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Optimization of Parameters of a Multifunctional Unit Based on a Spring Harrow

Gennady Maslov, Valery Lavrentiev, Valery Tsybulevsky, Elena Yudina, Vasily Tkachenko

Abstract*: *The article proposes a mathematical model and an algorithm for optimizing the parameters developed by the authors of a multifunctional tillage unit based on a spring harrow with simultaneous application of solid mineral fertilizers. Using the optimization criterion, the minimum reduced costs for the implementation of the technological process of soil harrowing with the introduction of mineral fertilizers by the proposed multifunctional unit, its parameters and operation mode are substantiated. The principal distinguishing features of the working body of the spring harrow are described in accordance with the RF patent for utility model.

Keywords: multifunctional unit, modeling, optimization, spring harrow.

I. INTRODUCTION

An important reserve for increasing the competitiveness of crop production is the use of multifunctional machine aggregates (MMA) in the mechanization of production processes. Such units are already widely used in our country [1, 2, 3] and abroad [4, 5, 6]. Their goal is to increase labor productivity and reduce costs by combining technological operations in one pass of the unit across the field. The solution to these problems for agriculture is always relevant [7, 8, 9]. Based on the studies performed, this article substantiates the optimal parameters and operation mode of the proposed MMA according to the optimization criterion of the minimum reduced costs for the soil harrowing process with the simultaneous application of solid mineral fertilizers.

II. MATERIAL AND METHODS

Modern methods of mathematical modeling and optimal design of complex production processes are widely used in science for technical and organizational support of crop production with the lowest cost of relevant resources [10-13]. Under the technical support understand the rationale for the appropriate operating conditions (soil type, headland, terrain, etc.) of the optimal parameters and operating modes of both simple machine-tractor units and multifunctional in our case. As a criterion of optimization, when modeling our proposed aggregate, we took the minimum of reduced costs Cpr for the soil harrowing process with the simultaneous application of mineral fertilizers:

$$C_{pr} = (U_E + 0{,}15K) \rightarrow \min \qquad (1)$$

where C_{pr} – optimization criterion minimum reduced costs, rub / ha;

U_E - operating costs for the operation of the unit, rub / ha;

К - capital investment for work, rub / ha;

0,15 - empirical coefficient.

The object of research - proposed MMA (Fig. 1) includes a tractor 1 with a hopper 2 mounted on it for applying mineral fertilizers and a spring harrow 5 on the rear.

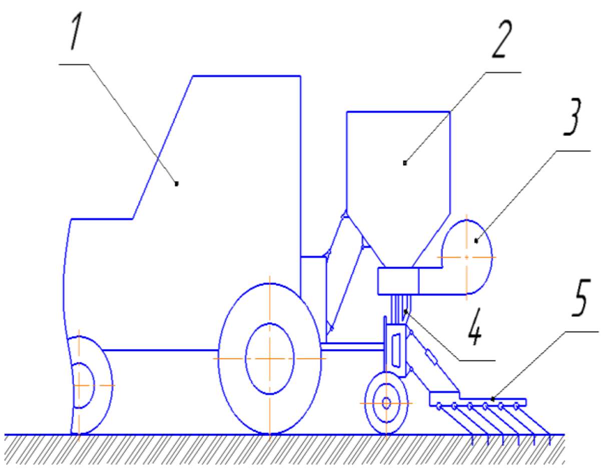

Fig. 1. General view of the proposed multifunctional unit:

1 - tractor; 2 - fertilizer hopper; 3 - fan; 4 - dispenser; 5 - spring harrow.

As a result of solving the problem, it is necessary to determine the following unit parameters: tractor engine power – N_e, hopper capacity V_b for fertilizers, the width of the harrow V_p, the working speed V_p of the unit, the length of the head L_p, the utilization factor of the working time τ of the unit, its productivity W per 1 hour of shift time, specific operating U_e and reduced costs. With a minimum value of C_{pr}, the values of all other parameters will be determined.

