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USING SERVICE SIMULATING TEST IN DESIGNING OF TILLAGE COMBINE

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Determining the optimal structure of the tillage combine for working in a particular company is a very difficult task due to many factors. While searching for the optimal choice, it is necessary to strive for having fewer combines in operation, reduce the fuel costs and compensate damages due to changes in agrotechnical terms and soil compaction during the combines' operation. In this article it is proposed to apply the Monte Carlo simulation for solving this issue. As a result of the analysis of models, it was observed that all combines can be divided into separate efficiency groups and form certain tillage complexes. After the analysis of these complexes, it was proposed to replace the tillage tools, which led to further reduction in total costs. So the transition to non-mouldboard technology in both high-efficiency and low-efficiency combines will lead to cost savings by 45%, and the introduction of new tools will reduce the fuel consumption by 61–64%. For high-efficiency machine complexes, non-mouldboard technology allows the reduction of the optimal number of aggregates by 25–32%. At the same time, the introduction of new tillage combines will reduce the number of operating combines by 50–58% due to reduced resistance and the combination of technological operations.

Keywords: Monte Carlo simulation; tillage combine; productivity; specific fuel consumption

The process of cultivation of soil refers to high-cost operations related to cereal cropping in agricultural production. The key indicators of the efficiency of a tillage combine include productivity and specific fuel consumption, which, in turn, depend on the complexity of work, the depth of processing and structure of the combine – the type of tractor and plough (FGNU Rosinformagrotekh, 2001; Rykov et al., 2013; Ranjbarian et al., 2017). The choice of the most optimal tillage combine structure for working in a particular enterprise is practically impossible due to many deterministic and random factors (Oskin, 2011; Galamboš et al., 2017). Usually, the low fuel consumption is taken as a key criterion (Karparvarfard and Rahmanian-Koushkaki, 2015; Moitzi et al., 2014), which may not be the best option since there is a high probability of obtaining a low-efficiency combine. The combine productivity influences the number of combines withdrawn from the field because there are certain normative agrotechnical terms for the execution of individual operations. Excessive deviation in agrotechnical terms leads to a decrease in the yield of cultivated crops (Kambulov et al., 2013). It should also be taken into account that when combines move along the field, the soil becomes compacted and the degree of such compaction depends on the type of tractor and the number of passes it made. Moreover, the number of passes depends on the utilised cultivation technology and on the type of soil-cultivating tools. It is necessary to search for new methods for optimising the structure of soil cultivating tools, on the basis of which it is possible to develop algorithms for developing of software products (Obour et al., 2017; Kvíz et al., 2014). This is especially vital for introduction of precision agriculture technology. The purpose of this paper is to design a statistical method of optimisation of soil-cultivating units and providing of recommendations on choosing the most appropriate options.

Material and methods

The characteristics of tillage tools, including towing combine, are well systematised in the collection (FGNU Rosinformagrotekh, 2001; Rykov et al., 2013; Bulgakov et al., 2017), in which the authors present regulations for all agricultural machinery produced in Russia and other countries, as well as the norms and standards for the work carried out by agricultural machinery produced by foreign companies. The norms related to the generation and fuel consumption for the main types of mechanised field and tractor-transport operations performed by machine-technological stations (MTS) are specified in this collection. Regarding the mechanised field works, they are differentiated according to the classes of main indicators of technological characteristics of the land (length of a rut, slope angle, obstruction, complexity of configuration, resistance of soil-cultivating machinery); requirements for field and transport operations (depth of soil cultivation, seeding rates, application of fertilisers, consumption of pesticides, yield); and machine and tractor combines (brand and number of combines, width of tension grip). The proposed production rates (productivity of mechanised combine per shift) are resulting from the working width of tension grip, working speed and net time of working.

