Research of passage capacity of combine harvesters depending on agrobiological state of bread mass

I M Kuzmich, I L Rogovskii, L L Titova\(^1\) and O V Nadtochiy

National University of Life and Environmental Sciences of Ukraine, 15, Heroiv Oborony str., Kyiv, 03041, Ukraine

\(^1\)E-mail: titovall@ukr.net

Abstract. The limits of reducing the numerical values of the coefficients of the influence of straw content, moisture, grain contamination, on the change in the throughput of the threshing-separating device and the productivity of the combine are calculated. The boundaries of the probable numerical values of the coefficients of straw content, moisture content and dockage of grain stand have been calculated. The probable boundaries of the numerical values of productivity after an hour of network (ha/h) were calculated, depending on the influence of single and general coefficients. The method for calculating the productivity of combines, depending on the weight of the influence of individual coefficients or their overall effect, is proposed, which will make it possible to predict the likely change in productivity in a particular field and during the harvest period with minimization of biological crop losses. To obtain the resulting coefficient of influence of the state of grain, it should be taken into account that the direction of change in the value of the coefficient of influence must coincide with the direction of its influence on the throughput. That is, the minimum value of moisture, straw content and debris corresponds to the maximum value of the throughput of the threshing-separating device.

1. Introduction

The influence of the agrobiological state of the grain mass on productivity is stated in literary sources [1], and in practical conclusions it is declared by adjectives [2], but there is no analytical confirmation of the numerical values [3]. The implementation of the technological operation of harvesting the main condition is the quality of threshing of the grain mass and the stability of the passage of the technological process [4], through the implementation of the throughput indicator for combines of classes and design schemes [5]. The performance of combine harvesters depends on many objective and subjective factors and factors, the impact of which on the actual performance can be expressed by functional dependence:

\[
W_f = W_A \cdot f(q_f) = W_A \cdot f(k_1, k_2, k_3, k_4, k_{Bp}, k_{Vp}, k_A, k_{Ne}, k_q) \tag{1}
\]

where: \(k_1, k_2, k_3, k_4\) – coefficients that take into account the characteristics of the agrobiological state of the grain mass: straw moisture, straw content, grain moisture, dockage of grain [6]; \(k_{Bp}, k_{Vp}\) – coefficients that take into account the average value of the header width and the average value of the working speed [7]; \(k_A, k_{Ne}, k_q\) – availability factors, the degree of reduction of engine power, from the nominal value and the coefficient of capacity reduction [8].

The development of technological maps for harvesting the values of the influence coefficients by specialists of agricultural enterprises are selected empirically [9], based on their own generalized
experience or qualifications [10]. To reduce the influence of the subjective assessment of the influence of operating factors, characteristics, on the productivity of combines, the numerical values of their influence should be calculated [11]. Harvesting is characterized by certain quality indicators: technological standards (throughput) [12] and permissible deviations from them (technological tolerance for standards) [13]; the accuracy of the developed requirements [14] or the level of comparison of the quality indicators obtained in real production with the acceptable ones [15].

The uniformity of the grain mass feeding into the threshing apparatus depends on the influence of a significant number of factors [16]: uneven plant density, height and moisture of the crop, use of the header width, uneven mowing height, uneven feed by the header auger and floating inclined transporter, cultivation of a specific field, the degree of dockage of grain. In the literature [17], the throughput of the threshing-separating device of grain harvesters is shown as a constant value that depends on four starting design and operational characteristics and six empirical coefficients (0.458, 32, 0.26, 1.5, 0.8, 0.83). Practice shows [18] that in real production conditions, throughput and, accordingly, productivity is a variable value that depends on objective and subjective factors and characteristics. The objective factors are: soil and climatic conditions, relief and contours of fields, physical and mechanical properties of crops, design and operational characteristics of combines [19]. Subjective factors: dockage of grain, straw content, moisture content of the grain mass and grain, agricultural culture, qualification of combine operators (selection of the optimal working speed), cutting height, cutting width of header [20].

