Optimization of acreages as an element of sustainable development of natural landscapes

V Chibis¹,²* and I Kutyshev¹

¹ Omsk State Agrarian University named after P.A. Stolypin, Institutskaya square 1, 644008, Omsk, Russia
² Omsk Agrarian Research Center, Koralev Avenue 26, 644012, Omsk, Russia

E-mail: vv.chibis@omgau.org

Abstract. The alternation of crops for a long time will remain a fundamental element of the zonal technologies of their cultivation. The use of mathematical modeling methods will allow to reach a new level in solving the issues of effective use of arable land through the use of models that optimize it. Especially, the results of studies based on long-term observations will be valuable. We used data from long-term stationary experiments to study the alternation of crops in crop rotations that took more than five rotations. The stationary experiments are located in the forest-steppe zone of Western Siberia in the fields of the Omsk Agrarian Scientific Center. The purpose of the research was to optimize the use of arable land based on mathematical modeling methods to preserve soil fertility. In the work, a model that takes into account the conditions of the agroecosystem is used (humus balance, labor costs, energy costs, etc.). It allows one to optimize the cultivated area, while maintaining soil fertility, ensuring the production of products at a consistently high level, with increasing economic and energy efficiency. The article shows that in grain-crop crop rotations, the yield is generated due to the natural fertility of the soil, as evidenced by the negative humus balance, which reaches 0.18-0.78 t/ha. During the alternation of the fruit-changing alternation, the crop was formed against the background of the reproduction of the organic matter of the soil by increasing the plant residues from the use of fertilizers. The humus balance was positive (0.15-0.28 t/ha). When using employed steam along with clean steam, rape as siderate, and also straw as an organic fertilizer for grain crops, the amount of 2.01 t/ha of marketable grain was obtained (with a 16.8% share of pure steam, as well as occupied steam (11%) and spring grain (72.2%), of the arable land area). Increasing the area in the crop rotation of Western Siberia using straw, green manure, and occupied vapors as organic fertilizer, the soil fertility reproduction with a certain decrease in the yield of marketable grain up to 2 t/ha can be achieved.

1. Introduction

Mathematical modeling allows one to build an optimization model of the structure of the acreage for the commodity producer, taking into account their needs and the availability of resources. The structure of sown areas should be formed on the basis of a system-energy approach. Research in the mathematical modeling of the production process of plants is being intensively developed, as many published papers in this field show [1-3; 9].

When evaluating agroecosystems, the potential productivity of crop rotations should be determined to identify the structure of anthropogenic energy consumption for growing crops, to analyze in detail, the productivity of agroecosystems to evaluate. Conducting bioenergy analysis will allow to have an...
objective assessment of the energy potential of the agroecosystem and the feasibility of using anthropogenic energy in the cultivation of crops. The productivity of crop rotations is determined by the productivity of the crops within their structure, which react differently to rainfall and temperature during certain periods of vegetation. Many scientists in their studies have shown that the rotation of crop rotation and the productivity of crops reliably depend on the natural and climatic conditions and the structure of the sown areas [4, 5]. Thus, the goal of our research was to increase the productivity of field crop rotations based on optimizing the structure of arable land using mathematical modeling to improve the adaptive-landscape farming systems in the forest-steppe of Western Siberia.

2. Materials and Methods
The research was conducted in long-term stationary experiments to study the alternation of crops in crop rotations that took more than five rotations. The stationary is located in the forest-steppe zone of Western Siberia in the fields of the Omsk ASC, former SibNNIISH. Placement of plots in the experiment was randomized; the size of plots was 0.275 ha (110 × 25 m) and 0.138 ha (110 × 12.5 m); it was repeated 4 times. Field crop varieties are zoned for Western Siberia: spring wheat (“Omskaya 36”), spring barley (“Omsky 95”), soybeans (“Golden”), rapeseed (“Yubileyny”), oats (“Irysh 21”), corn (“Omka 135”). The soil of the experimental plot is black leached, slightly leached medium-humus, medium heavy, and loamy with a humus content in the arable horizon of 6.5-7%. The system of agrotechnical measures was built taking into account the recommendations of the Omsk Agrarian Scientific Center for the forest-steppe zone of Western Siberia [6]. In the process of building a model of agro-ecosystem performance, linear and non-linear regression analysis was used. The adequacy of the model was tested by the Fisher criterion. The confidence level was assumed to be 95%. To test the hypothesis of the correlation of residues, the Durbin-Watson criterion was calculated. Methods of regression, correlation analysis, and mathematical modeling were used [7].