Thus, the main indicators of the combine efficiency are two characteristics – the rate of production (productivity)

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and fuel consumption, which, in turn, depend on the complexity of work, the depth of processing and the combine structure (type of tractor and plough). As it was mentioned above, selection of an optimal combination of working machines is not an easy task due to the influence of different deterministic factors. Taking into account a criterion of the minimal fuel consumption might not be the best option because there is a high probability of obtaining combine with low efficiency (Tarasenko, 2012). Due to this fact, it is necessary to obtain an objective function with two optimisation criteria: fuel consumption and production rate (productivity). The productivity of combines affects the total number of operating combines during field work since there are certain regulatory agrotechnical terms. Agrotechnical terms are characteristic for all types of work and depend on the culture, previous culture and area of field work. The violation of these agrotechnical terms leads to a decrease in the yield of cultivated crops. The collection (Rykov et al., 2013; FGNU Rosinformagrotekh, 2001) includes the indices of the intensity of crop losses arising from the deviation of agrotechnical terms. The higher quantity of operating combines, the shorter terms are necessary for the work to be finished. It should also be noted that crop production costs include fuel costs (Akbarnia et al., 2013). As a rule, fuel is purchased in advance, and economy is compensated for energy costs after harvest. If soil cultivation is performed by means of low-productivity combines, there will be yield loss and consequently, a shortage of financial resources that could be used to compensate for energy costs. If the company does not have significant means to adjust the park for high-performance soil cultivation, and it has restrictions on the number of tractors and agricultural tools, and it is ready to go for a decrease in yield due to the violation of agrotechnical terms, the maximal permissible amount of damage that the company can afford will be equal to the cost of fuel (Akbarnia et al., 2013). This company must search for other sources of fuel cost compensation or will not receive a part of the profit from the sale of the crop (Rykov et al., 2013; Oskin and Tarasenko, 2013b; Oskin, 2011; Pakhomov et al., 2015). In search for the optimal structure of tillage combines, it is necessary to strive for having fewer combines in operation and to have minimal costs; this can be represented by the following formula (Oskin, 2013a):

$$\begin{cases} F = C_{fuel} - D_{total} \Rightarrow 0 \\ C_{fuel} + D_{total} \Rightarrow \min \end{cases} \tag{1}$$

Or, in case of soil cultivation:

$$\begin{cases} F = C_{fuel} \cdot (a_n \cdot d + b_n \cdot P_r + c_n \cdot G_c) - c_y \cdot C_f \cdot \left[k_u \cdot \left(\dfrac{S_P}{P_r \cdot N_a} - n_d \right) + \Delta\rho_{fact} \cdot k_{cy} \right] \Rightarrow 0 \\ C_{fuel} \cdot (a_n \cdot d + b_n \cdot P_r + c_n \cdot G_c) + c_y \cdot C_f \cdot \left[k_u \cdot \left(\dfrac{S_P}{P_r \cdot N_a} - n_d \right) + \Delta\rho_{fact} \cdot k_{cy} \right] \Rightarrow \min \end{cases} \tag{2}$$

where:

C_{fuel} – expenses for GSM (GSM – fuel and lubricants)
D_{total} – general damage resulting from the deviation of agrotechnical terms and soil compaction during the passing of combines
H – tilling depth
P_r – shift rate of production
G_c – group of work complexity
a_n, b_n, c_n – coefficient of approximation
c_y – crop yield
C_f – unit price of fuel
c_y – cropping capacity
C_κ – sale price of certain grain
k_u – coefficient of intensity of crop losses in case of deviation of agrotechnical terms (FGNU Rosinformagrotekh, 2001)
S_P – tillable acreage
N_a – number of operating combines
n_d – standard number of days or shifts for tillage
$\Delta\rho_{fact}$ – actual increase in soil density
k_{cy} – coefficient of yield reduction taking into account the soil compaction, ranging from 0.08 to 0.1, applied as mean value of 0.09

The complexity of further research on the objective function is caused by a large number of input parameters, which change randomly due to objective and subjective reasons. The best way for further analysis of the objective function would be performed by means of service simulating test. Usually, a simulated model is a program that allows the simulation of behaviour of a real system under different conditions, implemented on a PC. Simulated models represent the most flexible method for modelling of systems of any complexity, linear and nonlinear, with back coupling and control networks. Stochastic and automatic methods of mathematical description are often used to construct simulated models. Stochastic models investigate the complex behaviour of random variables and use the formulas of accepted distribution laws for calculations. The objects of customisation in such models are distribution parameters – average, dispersions, the amount of sampling. Simulation modelling was performed using the Monte-Carlo simulation method, which makes it possible to construct a mathematical model with an indefinite meaning of parameter. Being aware of their probabilistic distributions as well as the relationship between parameter changes (correlation), it is possible to obtain the probabilistic meaning of the desired parameter. The magnitudes of the variables (range, mean, standard deviation) were adopted depending on the combine structure, statistical data related to yield in a particular region and dominant market prices for fuel and grain.