2. Purpose of research
The purpose of this work was to obtain the dependence of the actual throughput of the threshing-separating device and the performance of the combines on the characteristics of the grain mass during combining: the straw content of the grain mass, the moisture content of grain and straw, the degree of contamination of the field.

3. Materials and methods
The following characteristics are standard: straw content \( \delta_c = 1.5 \); yield capacity \( U = 4 \text{ t/ha} \); straw moisture content \( M_b = 17\% \); grain moisture \( M_g = 15\% \); dockage of grain \( B_h < 5\% \). The nominal hourly productivity with a yield of up to 4 t/ha can be determined using the relationship:

\[
W_A = 0.36 \cdot B_h \cdot \left\{ N_{e_h} \cdot (1 - \delta_c) \cdot (N_M^2 + N_P) \cdot \eta_T + 10 \cdot g \cdot f \cdot G_T \cdot t \right\}^{-1}. \tag{2}
\]

With a yield of more than 4 t/ha, taking into account the throughput of the threshing-separating device of the combine from the dependence:

\[
W_A = 3.6 \cdot q_h \cdot \left\{ U \cdot (1 + \delta_c) \right\}^{-1}. \tag{3}
\]

To calculate the performance of the combine according to formulas (2), (3), it is necessary to determine the indicator of the throughput of the threshing-separating device, taking into account the influence of single agrobiological characteristics of the grain of the harvested crop. The throughput, in turn, is determined taking into account the numerical values of the individual coefficients. Obviously, the given characteristics of grain crops affect the increase in power consumption per unit of threshed grain mass. Experts in agricultural production know how the given characteristics of the grain stand, especially contamination, affects the change in the physical and functional parameters of the pitched board, the sieve mill, the inner surfaces of the straw walkers. The liquid that is squeezed out by the drum from the wet mass of weeds with a moisture content of 60-70% has high adhesion properties and falls on the working surface of the screen, sieves and the inner (working) surfaces of the straw walkers. This contributes to the adhesion of dust, chaff, chopped straw on them, and the creation on the surface (especially of the pitched board) of a monolithic hard surface, sometimes up to 50-70 mm thick. After which the pitched board loses its functional characteristics to separate grain from the chaff. To clean the pitched board from the adhesion of dirt, considerable physical effort and special technical devices are required, as well as an additional 4 hours of working time. The inhomogeneity of the thickness of the dirt around the perimeter of the pitched board is the cause of imbalance and possible breakage of the
mountings. The accumulation of dirt on the working surfaces of the sieves, straw walkers leads to an increase in grain losses behind the harvesters of the threshing-separating device. In turn, weed residues have a greater mass, geometric dimensions and other aerodynamic properties than chaff and chopped straw and also causes increased grain losses. The influence of straw content, moisture and debris on the throughput of the threshing-separating device can be determined as follows: the influence of straw content (we use the inverse value of the coefficient):

\[ qn(k_{1\text{max}})^{-1}, qn(k_{1\text{min}})^{-1}, \]

where \( k_{1\text{max}} \) and \( k_{1\text{min}} \) – respectively the maximum and minimum value of the coefficient of the influence of straw content on the throughput of the harvester of the threshing-separating device.

The influence of grain moisture (we use the inverse value of the coefficient):

\[ qn(k_{2\text{max}})^{-1}, qn(k_{2\text{min}})^{-1}, \]

where \( k_{2\text{max}} \) and \( k_{2\text{min}} \) – respectively, the maximum and minimum value of the coefficient of the influence of grain moisture on the throughput of the threshing-separating device of the combine.

The influence of dockage of grain:

\[ qn(k_{3\text{max}})^{-1}, qn(k_{3\text{min}})^{-1}, \]

where \( k_{3\text{max}} \) and \( k_{3\text{min}} \) – respectively, the maximum and minimum value of the coefficient of the influence of grain contamination on the throughput of the combine harvester of the threshing-separating device.

