HARVESTING OF MIXED CROPS BY AXIAL ROTARY COMBINES

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Abstract
The choice verification of operating modes of axial-rotary combine harvesters for harvesting mixed crops of cereal grain and leguminous crops has been carried out. A mathematical model has been compiled to determine the operating modes of axial-rotary threshing and separating systems for harvesting mixed crops. Transfer coefficients have been introduced, one of themcharacterizes a complete threshing of the cereal grain, and the other reflects minimal damage to the grain legume component. The dependences of macro- and microdamages of grains and legumes in mixed crops during harvesting by combines of this type are obtained. The operation modes of the combine harvester RSM-181 "TORUM" for cleaning mixed sowings of white lupine and triticale were substantiated. A clearance between the rotor and the deck of 35 mm and a rotor speed is from 400 to 450 min^{-1} were recommended.

Key words: *harvesting; mixed crops; grain losses; grain damage.*

INTRODUCTION

Mixed crops (the duplicate term is heterogeneous crops) are crops of two or more crops on the same arable land diseases (*Miu, 2016*). They cannot be attributed to compacted crops, where the cultivation of one crop (usually tilled) in between rows sow another crop. But their use was one of the methods of increasing the productivity of arable land, increasing soil fertility and reducing the pesticide load on the environment.
In such crops, higher photosynthetic productivity is achieved by increasing the total leaf surface area to 60 thousand m^2 / ha, which is 15–20% more than in single-species crops. In this case, the efficiency of photosynthesis was achieved by increasing the multi-tiered agroecosystem, a more uniform distribution of leaves in height, more complete absorption of solar energy due to the suppression of the weed component in crops (*Constable, Somerville, 2003*). The synergistic effect of increasing the productivity of mixed sowing due to more economical consumption of moisture, improved plant nutrition, better use of sunlight and reduced yield losses from a decrease in the numerical composition of the weed component and the prevalence of. The creation of lupine-cereal mixed crops, allows you to get a protein-balanced grain yield without the use of mineral fertilizers, herbicides and other plant protection products (*Aldoshin, 2018*). The most difficult technological method is the cleaning of mixed crops due to the difference in the properties of the crops belonging to them (*Aldoshin, 2016*). The purpose of the study is to evaluate the effectiveness of harvesting lupine-cereal mixed crops with axial-rotary combine harvesters RSM-181(RostSelMash) "TORUM".

MATERIAL AND METHODS

The axial-rotary local control system of the RSM -181 "Torum 740" combine includes four sections: a receiving chamber with a solid, smooth casing, a threshing and separating section, a discharge zone. The angle of the rotor coverage with the lattice surface of the casing in the threshing and separating sections is 360 °. The rotor case rotates at a frequency of 8 min-1. The diameter of the rotor is 762 mm, length 3200 mm. The combine can be equipped with engines of 300 and 370 kW (*Aldoshin, 2018*).
Modes of operation for axial-rotor threshing separating device are more benign. The gap between the rotor and the deck is larger than in the "classical". At the same time, the time spent by the device is much longer, so it allows it to inflict significantly more strikes on the mass, providing threshing of the

grain crop, which is the part of the mixed crops. In addition, the separation area significantly exceeds the parameters of the "classical", which ensures a good selection of both the grain and cereal crops (*Jech, 2011*).

RESULTS AND DISCUSSION

The task of high-quality threshing of grain without exceeding the limit of damage can be solved in a compromise manner (*Aldoshin, 2016*). On the one hand, it is necessary to ensure high-quality threshing of the cereal grain crop, excluding grain losses underground, on the other hand, to ensure a fairly low level of damage to the grain-legged component of mixed crops (*Zhalnin EH.V, 2016*)

We introduce the transfer coefficients characterizing the fragmentation and loss of grain, representing the ratio of the increment of the output parameter to its input value

$$R_i = \frac{d_i}{d_{i-1}}, \tag{1}$$

where d_i, $d_{i,-1}$ are respectively, the fragmentation of the *i*-th and *i-1* objects of the combine, and when assessing the loss of grain

$$R_i' = \frac{\Pi_i}{\Pi_{i-1}}, \tag{2}$$

where Π_i, Π_{i-1} losses of the *i*-th and *i-1* objects of the combine.
The total damage to the grain can be represented as a function

$$\partial_\Sigma = f_0(q, w, s, k_n \ldots) R_\Sigma \tag{3}$$

where f_0 *(q, w, s, k_p ...)* is the initial input effect, depending on the supply of the grain mass *q*, its moisture w, contamination s, uneven supply of the threshed mass to the local government k_n, etc.
Gear ratios depend on factors that differ in the nature of origin: structural (К), technological (*T*), and operational (*Э*). Therefore, they are vector quantities.

$$R = \{K, T, Э\}. \tag{4}$$

Then

$$\begin{gathered} K = \{K_1, K_2, K_3 \ldots \ldots K_i . .\}, \\ \mathrm{T} = \{\mathrm{T}_1, \mathrm{T}_2, \mathrm{T}_3 \ldots \ldots \mathrm{T}_i . .\}, \\ Э = \{Э_1, Э_2, Э_3 \ldots \ldots Э_i . .\}, \end{gathered} \tag{5}$$

where K_i, T_i, $Э_i$ are respectively the *i*-th constructive, technological and operational factors.

