A grain harvester performance according to unloading time and modes

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Abstract. The paper presents an analysis of the two ways of unloading the harvester grain hopper – unloading at standstill and unloading on the move. A passive experiment has been carried out during wheat harvest by measuring the loading time of a full harvester hopper into the transport vehicle. During its time measurement it has been found that for 237.4s the harvester is stopped and does not reap and does not perform actual output. The actual grain harvester output when unloading at standstill has been determined 17.15t/h (25.22 da/h) and the actually possible output if the harvester runs the same performance and unloads on the move it will reach an output of 20.91t/h (30.74 da/h), i.e. its output will increase by 19%. It has been found out that crop harvesting times can be shortened if the method unloading on the move is used, by about one day in harvesting the crop, respectively.

Keywords: grain harvester, unloading time, output

Introduction

The output of grain harvesters is a major technical and economic indicator. It represents the work done by the harvester for a unit of time. There are two main ways of unloading the grain harvester hoppers: unloading on the move and unloading at standstill (Delchev et al., 2016; Tihanov, 2017). In terms of the organization of transport, the means of unloading can be classified as direct and indirect transport services (Scheuren et al., 2013). In relation to the optimization of grain tank unloading and the coordination between harvesters and vehicles, some authors (Ali et al., 2009) examined two scenarios of unloading: continuous and interrupted harvest. During continuous harvest, the hopper is unloading on the move or at a standstill and the harvester does not leave the processed strip. During interrupted harvest, the harvester leaves the strip and moves to the vehicle. In Bulgaria, in approximately 90% of the farms, unloading is carried out at standstill. In some of them (about 13%), the harvesters leave the harvested strip, move to the edge of the field and unload in transport vehicles (tractors or trucks) located outside the field (Tihanov, 2017).

Unloading on the move. At this unloading method the harvester continues to reap and the transport vehicle moves in parallel with it and the hopper is unloaded (Scheuren et al., 2013; Zhang, 2014). The advantage of this unloading is that there is no waste of time and no reduction in the hourly yield of the grain harvester since there is no stop for unloading the grain hopper (Tihanov, 2017). In general, this unloading method is more difficult because it requires precise synchronization between the operators of the two machines in order for the unloading to take place (Ali et al., 2009). Also, when there is no synchronization between the two machines, there is a danger of grain spilling. When unloading on the move, the distance travelled by the transport vehicle in the field is greater, resulting in unnecessary soil compaction and increased fuel consumption. A 100% filled hopper is not always unloaded since the transport vehicle that had arrived earlier to the harvester has to travel in parallel with it, waiting for the hopper to be filled. This, in turn, results in a decrease of the coefficient of utilizing the static load carrying capacity of the transport vehicle and ultimately leads to a decrease in the efficiency of transport (Delchev et al., 2002). Another disadvantage of this method is that it is difficult to apply in small-sized areas (Tihanov, 2017).

Unloading at standstill. With this method, operators are considerably relieved, especially in terms of coordination between the two machines (Tihanov, 2017). The disadvantage of unloading at standstill is the loss of time during which the harvester can reap, and therefore works with smaller output since it does not reap during standstill and there is zero output (Delchev et al., 2016). The needed unloading time of each grain tank in the vehicle decreases the harvester performance. In fact, this is the period of time when the harvester does not harvest and that time can be presented as a sum of the times of the operations related to unloading (Delchev et al., 2002). It was found that the duration of the grain tank discharge operation is between 42.5 and 55min, which is measured for five different high-performance combines that discharge 10.000 bushels of wheat (approximately 280 tons) (Grain Handling, 2011).

The grain tank unloading time at a standstill also depends on the duration of the operations (activities) carried out by the vehicle, for example, from the time at which the harvester signalization for a full tank is present until the vehicle starts, and from the time at which the vehicle starts until its arrival under the harvester unloading auger. These times vary considerably since they are largely affected by the overall organization of the harvesting process. It was determined that if well organized, the time during which the harvester waits for the vehicle is 9.25min on average per day, but can reach 54.9min if the
process is badly organized (Lkhagvasuren, 2013).