To obtain the resulting coefficient of influence of the state of grain, it should be taken into account that the direction of change in the value of the coefficient of influence must coincide with the direction of its influence on the throughput. That is, the minimum value of moisture, straw content and debris corresponds to the maximum value of the throughput of the threshing-separating device. Combining all the coefficients of influence of the state of grain, the throughput of the threshing-separating device can be expressed by the dependence \( qnk_{3\text{max}}(k_{2\text{max}} \cdot k_{1\text{max}})^{-1}, qnk_{3\text{min}}(k_{2\text{min}} \cdot k_{1\text{min}})^{-1} \).

4. Results and discussion

To take into account the influence of straw content, the authors [7] proposes to use the coefficient \( k_1 \), the value of which is determined from the expression:

\[ k_1 = (1 - c_0) \cdot (1 - c)^{-1} = (1 - 0.66) \cdot (1 - 0.64)^{-1} = 0.94, \quad k_1 = 1 - 0.94 = 0.06 \approx 6\%. \]

where: \( c_0, c \) – calculated and actual grain content in straw, in unit fractions.

Machine test stations define this factor differently: \( k_1 = 0.6(1 + [\delta_c]^{-1})^{-1} = 0.6(1 + [1.5]^{-1})^{-1} = 1 \). The calculated values of the coefficient, depending on the straw content, are shown in table 1. As can be seen from table 1, a change in straw content from \( \delta_c = 0.9 \) increases the influence coefficient \( k_1 \) from 0.79 to 1.09, that is, by 30%. The influence of the moisture content of the grain mass on the value of the coefficient of influence \( k_2 \) for weed grain crops can be determined from the relationship:

\[ k_2 = \left( \left\{ 100 - B_g \right\} \cdot \left\{ 100 - B_s^1 \right\}^{-1} + \delta_c \cdot \left\{ 100 - B_s \right\} \cdot \left\{ 100 - B_s^1 \right\}^{-1} \right) \cdot (1 + \delta_c)^{-1}, \]

where \( B_g, B_s, B_g^1, B_s^1 \) – respectively, the standard conditional moisture content of grain and straw and their actual value%.

| \( \delta_c \) | 0.9 | 1.0 | 1.1 | 1.2 | 1.3 | 1.4 | 1.5 | 1.6 | 1.7 | 1.8 | 1.9 |
|--------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| \( k_1 \)    | 0.79| 0.83| 0.87| 0.91| 0.94| 0.97| 1.00| 1.02| 1.05| 1.07| 1.09|
| \( (k_1)^{-1} \) | 1.266| 1.208| 1.199| 1.093| 1.063| 1.030| 1.0 | 0.98 | 0.952| 0.934| 0.917 |
For calculations, we will take a change in the moisture content of grain $B_g$ from 20% to 13%, straw $B_s$ from 22% to 15%. As evidenced by the data in table 2, a decrease in the moisture content of grain $B_g$ from 20 to 13% and straw $B_s$ from 22 to 15% reduces the influence coefficient $k_2$ from 1.063 to 0.976 or by ≈9%. In case of contamination of the grain mass, the value of the coefficient of influence $k_3$ is determined from the dependence:

$$k_3 = \left(100 - B_g\right) \cdot \left(100 - B_{g}'\right)^{-1} \cdot (1 - \varepsilon)^2,$$

or $k_3 = -0.025 \cdot \varepsilon^{0.538} + 1.037,$

where $\varepsilon$ – the content of weeds in the grain mass in unit fractions.

**Table 2.** Influence of grain and straw moisture on the value of the coefficient.

| Indicators | Moisture content of grain and straw % |
|------------|--------------------------------------|
| Corn       | 20 19 18 17 16 15 14 13             |
| Straw      | 22 21 20 19 18 17 16 15             |
| $k_2$      | 1.063 1.048 1.037 1.024 1.012 1.000 0.988 0.976 |
| $(k_2)^{-1}$ | 0.941 0.954 0.964 0.976 0.988 1.0 1.012 1.0245 |

The calculated values of the influence of contamination on the coefficient indicators are given in table 3 under standard conditions $B_g = 15\%$, $B_s = 17\%$. The work [7] shows a method for calculating the throughput of the threshing-separating device of grain harvesters using the example of combine harvesters Slavutich KZC-9F.