Results and discussion

The implementation of Monte Carlo simulation was carried out using a special customisation in Excel. The add-in MS Excel "Simulation Monte Carlo" (Monte-Carlo 6.xla) is implementing the collection and processing of information in an Excel workbook in statistical modelling using the Monte Carlo method. The results are presented in numerical and graphical form. Calculations were conducted on the square of tilled area of 1,000 hectares. Eleven variable parameters were varied in modelling. For each combine, modelling was carried out for three standard agrotechnical terms (5; 10; 15 days) and for a variety of agrophones. The

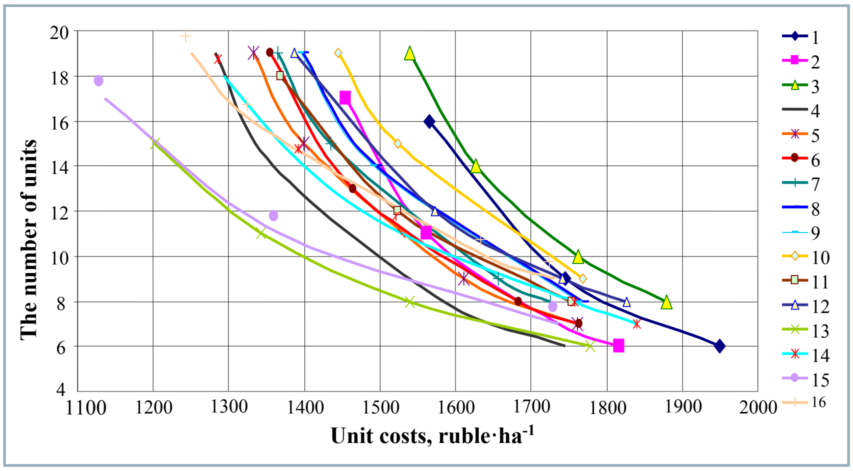

Fig. 1 The dependency diagrams of combines on the costs for each group

dependency diagrams of the number of combines on the costs for each group are plotted (Fig. 1). Each group includes a traction combine (tractor) in a certain combination with tiller. There were 16 such groups. The closer the diagram to the bottom of grid, the more efficient the group is. As a monetary unit, the Russian ruble was adopted.

Table 1 is based on the standard number of days for soil cultivation and combine structure and provides data on the number of combines and the actual number of days required for tillage with a total damage of 1,750 rubles·ha^{-1}. For example, for the first group (K701 + PTC9-35), for the standard of tillage equal to 5 days, it is necessary to have 9 combines, and tillage will take 10 days; for the standard of 10 days, 6 combines are necessary and tillage will take 15 days, for 15 days – 5 combines and 18 days. The data indicate that the more efficient the combines are, the fewer of them are necessary; the delay in standard duration of tillage will not result in significant damage in such a case (Oskin, 2013a; Oskin and Tarasenko, 2014).

Table 1 Summary data of the number of combines and the required number of days for tillage

Group of the structure of combines, Aggregate structure	Number of aggregates / actual number of days for tillage		
	Standard number of days		
	5	10	15
1; K701+PTK9-35	9/10	6/15	5/18
2; K700+ PGP7-40	7/12	5/17	4/21
3; K700+ PP8-35	10/12	7/17	6/19
4; ITr-220+ IP1-4	6/17	5/20	4/25
5; ITr-180+ IP1-4	7/17	6/20	5/24
6; ITr-180+ IP1-6	7/16	6/19	5/22
7; T-150K + PLN6-35	8/16	6/21	5/25
8; T-150K +PLN5-35	8/16	6/21	5/25
9; T-150K + PN4-40	8/16	6/21	5/25
10; T-150K + PLN4-35	9/16	7/20	5/25
11; MTZ-1221 + IP1-6	8/17	6/23	5/28
12; MTZ-1221 + PN4-35	9/17	7/25	6/25
13; T4-A + PN6-35	6/24	5/29	4/36
14; T4-A + PN4-35	8/21	7/22	6/28
15; DT-75M (Agromash 90TG)+ PN6-35	7/25	6/30	5/36
16; DT-75M (Agromash 90TG)+ PN4-35	9/23	8/26	6/34