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* Correspondence Author

Gennady Maslov *, department of operation machine and tractor park, Kuban State Agrarian University named after I.T. Trubilin, Krasnodar, Russia. Email: eksp-mtp@kubsau.ru

Valery Lavrentiev, Kuban State Agrarian University named after I.T. Trubilin, Krasnodar, Russia. Email: eksp-mtp@kubsau.ru

Valery Tsybulevsky, department of tractors, cars and technical mechanics, Kuban State Agrarian University named after I.T. Trubilin. Email: eksp-mtp@kubsau.ru

Elena Yudina, department of operation machine and tractor park, Kuban State Agrarian University named after I.T. Trubilin, Krasnodar, Russia. Email: eksp-mtp@kubsau.ru

Vasily Tkachenko, department of operation machine and tractor park, Kuban State Agrarian University named after I.T. Trubilin, Krasnodar, Russia. Email: eksp-mtp@kubsau.ru

Figure 2 shows a block diagram of an algorithm for optimizing the parameters of the proposed MMA for harrowing the soil with fertilizer. The method for constructing the flowchart was adopted from the experience of our earlier publications [7, 8].

10 operators are included in the flowchart (Fig. 2): 2-8 - arithmetic, 9_{th} - logical, 1_{st} - input of initial data, 10_{th} - printing of the results of solving the problem. All decoding of parameter symbols in fig. 2. Besides: C_B^T - carrying value of the tractor, thousand rubles; C_{M_o} - coefficient of resistivity of the proposed unit at a working speed of 4 km / h, kN / m

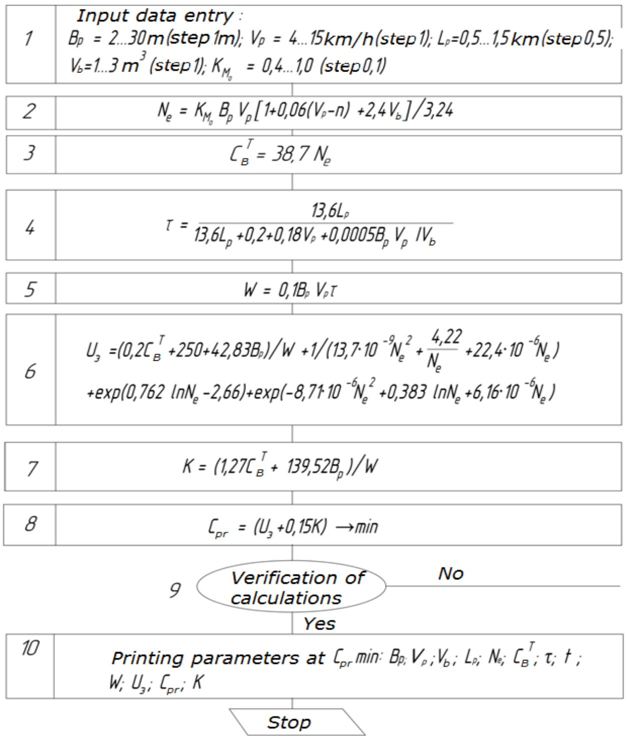

Fig. 2. Block diagram of the algorithm for optimizing the parameters of MMA for harrowing the soil with simultaneous application of fertilizers

To solve the problem, a special computer program has been developed.

III. RESULTS AND DISCUSSION

As a result of solving the problem, the optimal MMA parameters and its operation mode were obtained (Table 1).

