Prediction method of the variants of annual field work complexes and its implementation

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Abstract. The prediction method of the variants of annual field work complexes provides justification for machine and tractor fleet structure. It gives a graphical view of the load of power machines, evaluation and selection of mechanization equipment for a particular job or complex of works, taking into account the condition that the cost of equipment should be covered by a decreased number of employed operators and harvest losses. The authors propose an algorithm for the implementation of this method, which has led to the creation of a program Agro. A simulation is carried out using the example of a model agricultural organization. The authors confirm the inverse relationship between increasing the power capacity of tractors and the need for machinery.

1. Introduction

In Russia, in the context of digitalization of Federal and regional registers of technologies and technical means for comprehensive mechanization of agricultural production, it is possible to justify the technologies and machinery for crop production. It is possible to work with the simplest technologies, having an inexpensive machine and tractor fleet (MTF) and producing low production cost grain, but then you will need more machine operators and at the same time there will be the lowest level of productivity. Power saturated machinery will require financial expenses, but it will double or triple productivity. Every agricultural producer chooses technologies and machinery for crop production, depending on the resources and the available number of machine operators. This can be done with the help of advanced tools which will help to automate the formation of annual complexes of field works. In this regard it has become relevant to develop methods which will help to choose technology and structure of machine and tractor fleet for different types of producers depending on the level of their resource supply and specific soil and climatic conditions. Thus, the task is reduced to economic and mathematical task.

In Russia V A Bulavsky and L V Kantorovich (1962) were the first to propose a method of linear programming for this purpose.

Its implementation in crop production was described by Y K Kirtbaya (1981), R S Kabatova (1969) In China, for example, Z Qingzhen, W Changyu, Z Zhimin, Z Yunxiang, W Chuanjiang used the method of linear programming in the optimization of agricultural production. They got four models, each had 3000 variables and 100 restrictions, 3 million units of data were used [1]. H T Sogaard, and C. G. Sorensen worked on the optimization of machine and tractor fleet. They noted that labor and equipment
costs are the highest [2]. Scientists I M Hassan, I M N G Sami, A A O Mohamed, M A Omran created a program to evaluate field efficiency, equipment efficiency and choose the optimal composition of the equipment [3]. R S Parmar, R W McClendon, W D Potter developed a simulation model to optimize peanut farm machinery selection in order to maximize profit and proposed a genetic algorithm to provide an optimal solution [4]. V Lenski, E M Ivanov, E Kazhdan suggests supplementing the algorithm for optimization of machine and tractor fleet with scheduling of field work [5, 6].

Thus, depending on the task faced by an agricultural producer, it is necessary to choose tools for strategic management of an agricultural organization. We agree with H T Sogaard, and C G Sorensen’s opinion. In current Russian economic conditions the system of machines and the system of labor have become the most important systems, requiring the highest financial costs. So we suggest a prediction method of the variants of annual field work complexes as a tool for strategic management.

2. Materials and methods
It is possible to calculate equipment needed for agricultural production technologies only by using a systematic approach; analysis of complex systems – systems of machines and technologies; economic and energy evaluation. These calculations are a part of the task of optimal planning of field work. The proposed prediction method of the variants of annual field work complexes is an economic and mathematical method based on graphical display of annual complexes of work and the use of power machines in them.

2.1. Prediction method of the variants of annual field work complexes
The algorithm of the prediction method of the variants of annual field work complexes can be represented by the following blocks.

BLOCK 0. Preparation of initial information on the farm, on agricultural machinery and technology of cultivation and harvesting of crops, on performance and efficiency of machinery

BLOCK 1. Annual field work complexes are formed in the following way. A schedule of all field works performed by tractors of general purpose, beginning with class 3 tractor, then 5 and 8 is created.

BLOCK 2. Calculation of the minimum hourly output. Choosing high-performance machine-tractor aggregates with a power machine $i$ of the highest efficiency for developing a basic plan makes it possible to determine the minimum time necessary to perform the annual set of works $L$.

BLOCK 3. Formation of complexes of machinery for performance of annual complexes of works. A complex of machinery consists of the power machine $i$ with a train of agricultural machines necessary to perform the annual complex of works $j$. The proposed method consists in performing annual complexes of works with a machine-tractor aggregate with a new make of power machine of lower capacity within the set time limit. It is necessary to choose interchangeable power machines and to form a train of agricultural machines suited to perform the complex of works.

BLOCK 4. Calculation of the output in conditional reference hectares. At this stage the output during performance of annual complexes of work $L$ of the basic plan with a set time is calculated.

BLOCK 5. Determination of operating costs for annual complexes of works (the method of operating costs calculation is used [7]).

BLOCK 6. Calculation of operating costs for 1 conditional reference hectare (c.ref.ha). The calculation of operating costs per unit of work performed is carried out for each annual complex.

BLOCK 7. Quality control of annual work complexes. If for the given group of power machines of make $i \neq L$, one must move to the next annual complex of works and continue calculations starting with block 3. If $i=L$, all annual complexes of works are looked through and one can pass to the next group of power machines of make $L+1$ through block 8.

BLOCK 8. Control of restrictions on the number of groups of power machines. If $i \neq L$, the calculations are not fully carried out for all groups of power machines of make $i$ and they should be continued starting from block 3. If $i=L$, then all the given groups of power machines $i$ for the basic plan are looked through and it is possible to proceed to the next block 9.