In this case, the ratio of their actual values to the required values is determined.

$$K_\mu = W_\mu / w_\mu^{mp}, \tag{6}$$

where W_μ is the actual value of the parameter; w_μ^{mp} is the required parameter value.

As an aggregation function can be taken:
additive function

$$\varphi(W) = \sum_{i=1}^{m} \gamma_i w_i; \tag{7}$$

where γ^i is the coefficient of relative importance of the particular indicator w_i, *m* is the number of particular indicators of the efficiency of the combine harvester;
multiplicative function

$$\varphi(W) = \prod_{i=1}^{m} w_i^{\ \gamma_i}; \tag{8}$$

aggregate function
ϕ (W) = min┬i 〖{w_i / 〖γ _i};〗

$$\varphi(W) = \min_i \left\{ \frac{w_i}{\gamma_i} \right\};$$
$$\gamma_i \neq 0; i = \overline{1, m}; \qquad (9)$$

power function

$$\varphi(W) = \left[\frac{1}{m} \sum_{i=1}^{m} w_i^p \right]^{\frac{1}{p}}, p \neq 0, \qquad (10)$$

where p is an indicator that reflects the required level of compensation for small values of some equivalent indicators with large values of others.
As p=∞, no compensation is allowed, and the limiting form of the aggregation function (10) coincides with (9). In the case of p=0, it is necessary to ensure the same levels of partial indicators; function (10) coincides with (8), therefore, to select a combine harvester with the best indicators of function (8), (9) and (10), they cannot be used in this form.
The aggregated function in the form of additive (7) is not advisable to use to solve our problem. This is due to the fact that the selected performance indicators are heterogeneous. Threshing separator can be used as a function of one indicator to another:

$$\varphi(W) = \frac{\prod_{i=1}^{m_1} w_i}{\prod_{i=m_1+1}^{m} w_i}; \qquad (11)$$

where i = (1, m_1) - partial indicators, the values of which it is desirable to increase, i = (m_1 + 1, m) reduce.
Indicators i = $\overline{(1, m_1)}$, can be identified with the provision of full grain threshing in local government, and indicators, i = $\overline{(m1 + 1, m)}$ - with minimization of grain damage during harvesting mixed crops.
However, the indicators of the first and second groups are heterogeneous, have different physical meaning and dimension. Also, the aggregation function from expression (11) is a vector quantity. To bring it to a scalar form and to compensate for the heterogeneity of particular indicators, their different physical meaning and dimension, we use an equivalent transformation. In this case, the function of the aggregated indicator will take the form:

$$\varphi(W) = \frac{\prod_{i=1}^{m_1} \frac{w_i}{w_i^{TP}}}{\prod_{i=m_1+1}^{m} \frac{w_i}{w_i^{TP}}}; \qquad (12)$$

Designating

$$\prod_{i=1}^{m_1} \frac{w_i}{w_i^{TP}} = k_1, \qquad \prod_{i=m_1+1}^{m} \frac{w_i}{w_i^{TP}} = k_2, \qquad (13)$$

Will get

$$\varphi(\mathrm{W}) = \frac{\mathrm{k}_1}{\mathrm{k}_2} \qquad (14)$$

Then the performance indicator will take the form

$$k_{\text{э}} = m\{k_{1i}/k_{2i}\} \qquad (15)$$

Using the method of "Least squares", one can evaluate the measure of approximation of the actual result to the desired. Using the efficiency function (12), we note that in order to increase the efficiency of an axial-rotary control, private efficiency indicators w should tend to the values

In this case, the indicator k_{1i} has the meaning of the effect of complete threshing of the grain of ear crops, and k_2 - reflects the minimal damage to the leguminous component.

An increase in the indicators of the first group $k_{1i}$is aimed at achieving one goal, while the second group k_{2i} leads to the opposite result. In case of heterogeneity, the particular efficiency indicators included in the function φ (*Пэ*) may differ according to their influence on the threshing process and separation in axial-rotary local self-government. Then it becomes necessary to introduce in expression) the coefficients γ of the relative importance of the elementsk_{1i}. In this case, it is legitimate to assume that the value of γ for the element k_{1i}will correspond to the coefficient of relative importance of the i-th particular efficiency indicator. The values of the coefficients of the relative importance of partial performance indicators can be determined by the method of expert evaluation. Considering the possible options for the inclusion of in dependence (15), we arrive at the following:

Since ∑ (i = 1) (i = m) 〖γ = 1〗 ,

with the number of particular indicators m> 1, γ〗 _i ≠ 1 and γ_i 0.

