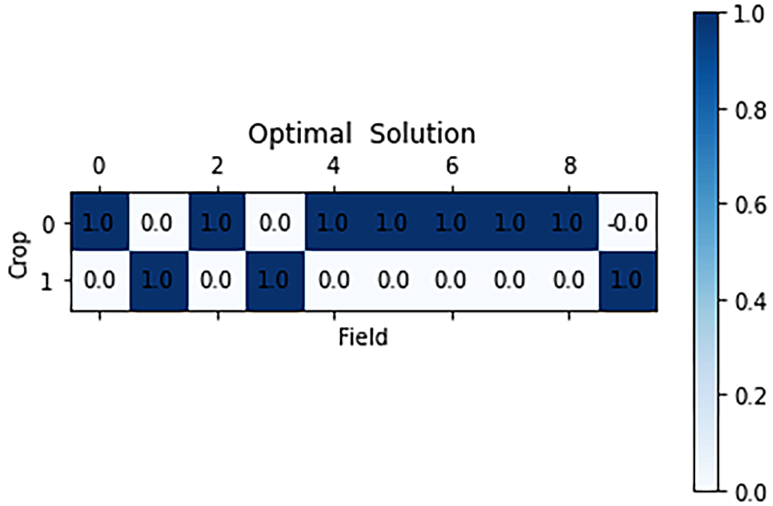

Fig. 1. Genetic Algorithm Solutions.

The following solutions were obtained using the ant algorithm
Optimal solution:

[[0. 0. 0. 0. 1. 0. 0. 1. 1. -0.]
[1. 1. 0. 1. 1. 0. 0. 1. 1. 1.]]

This means that the optimal crop rotation program involves sowing on field 1 in the following years: 5, 8 and 9. The optimal crop rotation program provides for sowing on field 2 in the following years: 1,2, 4,5, 8, 9 and 10.

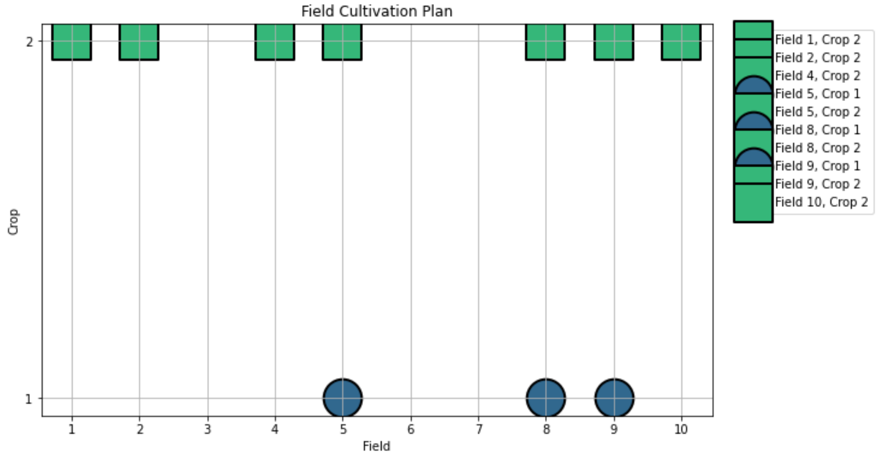

Fig. 2. Solutions using the ant algorithm.

We have obtained the optimal solution for this linear programming problem. This solution is represented in the form of values of the variables and a matrix showing the optimal distribution of the variables. The solution satisfies all the constraints of the problem. Each variable takes values within acceptable intervals, and the constraints of the problem are met. The optimal solution can be used to make decisions under real-world conditions. Depending on the context of the model, these results can be useful for optimizing resources, managing production processes, or making strategic decisions. In general, optimization models such as linear programming are powerful tools for solving a variety of management and decision-making problems, and the results obtained can significantly contribute to process efficiency and optimization. The development and use of a mathematical optimization model for crop placement in a cotton-alfalfa rotation represents an important tool for modern agricultural enterprises, facilitating more efficient land management and increased economic efficiency.

4 Conclusion

In this study, methods for optimizing crop rotations in agriculture using genetic and ant algorithms were considered and implemented. These methods provide tools for efficient distribution of crops across fields, taking into account various cost factors and crop rotation constraints. A genetic algorithm inspired by natural selection processes allows finding optimal solutions in the space of possible crop distribution options. Using the mechanisms of mutation and crossing, the algorithm converges to the optimal solution while satisfying the constraints. The ant algorithm, based on the behavior of ants in finding shortest paths, allows you to find optimal routes in the space of fields and crops. The intelligent behavior of ants, depositing pheromones on paths with the best solutions, contributes to finding optimal solutions.

In conclusion, it can be noted that the development and implementation of scientifically based cotton crop rotation systems is an important aspect of agriculture, especially in cotton growing. Despite expert assessments and balance calculations, there is a need to use an economic and mathematical model for the optimal choice of crop rotation scheme. The system of crop rotation optimization models provides valuable guidance for selecting optimal patterns and types of cotton crop rotations, taking into account various soil conditions. This allows you to increase production efficiency and meet the economic and social conditions of the economy. However, with a possible variety of recommended schemes, it is important to use an economic-mathematical model to accurately select crop rotations that will satisfy all the criteria. This approach makes it possible to make the process of choosing a crop rotation scheme more reasonable and adapted to the conditions of a particular farm.

References

1. V.N. Romanov, V.K. Ivchenko, I.O. Ilchenko, M.V. Lugantseva, *The influence of basic tillage techniques in crop rotation on the dynamics of moisture and agrophysical properties of leached chernozem*, Achievements of science and technology of the agro-industrial complex (2018)
2. B.I. Niyazaliev, Agrarian science **2**, 5-6 (2016)
3. N.R. Hulugalle, B. McCorkell, V.F. Heimoana, L.A. Finlay, Journal of Cotton Science **20(4)**, 294-298 (2016)
4. R.Z. Naqvi, S.S.E.A. Zaidi, K.P. Akhtar, Gossypium arboretum. Scientific reports **7** (2017)
5. S.A. Kazemeini, R. Moradi Talebbeigi, M. Valizade, Archives of Agronomy and Soil Science **62(3)**, 395-412 (2016)
6. M.A. Locke, L.J. Krutz, R.W Steinriede, S. Testa, Soil Science Society of America Journal **79(2)**, 660-671 (2015)
7. D.M. Zhang, W.J. Li, C.S. Xin et al., Field crops research **138**, 63-70 (2012)
8. J. Lofton, B. Haggard, D. Fromme, B. Tubana, Journal of Cotton Science **18(3)**, 376-384 (2014)

9. W.T. Pettigrew, H.A. Bruns, K.N. Reddy, Journal of Cotton Science **20(4)**, 299-308 (2016)
10. H. Zhang, H. Liu, C Sun et al., Water **9(7)** (2017)
11. G.Z. Yang, H.Y. Tang, Y.C. Nie, European journal of agronomy **35(3)**, 64-170 (2011)
12. 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), Dushanbe, Tajikistan (2022)
13. D.T. Muhamediyeva, M. Rahmonova, M.E. Shaazizova, *Application of artificial intelligence technologies to select the optimal cotton crop root scheme* Proc. SPIE 12637, International Conference on Digital Transformation: Informatics, Economics, and Education (DTIEE2023) (2023)