On the basis of efficiency, all units can be divided into 4 groups (Table 2). The first group – combines of high efficiency (costs per unit 1136–1342 rubles·ha^{-1}): tractors T4-A, DT-75M, "Agromash-90TG" with ploughs PN6-35; the second group – combines of moderately high efficiency (costs per unit 1358–1465 rubles·ha^{-1}): tractors John Deere, New Holland, Denz-Far with four-furrow ploughs John Deere, as well as with six-furrow ploughs "Kivon" and "Lemken" mod. 160-6 as well as the tractors T4-A, T-150K with ploughs PN4-35 and PLN6-35; the third group – combines of moderate efficiency (costs per units 1492–1529 rubles·ha^{-1}): tractors T-150K with ploughs PLN6-35, PLN5-35, PN4-40, and "Kivon" and "Lemken"; the fourth group – combines of low efficiency (costs per unit 1562–1745 rubles·ha^{-1}): tractors K701 with ploughs PTK9-35, PGP7-40, PP8-35 and tractor T-150K with ploughs PLN4-35, as well as tractors MTZ-1221 with ploughs PN 4–35.

The efficiency of changing the tiller on one tractor was evaluated during tillage, which made it possible to conclude the following: for the K-700 tractor, the most effective is the PGP-7-40 type and working with it, the costs are lower by 22% on average in comparison to PTC9-35 and by 32% in comparison to PP8-35. For T-150K, the replacement of the plough of type PLN6-35 does not have significant impact on efficiency – the costs are lower only by 3% in comparison to PLN5-35 and PN4-40, and by 9% in comparison to PLN4-35. For the tractor models T4-A and DT-75M, the change of plough PN6-35 to PN4-35 leads to the reduction in costs by 16%.

Therefore, it can be stated that the type of tool affects the efficiency of combine, but not in all types of tractors. The efficiency of combines while changing the tractor type working with the same tiller is also calculated. The results show a low dependence of efficiency on the replacement of towing combine – up to 10%. The modelling of other agrophones (2 old

Table 2 Structure of combines' depending on efficiency in traditional tillage

The most effective variant		The least effective variant	
Tillage			
Group	Structure	**Group**	Structure
13	T4-A+ PN6-35	**1**	K701+ PTK9-35
15	DT-75M (Agromash 90TG) + PN6-35	**3**	K700 + PP8-35
16	DT-75M (Agromash 90TG) + PN4-35)	**12**	MTZ-1221 + PN4-35
Dragging			
	T-150 + (DZSSorBZTS)		K-701 + (DZSSorBZTS)
	T-4A + (DZSSorBZTS)		K-700 + (DZSSorBZTS)
	DT75M + (DZSSorBZTS)		
Disking 1st agrophone			
6	T-150 + BD-10	**2**	K-701 + BDT-7
11	T-4A, T-4M +BD-10	**4**	K-700, K-700A + BDT-7
		10	MTZ-1221+IDb-6
Disking 2nd agrophone			
7	T-150 + (LDG-15, BD-10, BDT-7)	5	ITr-180 + IDb-6
9	T-4A, T-4M + (LDG-15, BD-10, BDT-10; BDT-7)	8	MTZ-1221 + (BD-10, BDT-7, IDb-6)
10	DT-75M + (LDG-10, BDT-3)		
Tilling			
1	K-701 + KSHU-18-1, K-700 + KSHU-18-1	6	ITr-180 + IKp-4
2	K-701 + KSP-4-4, K-700 + KSP-4-4	11	MTZ-1221 + IKp-6.
12	T-4A, T-4M +KSP-4-4	16	MTZ-80, MTZ-82 + IKp-6
		17	MTZ-80, MTZ-82 + KPS-4-1
Tilling with dragging			
1	K-701 + KSHU-18-1, K-700 + KSHU-18-1	11	MTZ-1221 + IKp-6
2	K-701 + KSP-4-4, K-700 + KSP-4-4	15	DT-75M + KSHU-8-1, KSP-4-2
Compacting			
6	DT-75M+ 3KK-6	8	DT-75M + 3KVB-1,5
7	DT-75M+ KKN-2,8	9	DT-75M + 3KVG-1,4
		10	DT-75M + 3KVG-1,4