When γi 1, the influence of ki on the complex index should increase, and when γi → 0, it should weaken.

With the growth of the value of γi, the coefficient k_{1i}should increase, and k2i should decrease.

When γi → 0, the influence of the i-th partial index on the complex index should not be completely rejected.

Since we have chosen two particular indicators to study the quality of the axial-rotary LSG of combine harvesters - direct losses and grain damage, which need to be reduced, then the efficiency indicator takes the form

$$k_э = m\{1/k_{21}k_{22}\}, \tag{16}$$

and taking into account the coefficients of the relative importance γ of particular indicators, a comprehensive performance indicator is determined as follows:

$$k_э = m\left\{\frac{1}{\gamma_1 k_{21}\, \gamma_2 k_{22}}\right\}, \gamma_2 k_{22} \tag{17}$$

Given the expression of the coefficients k_{21} and k_{22}, we get

$$k_э = m\left\{\frac{1}{\gamma_1 \frac{П_з}{П_з^{\partial on}} \gamma_2 \frac{П_{\partial p}}{П_{\partial p}^{\partial on}}}\right\}, \tag{18}$$

Suppose that 〖γ₁ = γ〗 , then, we obtain an expression to determine the complex criterion of the effectiveness of the quality of work of the local government:

$$k_э = m\left\{\frac{П_з^{\partial}\, П_{\partial p}^{\partial}}{П_з\, П_{\partial p}}\right\}, \tag{19}$$

The dependence of direct losses and grain crushing can be obtained on the basis of experimental data, investigating the influence of various factors 〖X1, X〗, Xn on the operation of an axial-rotor. According to the results of processing the results of experiments, we obtained the following dependences (Fig. 1, 2).

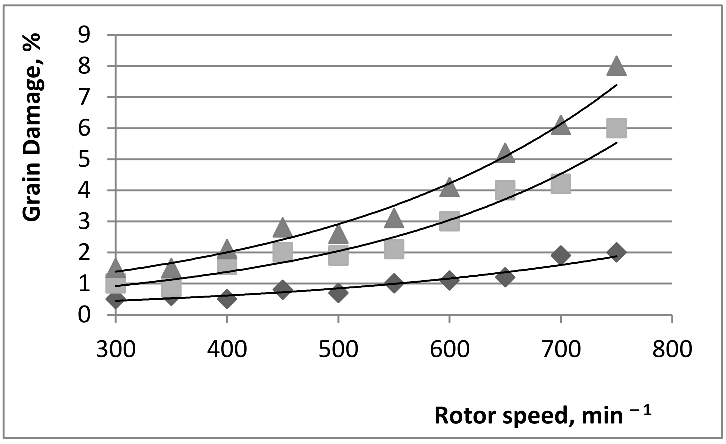

Fig. 1 Dependence of grain damage on rotor speed, min $^{-1}$, (gap between rotor and deck 35 mm):general damage; macrodamage; microdamage

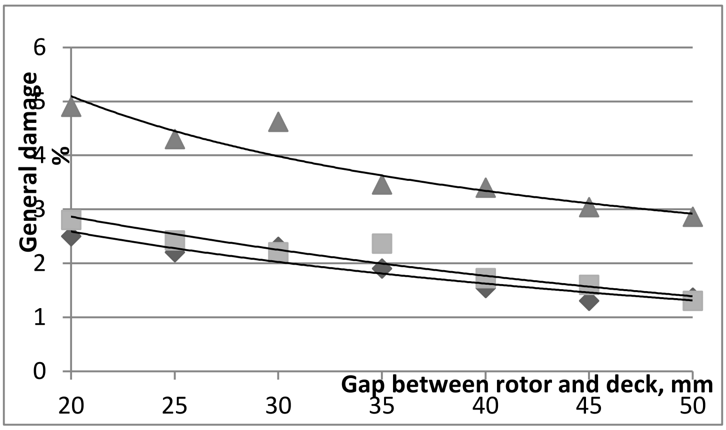

Fig. 2 Dependence of grain damage on the gap between the rotor and deck:
rotor speed, 350 min ^{1} –; rotor speed, 450 min $^{-1}$; rotor speed, 550 min $^{-1}$

CONCLUSIONS

The results show that, a sharp increases in grain damage occurs with an increasing in the rotor speed of more than 450 min^{-1}As the gap between the rotor and the deck increases, the damage to the grain decreases at all the considered rotor speeds. It should also be noted that with large gaps between the rotor and the deck (from 40 to 50 mm) there is undersized ground triticale.

Axial-rotary combine harvesters can be used for harvesting mixed crops of cereal crops and leguminous crops. In this case, it is necessary to set the rotor speed from 400 to 450 min^{-1}, and the gap between the rotor and the deck should be 35 mm.

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