Table – I: Optimal parameters and operation mode of MMA

Name of parameters	Value
Tractor engine power N_e, kw	145,8
Tractor book value C_B^T, thousand roubles	5640,7
Implement coverage B_p, m	26
Fertilizer hopper capacity V_b, m^3	1,0
Working speed V_p of movement, km / h	12
Soil resistivity coefficient at V_p = 4 km / h, kN / m	0,4
Productivity MMA W, ha / h	25
Coefficient of use of shift time τ	0,8
Cycle time during operation of MMA t_s, h	0,54
The number of cycles per shift n_c, m	12
Optimum headland L_p, km	1,5
Specific operating costs for the work of MMA U_e, rub / ha	183,1
Specific reduced costs C_{pr}, rub / ha	247,8
Specific capital investment K, rub / ha	430,9

The optimal parameters of MMA were obtained with the minimum value of the optimization criterion - the minimum of specific reduced costs C_{pr}. MMA is characterized by a high productivity of 25 ha / h, at which it not only carries out soil harrowing, but also introduces mineral fertilizers. Our improvement in the design of the spring harrow consists in changing the design of the tooth in order to reduce traction resistance and improve the quality of crumbling soil. The optimal operating mode of the MMA is ensured at an operating speed of 12 km / h. The proposed unit according to our calculations provides high efficiency. It can take a leading place in the development of intensive and high technologies for the production of crop production, ensuring the achievement of highly efficient indicators and serve as the basis for the technologicalization of the industry. But he must work in the soil cultivation system in order to create a homogeneous, powerful, well-cultivated root layer, providing the necessary conditions for the development of plants and obtaining high, sustainable yields [14].

In the developed block diagram of the algorithm for optimizing the MMA parameters, the sixth arithmetic operator calculates the operating costs (U_e) for performing the work. These costs include depreciation, deductions for repairs, salaries, fuel and lubricants (TCM) and others. In the formula for calculating U_e (block 6), we deduced the dependences of the specific fuel consumption (kg / h) on the operation of the aggregate G_r (Fig. 3), on the idle passages of the aggregate G_x (Fig. 4) and on stops with the engine running G_o during the shift (Fig. 5).

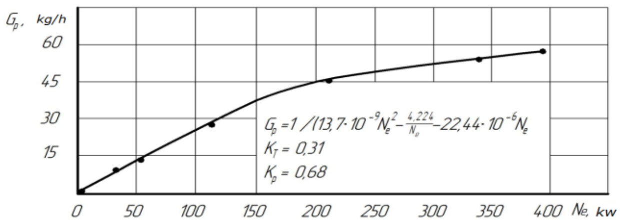

Fig. 3. Dependence of G_r on N_e for MMA

We also obtained by the method of analysis of the shift time the dependence of the shift time utilization factor τ (block 4):

$$\tau = \frac{13,6L_p}{\left(13,6L_p + 0,2 + 0,18V_p + 0,008B_p\frac{V_p}{V_b}\right)} \quad (2)$$

Depending on τ (2), all the operating conditions of the MMA were taken into account: the rut length L_p, the capacity of the fertilizer hopper V_b, the implement working width Bp, and the operating speed V_r. Also, the dependences of τ and unit productivity on operating conditions L_p, B_p, V_b and operating mode V_p were constructed.

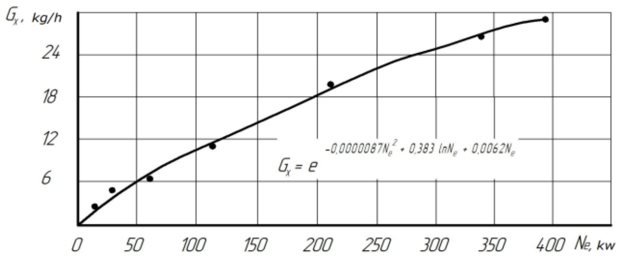

Fig. 4. Dependence of G_x on N_e for MMA

The specific fuel consumption components in kg / h (Fig. 3-5) depend on the engine power N_e. The adequacy of the dependencies is confirmed by the Cochren criterion: its calculated value for all the curves is less than the tabular one.