BLOCK 9. Optimization of the choice machinery complex. The choice of complexes of machinery
$X_0$ for the performance of a set annual complex of works $l$ is considered optimal when the operating costs per unit work performed are minimal. Complexes of machinery, the use of which gives the smallest value of these costs, eventually, help to minimize the operating cost of the whole machine and tractor fleet during the year. If during a complex of works performed by different power machines equal operating costs per unit of work are obtained the optimal plan includes the complex of machinery with the power machine of the highest efficiency.

BLOCK 10. Control of restrictions on the volume of work. The volume of the annual complex of works is considered unfulfilled, if for

$$P_{l_{\text{max}}} - P_{l_{\text{min}}} = \Delta P_i$$

under the condition

$$\Delta P_i > \varepsilon,$$

where $P_{l_{\text{max}}}$ – output of the most efficient power machine, c. ref. ha; $P_{l_{\text{min}}}$ – output of the power machine included in the optimal plan, c. ref. ha.

2.2. Implementation of modeling

The principle of annual field work planning is as follows: The basic plan of field work for general purpose tractors for one year is made. Then a tractor, for example, of class 3 begins to work. From the total amount of field work for each technological operation the first tractor does the volume of work equal to the productivity of a machine-tractor aggregate (MTA) with this tractor. Thus, we get the first annual complex of field works. Similarly, the second tractor will carry out the second annual complex of field work. The new annual complex of field works corresponds to the full implementation of the entire scope of field work. Then other tractors of class 5 and 8 will perform their annual complexes of field work depending on the efficiency of MTA during these agricultural operations. For each technology and corresponding machine and tractor fleet economic indicators are calculated. For general purpose tractors its own basic plan of annual field works is made. The formation of annual complexes of field work is carried out following the same method. An example of the formation of annual complexes of field work is shown in Figure 1.

![Figure 1. Distribution of annual load for K-744P1, extensive technology.](image-url)
The vertical line sets volumes of work, ha. On the horizontal line the time periods of field work are set, days. The agricultural year is divided into time periods. Set the duration of each period. For \( D_t = 5 \) days, \( t = 1, 2, \ldots, T \), then \( T = 72 \). For each period it is possible to determine the reserve of working time in hours for one power machine of this make. The reserve of working time is the maximum possible value of hour loading for one power machine during this period. On the chart on the ordinate axis postponed the volume of work, ha. on the abscissa time periods of field work, days.

Previously, annual field work complexes were estimated by operating costs per one conditional reference hectare. However after improving the method of choosing alternative options for resource-saving technologies of crop production [2, 7] an additional indicator was introduced. This indicator is the need for machine operators for 1 hectare of the field.

The following composition of machine and tractor fleet was justified for traditional intensive technology based on moldboard plowing for a model farm in the forest-steppe zone with the structure of sown areas: arable land – 11600 hectares, grains – 5906, annual grasses – 1751, perennial grasses – 2268, fallow lands – 1735 hectares. The results are shown in Table 1.

| Indicators                     | Make of tractor |
|-------------------------------|-----------------|
| The cost of MTF, million rubles | K-744P1         | MTZ-1822.3 | DT-75M |
| Operating cost, million rubles | 102.36          | 72.85      | 67.98  |
| The need for tractor drivers, people | 14              | 17         | 26     |

The transition to resource-saving technologies with minimal tillage can reduce the need for tractors by 1.7-2.5 times (Table 2).

| Indicators                     | Make of tractor |
|-------------------------------|-----------------|
| The cost of MTF, million rubles | K-744P1         | MTZ-1822.3 | John Deere 9430 |
| Operating cost, million rubles | 65.73           | 61.84      | 61.26  |
| The need for tractor drivers, people | 16.99          | 13.151     | 25.67  |

The basic principles of optimization of the machine and tractor fleet, work scheduling and the construction of an effective system of machines for crop production are presented in a number of publications [5, 8-12].

3. Conclusion

Thus, the authors propose introducing an additional indicator – the need for machine operators per 1 hectare of land into the method for choosing alternative technologies for the production of agricultural crops. Following the principle of necessity and sufficiency, technologies should be chosen taking into account the indicators of productivity, production cost of a unit of production and the need for machine operators. The advantages of resource saving technologies on the basis of the minimum processing of the soil is obvious. The transition to resource-saving technologies can reduce the cost of machinery and tractor fleet by 1.5 times for class 5 tractors.

The need for machine operators for the production of grain in Siberia can be reduced by the following techniques:
- by using more power-saturated equipment;
by transition to resource-saving technologies based on minimum and zero tillage;
by organizational and technological measures.

The comparison of cultivation technologies of different crop producers with different resources have shown:
- if a producer can afford only seed treatment (100 rubles per hectare of crops of grain) and has 3.5 – 4.0 people per 1 thousand hectares of grain, they should apply extensive technology.
- if a producer can afford fertilizers and plant protection from weeds and diseases for the sum not less than 5 thousand rubles per hectare and machine operators from 2.4-3.0 people per 1 thousand hectares, they can work on normal technology.
- if a producer can afford fertilizers and chemicals in quantity no less than 10 thousand rubles per ha, and machine operators 2.4 - 3.0 people per thousand hectares, they can work using intensive technologies based on moldboard plowing or deep cultivation.

If they have means no less than 10 thousand rubles per hectare and the quantity of machine operators 2.1-1.7 people per 1 thousand hectares, they have to switch to resource-saving technologies on the basis of minimum or zero tillage.

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