**Table 3.** Influence of grain mass contamination on the value of the coefficient.

| Indicators | Relative contamination of the grain mass % |
|------------|--------------------------------------------|
|            | 5 10 15 20 25 30 35 40 45 50             |
| $k_3$      | 0.976 0.957 0.943 0.929 0.912 0.882 0.875 0.868 0.850 0.840 |

The calculated values of the influence of the coefficients on the performance indicators of the threshing-separating device are given in table 4. In particular, the data in the table indicate that the total effect of all coefficients on the throughput of the threshing-separating device can reach 43%. Relying on addictions stated above, the throughput of the threshing-separating device of combine harvesters Slavutich KZC-9F for example was determined under standard conditions: yield capacity $U = 4$ t/ha, grain crop – wheat, straw moisture $B_s = 17\%$, dockage of grain – 0%, grain moisture $B_g = 15\%$, grain: straw ratio – 1:1.5, engine power $Ne = 173$ kW, combine mass – 16.8 kN, transmission efficiency $\eta_T = 0.88$, rolling coefficient $f = 0.12$, specific threshing power $N_M = 9.1$ kW s/kg, $N_P = 2.1$ kW s/kg. As follows from the indicators in table 4 and figure 1, the straw content of grain stands has the greatest impact on reducing the throughput of the threshing-separating device.

**Table 4.** Calculated values of the coefficients of influence on the throughput capacity of the threshing-separating device of combine harvesters Slavutich KZC-9F.

| Characteristics of the grain | Value |
|-----------------------------|-------|
|                             | $\Delta_{min}$ | $\Delta_{max}$ | $k_{min}$ | $k_{max}$ | $q_{max}$ | $q_{min}$ | %   |
| Straw content               | 0.9    | 1.9    | 1.265    | 0.917    | 11.57    | 8.31      | -27% |
| Humidity                    | 15%    | 22%    | 1.026    | 0.94     | 9.38     | 8.60      | -8.1% |
| Clogging                    | 5%     | 50%    | 0.976    | 0.84     | 8.60     | 7.68      | -16.1%|
| Total impact                | 1.265  | 0.724  | 11.57    | 6.62     |          |           | -43% |

The change in straw content $\delta_{c} = 0.9\ldots1.9$ accordingly leads to a change in the throughput from $q_{n_{max}}$ to $q_{n_{min}}$ kg/s. In percentage terms, this influence is 27.4%. The influence of debris when
changing from 5 to 50% reduces the throughput of the threshing-separating device by 16.1%. The minimum impact on the throughput of the combine harvester is made by the moisture content of grain and straw and is 8.1%.

The calculation of the performance of combine harvesters Slavutich KZC-9F at the standard characteristics of grain according to the formula (2) showed the value \( W_A = 4.05 \text{ ha/h} \). A change in straw content from 0.9 to 1.9 affects productivity, changing it in inverse proportion from 5.12 to 3.71 ha/h, that is, it changes by 27.5%. Humidity with a change from 22 to 15% affects productivity in the range from 4.15 to 3.8 ha/h or 8.4%, and a change in dockage of grain from 5 to 50% affects, respectively, in the range from 3.95 to 3.4 ha/h or 14%.

5. Conclusions
The probable boundaries of the change in the numerical values of the throughput of the threshing-separating device of combine harvesters Slavutich KZC-9F are calculated, depending on the influence of single and total coefficients of influence. The greatest influence on the change in the throughput of the threshing-separating device is the straw content of the grain stand (within 27%), the lowest moisture content of the straw mass (within 8%).

Contamination significantly affects the throughput of the threshing-separating device and an increase in mechanical losses for the threshing-separating device (5-6 times) in comparison with the standard value (1%) of the gross tax.

Changing the cutting height of grain by 1-1.5 cm increases the throughput of the threshing-separating device of combine harvesters Slavutich KZC-9F by \%, or by 0.1-0.12 kg/s. The productivity, respectively, by 0.04-0.05 ha/1%. The increased dockage of grain by 5% reduces the throughput of the threshing-separating device by 0.147 kg/s, and the productivity by 0.0065 ha/5%.