arable lands, stubble with grain-cereal and annual grasses, 3 fields after root crops harvest and repeated ploughing) was carried out only for individual representatives from each group and showed that on the second agrophone, total costs per unit have not practically changed for the first and second efficiency groups. On the third agrophone, the costs per unit are lower for all categories. Agrophone affects more strongly the groups which use the K-701, MTZ-1221, T-150K tractors than tractors operating with the appropriately trailed tillers. Thus, it can be concluded that improving the tillers will lead to an increase in the efficiency of both these combines.

Similarly, modelling was carried out for other technological operations related to tillage. After that, one representative was selected from each group. Table 2 is produced as a result. It shows the main technological operations for traditional tillage and the structure of the representatives depending on their efficiency.

For a heavy-duty cycle between a high-efficiency group and a low-efficiency group, there is practically no difference in the optimal number of combines, apart from the level of requirements for agrotechnical terms (from "hard" to "soft"). There is a significant difference in the total costs between efficiency groups: the high-efficiency group exceeds the low-efficiency by the value ranging from 1.43 to 1.6 thousand rubles·ha^{-1} (by 33–37%). Also, the fuel costs of high-efficiency group are lower by the value from 0.38 to 0.71 thousand rubles·ha^{-1} (by 26–50%).

For derated operation, the low-efficiency group for the "standard" level is more meaningful; the optimal number of combines would be: for hard requirements – 14; for normal requirements – 6; for soft requirements – 5. At the same time, the excess of the total costs of a low-efficiency group ranges from 1.3 to 1.4 thousand rubles·ha^{-1} (by 37–40%) in comparison with the high-efficiency group. The excess of fuel costs for a low-efficiency group is from 0.23 to 0.38 thousand rubles·ha^{-1} (by 29–45%). It should be noted that fuel costs, in all cases, are at the level of 30–35% of the total cost of fuel and compensation of damage from soil pollution and violation of agrotechnical terms.

Conclusion

The analysis of the obtained data showed that the improvement of tillers will lead to an increase in the efficiency of examined combines. For this purpose, the modelling of combines' structure was performed by replacing the tillers with newly developed and protected patents. The structure of new complexes of combines of different efficiency is presented in Tables 1–2. The analysis of the data obtained from the modification of combines shows that all costs reach the case of traditional tillage. However, if the yield increase is 10%, then the additional profit (approximately 3.5 thousand rubles·ha^{-1}) will cover even the total costs for compensation of damages and fuel.

The results of a comparison of all costs for original and new combines proves that, for high-efficient combines, the non-mouldboard technology allows the reduction of optimal number of combines by 25–32% (depending on the level of requirements for agrotechnical terms). At the same time, the introduction of new tillers will reduce the number of operating combines by 50–58% due to reduced resistance and the combination of technological operations. Similarly, for low-efficiency combines, the non-mouldboard technology leads to a reduction in the number of older combines by 11–14% and in new combines by 14–27%.

Thus, changing the technology of tillage for low-efficiency combines has lower impact on the optimal number of combines in operation. The change in tillage also leads to a change in costs. With the transition to the non-mouldboard tillage by high efficient combines, the total costs are reduced by 27%, and for the new complex of combines by 48–50%. For low-efficiency combines, it is similar – for non-mouldboard tillage, the costs are reduced by 12%, and for new combines, the costs are reduced by 55%. The improvement of cultivation tools leads to increase in efficiency, with average efficiency units being MTZ-1221 and T-150K (Russian production) and the most efficient John Deere and New Holland. The introduction of new working tools to low-efficiency combines has greater impact on total costs than to high-efficiency combines. The analysis of fuel costs shows that the transition to non-mouldboard technology in both groups of combines will lead to savings of this resource by 45%, and the introduction of new tillers will reduce fuel consumption by 61–64%.

The developed models can be successfully used in the software of on-board tractor computers or utilised by main specialists (while planning agricultural works). Similarly, it is possible to obtain dynamic models for other technological processes of crop production. All developed models will allow reducing the production costs and getting closer to precision agriculture.

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