3. Results
We found that the introduction of grain crops and soybeans into the crop rotation with a share of 15-25% will increase the yield of feed protein units by 0.3-0.7 tons from 1 ha of crop rotational area. Provided that a high level of grain yield in comparison with spring wheat will remain (Table 1).

The yield of grain, KPI, feed units, and digestible protein from one hectare of arable land also refers to the indicators of the efficiency of crop rotation. These indicators are directly dependent on the set of crops in crop rotation and the number of fields. In the conditions of 2010–2018, crop change rotations were effective due to their saturation with legumes and forage crops, mainly.

| Rotations | Grain yield | Output, 1 hectare of arable land |
|-----------|-------------|----------------------------------|
|           |            | grains | feed units | digestible protein | KPI |
| Grains fallow rotations (control) | | | | | |
| Steam - wheat - wheat - oats | 2.17 | 2.01 | 2.43 | 0.19 | 3.21 |
| Occupied steam - wheat - wheat - oats (without chemicals) | 1.65 | 1.31 | 2.54 | 0.12 | 3.91 |
| Occupied steam - wheat - wheat - oats (with chemicals*) | 2.32 | 1.95 | 3.87 | 0.31 | 6.78 |
| Fruiting crop rotations | | | | | |
| Soy - wheat - barley - oats | 1.99 | 2.06 | 2.55 | 0.23 | 4.00 |
| Occupied steam - wheat - barley - oats (without chemicals) | 1.87 | 1.4 | 2.87 | 0.28 | 5.42 |
| Occupied steam - wheat - barley - oats | 2.36 | 2.11 | 4.18 | 0.38 | 9.75 |
Based on the data on the crop rotations under study and their links, a mathematical model for optimizing the structure of the sown areas has been developed. Data on five crops cultivated in various links of crop rotations are included in the model against the background of N₃₀P₃₀ + straw and siderats.

The developed model contains 170 variables and 280 constraints.

The areas of individual crops in crop rotations (\(x_{ik}\) – the area of the \(i\)-th crop in the \(k\)-th crop rotation or link), the area of crop rotations (\(x_k\)), the total area of arable land, the output of products (\(P_j\) – the volume of the \(j\)-th type of production), production costs, net income (\(Y_j\) is the volume of the \(j\)-th value indicator; \(Q_j\) is the volume of the \(j\)-th type of resource), energy costs, energy increment, and others are defined as variables.

The maximum production of a \(j\)-th product serves as an optimality criterion:

\[
Z = \sum_{i \in N_1} \sum_{k \in N_2} b_{jik} \cdot x_{ik} \rightarrow \text{max}
\]

where: \(N_1\) – many cultivated crops; \(N_2\) – many crop rotations and their links; \(b_{jik}\) – the yield of \(j\)-th species from a unit area of the \(i\)-th culture of the \(k\)-th crop rotation or link.

Obtaining agricultural products is possible under certain conditions described by the system of restrictions. The main restrictions are on the balance of humus, production costs, labor costs, energy costs, energy increment with and without humus. The system also includes restrictions:

- On arable land:
  \[
  \sum_{k \in N_2} x_k = Q_j \quad j \in M_4
  \]

- By crop rotation:
  \[
  \sum_{i \in N_1} x_{ik} \leq x_k \quad k \in N_2
  \]

- By area of individual crops within crop rotations:
  \[
  \sum_{i \in N_1} x_{ik} = C_{ik} \cdot x_k \quad k \in N_2
  \]

- On production resources:
  \[
  \sum_{i \in N_1} \sum_{k \in N_2} a_{jik} \cdot x_{ik} \leq Q_j \quad j \in M_4;
  \]

- On production:
  \[
  \sum_{i \in N_1} \sum_{k \in N_2} b_{jik} \cdot x_{ik} \Rightarrow B_j \quad j \in M_5;
  \]

- On production costs:
  \[
  \sum_{i \in N_1} \sum_{k \in N_2} a_{jik} \cdot x_{ik} = Y_j \quad j \in M_6;
  \]

- On gross output:
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\[ \sum_{i \in N_1} \sum_{k \in N_2} d_{ik} * X_{ik} = Y_j \quad j \in M_7; \]  

where \( M_4 \) – many production resources; \( c_{ik} \) – a share of \( i \)-th crop in the \( k \)-th crop rotation; \( d_{ik} \) – a gross output per unit area of the \( i \)-th crop in the \( k \)-th crop rotation; \( a_{jk} \) – \( j \)-th resource costs per unit area of \( i \)-th crop in the \( k \)-th crop rotation or link; \( M_6 \) – many types of products; \( M_8 \) – a lot of production costs; \( M_7 \) – a lot of gross output; \( B_j \) – a guaranteed production volume of the \( j \)-th species.