References
[1] Yata V K, Tiwari B C and Ahmad I 2018 Nanoscience in food and agriculture: research, industries and patents Environmental Chemistry Letters 16 79-84
[2] Dubbini M, Pezzuolo A, DeGiglio M, Gattelli M, Curizio L and Covi D 2017 Last generation instrument for agriculture multispectral data collection CIGR Journal 19 158-63
[3] Rogovskii I L, Stepanenko S P, Novitskii A V and Rebenko V I 2020 The mathematical modeling of changes in grain moisture and heat loss on adsorption drying from parameters of grain dryer IOP Conference Series: Earth and Environmental Science 548 082057
[4] Miu V 2016 Combine harvesters: theory, modeling and design CRC 6 208-24
[5] Molenda M, Horabik J, Thompson S and Ross I 2004 Effects of grain properties on loads in
model silo *International Agrophysics* 18 329-32

[6] Yezekyan T, Marinello F, Armentano G, Trestini S and Sartori L 2020 Modelling of harvesting machines’ technical parameters and prices *Agriculture* 10(6) 194-204

[7] Rogovskii I, Titova L, Novitskii A and Rebenko V 2019 Research of vibroacoustic diagnostics of fuel system of engines of combine harvesters *Engineering for rural development* 18 291-8

[8] Aldoshin N and Didmanidze O 2018 Harvesting lupines albus axial rotary combine harvesters *Research in Agricultural Engineering* 64(4) 209-14

[9] Golovkov A, Moskovskiy M and Khamuev V 2019 Justification of the type of combine harvester for farms *E3S Web of Conferences* 126(2) 00029 doi:10.1051/e3sconf/201912600029

[10] Rogovskii I, Titova L, Trokhaniak V, Trokhaniak O and Stepanenko S 2020 Experimental study of the process of grain cleaning in a vibro-pneumatic resistant separator with passive weeders *Bulletin of the Transilvania University of Brasov Series II: Forestry Wood Industry Agricultural Food Engineering* 13 (62) 117-28

[11] Isaac N, Quick G, Birrell S, Edwards W and Coers B 2006 Combine harvester econometric model with forward speed optimization *Applied Engineering in Agriculture* 22 25-31

[12] Xu L, Chai X, Gao Z, Li Y and Wang Y 2019 Experimental study on driver seat vibration characteristics of crawler-type combine harvester *International Journal of Agricultural and Biological Engineering* 12(2) 90-7

[13] Hrynkiv A, Rogovskii I, Aulin V, Lysenko S, Titova L, Zagurskіy O and Kolosok I 2020 Development of a system for determining the informativeness of the diagnosing parameters of the cylinder-piston group of the diesel engines in operation *Eastern-European Journal of Enterprise Technologies* 3(105) 19-29

[14] Šotnar M, Pospíšil J, Mareček J, Dokukilová T and Novotný V 2018 Influence of the combine harvester parameter settings on harvest losses *Acta Technologica Agriculturae* 3 105-8

[15] Zhang X 2018 Vibration control method for a crawler-type combine harvester *Emirates Journal of Food and Agriculture* 30 873-82

[16] Chen S, Zhou Y, Tang Z and Lu S 2020 Modal vibration response of rice combine harvester frame under multi-source excitation *Biosystems Engineering* 194 177-95.

[17] Tsapko Yu, Rogovskii I, Titova L, Bilko T, Tsapko A, Bondarenko O and Mazurchuk S 2020 Establishing regularities in the insulating capacity of a foaming agent for localizing flammable liquids *Eastern-European Journal of Enterprise Technologies* 5(10-107) 51-7

[18] Hongze L and Konglai Z 2007 Ecological agriculture comprehensive efficiency evaluation Index system and assessment method *China Forestry Economy* 9 19-22

[19] Bevly D M, Gerdes J C and Parkinson B W 2002 A new yaw dynamic model for improved high speed control of a farm tractor *Journal of Dynamic Systems, Measurement, and Control* 124(4) 659-67

[20] Ebrahimi R, Esfahanian M and Ziaei-Rad S 2013 Vibration modeling and modification of cutting platform in a harvest combine by means of operational modal analysis *Measurement* 46(10) 3959-67