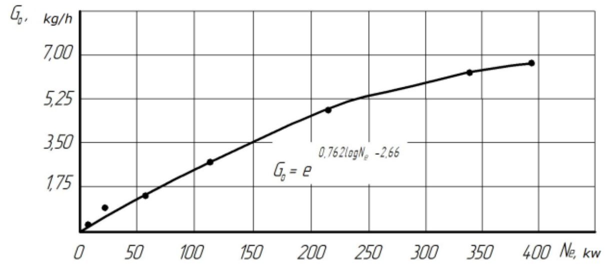

Fig. 5. Dependence of G_o on N_e for MMA

The dependence of the optimization criterion - reduced costs C_{pr} (Fig. 6) on the MMA working width and speed of movement shows a significant advantage of the optimal unit variant with a working width of 26 m. Thus, for an aggregate with a width of 26 m and a speed of 12 km / h, the minimum value of the reduced costs amounted to 247.8 rubles / ha.

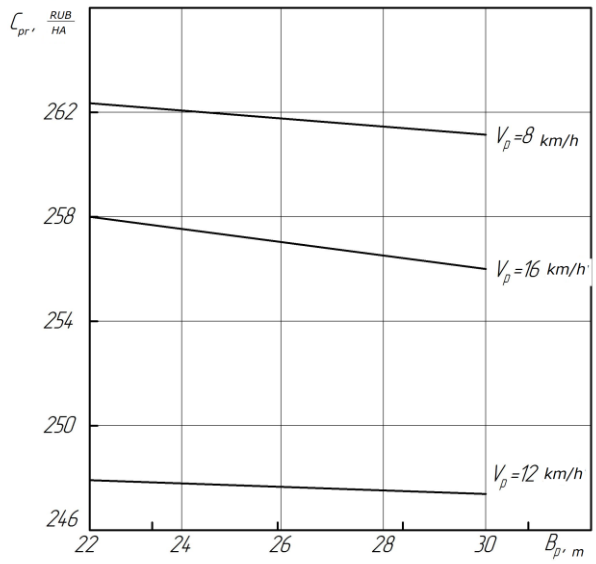

Fig. 6. The dependence of the reduced costs C_{pr} on the width of the MMA and the speed V_p

With a working width of 26 m and a speed of 16 km / h, they increased to 257 rubles, and with the same working width and speed of 8 km / h, the unit reduced costs increased 1.1 times.

Thus, the proposed unit provides significant efficiency, reducing unit operating costs by 10 percent.

IV. CONCLUSION

Based on the developed mathematical model and the flowchart of the optimization algorithm, the optimal parameters and the operating mode of the multifunctional machine unit for harrowing the soil (crops) with the simultaneous application of mineral fertilizers are substantiated. The tractor engine power was 145.8 kW, the implement's working width was 26 m, the working speed was 12 km / h, the productivity per 1 hour of shift time was 25 ha / h with a coefficient of utilization of the working time of change of 0.8 and the optimal hopper capacity for fertilizers was 1 m^3. The minimum value of the criterion for optimization of the model at the reduced costs for the work of the unit did not exceed 248 rubles / ha. The dependences of the components of the fuel consumption obtained by the tractor engine obtained by the approximation method (for running, idle and at a stop) can be used to optimize other types of units.

The proposed multifunctional unit, combining two technological operations (harrowing with the application of mineral fertilizers) in one pass across the field, releases one tractor with a machine for making solid mineral fertilizers.

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AUTHORS PROFILE

Gennady Maslov, doctor of technical sciences, professor, department of operation machine and tractor park, Kuban State Agrarian University named after I.T. Trubilin.

Valery Lawrence, graduate student in the scientific specialty 35.06.04 - technology, means of mechanization and power equipment in agriculture, forestry and fisheries, Kuban State Agrarian University named after I.T. Trubilin.

Valery Tsybulevsky, candidate of technical sciences, associate professor of the department of tractors, cars and technical mechanics, Kuban State Agrarian University named after I.T. Trubilin.

Elena Yudina, candidate of technical sciences, associate professor, department of operation machine and tractor park, Kuban State Agrarian University named after I.T. Trubilin.

Vasily Tkachenko, candidate of technical sciences, associate professor of the department of operation machine and tractor park, Kuban State Agrarian University named after I.T. Trubilin.

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