Currently, the main interest of farmers is to obtain high quality food grains. As a result of solving the problem with the help of the developed model, variants of the structure of sown areas, providing the greatest yield of food grains, were obtained (Table 1, 2).

**Table 2.** The structure of arable land for obtaining marketable grain at \((N_{30} P_{10}  \text{ and straw})\) on average for 2010 - 2018.

| Rotations | Permanent crops | Food grain output, t/ha | Return on grain, % | Energy ratio | Agroecosystem productivity, MJ/dn/GJ | Humus balance, t/ha |
|-----------|----------------|-------------------------|--------------------|--------------|--------------------------------------|---------------------|
| Grain fallow rotations | Steam - wheat - wheat - oats | 2.01 | 87.6 | 1.84 | 0.086 | -0.78 |
| Steam - wheat - wheat | 1.95 | 94.9 | 1.72 | 0.098 | -0.21 |
| Fruiting crop rotations | Soy - wheat - barley - oats | 2.06 | 91.0 | 2.01 | 0.123 | + 0.28 |
| Rape – wheat - barley - soy - oats | 2.11 | 94.9 | 2.14 | 0.127 | + 0.15 |
| Permanent soy - oats | 2.10 | 94.9 | 2.13 | 0.127 | + 0.14 |
| Permanent sowing | Permanent wheat | 1.10 | -12.6 | 1.34 | 0.040 | -0.18 |

Both grain-steam crop rotations and fruit-replaceable cultivation of grain make it possible to obtain from 2.11 to 1.10 t/ha of commercial grain.

**4. Discussion**

To increase the effectiveness of the use of arable land in the development of animal husbandry, increasing the efficiency of using arable land and introducing into the structure of the area of crops that increase the collection of fodder units and digestible protein is possible (soybeans and grain crops). The introduction of these crops in crop rotations increases the productivity of one hectare of arable land by 20-25% [8].

In general, the introduction of grain crops into crop rotations leads to an increase in yield by 0.3-0.5 t/ha, and the KPI increases by 0.5-0.8 tons per hectare of crop rotation area in comparison with spring wheat. The use of intensification tools will increase the productivity of both grain and fruit-replaceable crop rotations. In fruit-replaceable crop rotations, the increase from their use amounted to 0.15-0.22 t/ha of grain, 2.5-3.8 t/ha of digestible protein.

Thus, the proportion of crops should be 67-100%. Using the resulting model will allow one to determine what production is required to ensure the expenditure of material and cash from 1094 to 1636.5 thousand rubles/ha, as well as 23.0-44.6 GJ/ha of total energy and 5.8-10.4 GJ/ha for operating. The profitability of the production of feed units, taking into account by-products, will vary from 17.0 to 43.9%; it is from 87.6 to 94.9% for grain. Only permanently cultivating a culture is unprofitable. The energy efficiency ratio is 1.34-2.14, the agroecosystem productivity indicator is 0.040-0.127 MJ/dn/GJ. The highest return on energy costs (2.14) is noted in the rotation of rape – wheat – barley – soy – oat.

When optimizing the arable land, it is necessary to take into account that the crop formation occurs due to the natural fertility of the soil, as evidenced by the negative balance of humus, which changes by 0.18-0.78 t/ha. Increasing the intensity of land use in alternating-fruit alternation, the crop is formed against the background of the reproduction of soil organic matter by increasing plant residues from...
fertilizer use, the humus balance was positive, demonstrating 0.15-0.28 t/ha.

5. Conclusion
The introduction of a condition that does not allow a negative balance of humus turns off the possibility of using N\textsubscript{30}P\textsubscript{30} + straw, grain-pair crop rotations, where wheat crops are repeated, as they are accompanied by significant losses of humus. Reproduction of soil fertility with a maximum yield of 2.11-2.06 t/ha of food grain is possible with the following structure of sown areas: soybean and rapeseed for seed oil (25-40%) with grain (60-75%). At the same time, the profitability of the production of marketable grain amounted to more than 90%.

Thus, the commodity producer can choose various variants of the structure of sown areas, for example, reducing the share of pure steam to 14.3% and wheat to 43.2%, increasing the share of winter rye and industrial crops (rape, soybean) to 21.3%. This will allow to get 2.15 t/ha of food grain. By increasing the area in crop rotations using straw and colza as a siderate as an organic fertilizer, we can achieve the reproduction of soil fertility with a certain decrease in the yield of marketable grain to 2 t/ha.

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