Another factor that affects the harvester performance during grain tank unloading at a standstill is its tank capacity. The effect of the tank capacity on the hourly performance of two harvesters with different threshing capacities (small or high) showed that this performance is compared to the performance during unloading in motion, i.e. when not wasting time for stopping and unloading (Delchev et al., 2002). If the difference between the grain tank unloading performance in motion and at a standstill is presented in percentages, then these percentages will indicate the relative proportion of time when the harvester stops for unloading to the total working time. Moreover, the results showed that the grain tank unloading time reduces the performance significantly, especially in machines with small grain tank capacity.

The output indicator depends mainly on the technical parameters of the machines, but in some of them logistic factors have a significant influence on it. This is the case with grain harvesters. A key factor for their output is the time for unloading the full grain hopper. During unloading coordinated operations are carried out performed by the harvester and transport vehicle operators, having specific order and duration (Delchev et al., 2015). However, the unloading at standstill is the most widely used method because it is easy and does not require a high level of qualification and organization.

The objective of this paper was to explore and establish performance of a harvester unloading the hopper at a standstill and in motion.

Material and methods

The study was conducted during the harvesting campaign of 2018 when harvesting wheat of the Renaissance variety at volumetric weight of 720 kg/m³. The study was carried out with a Claas Lexion 660 grain harvester with a grain hopper volume of 10m³, header working width of 9.60 m, at an average work speed of 4.85 km/h. The harvester was served by two transport vehicles with a load capacity of 8t. The average wheat harvesting area was 800da. The yield of the harvested area was 680 kg/da, and the average moisture measured by the on-board grain moisture meter – 12.2%.

The following values for the working width utilization factor β=0.96 and working time utilization factor r=0.71 have been used to determine the grain harvester output (Trendafilov, 2012).

By time measurement the time for unloading a full hopper into the transport vehicle has been measured – tp, s. This is the period of time from the harvester stopping harvesting after filling its hopper until resuming the harvest started after the hopper is emptied, that is, time during which no output is achieved. The average value, the mean root square deviation and the limit relative error at γ=0.9 have been determined for the measured duration (Mitkov, 2011).

Based on the results obtained and data established through the study, the following hourly outputs of the grain harvester have been determined:

Actual technical output at unloading at standstill (Wₘᵦₜₜₜₜ) was determined from the actual values of the indicators recorded during the study by the formula (Delchev et al., 2002):

\[
W_{\text{мт}} = \frac{1}{B} \beta \cdot \frac{V_b \cdot \alpha \cdot D}{\frac{t_p}{\rho}} \cdot \frac{1}{1 + \tau} \cdot \frac{t_p}{h}
\]  

(1)

Where:

- Wₘᵦₜₜₜₜ is the hourly output of unloading the hopper at standstill, t/h;
- \(B\) – the working width of the grain harvester header, m;
- \(\beta\) – the working width utilization factor;
- \(V_b\) – the operation speed of the grain harvester, km/h;
- \(t\) – the working time utilization factor;
- \(D\) – the yield per decare, t/da;
- \(t_p\) – the unloading time of a hopper into a transport vehicle, h;
- \(V_b\) – the grain harvester hopper volume, m³;
- \(\rho\) – the volumetric weight of the grain, t/m³.

The same dependence (1) is used in calculating the actually possible output when unloading at standstill of the grain harvester (Wₘᵦₜₜₜₜₜ). In this case the difference was only in the parameter actual grain hopper volume of the grain harvester (\(V_b = 10\) m³).

The actually possible output when unloading on the move was determined by the formula:

\[
W_{\text{мм}} = B \cdot \beta \cdot \frac{V_b \cdot \alpha \cdot D}{\rho} \cdot \frac{1}{1 + \tau} \cdot \frac{t_p}{h}
\]  

(2)

Where: Wₘᵦₜₜₜₜₜ is the hourly output when unloading the hopper on the move, t/h.

The percentage change of processing time per area unit when unloading at a standstill compared to unloading on the move is:

\[
T_{\text{пс}} = \frac{T_{\text{пм}}}{T_{\text{пм}} \cdot 100} = \frac{t_p}{S} \cdot 100 = \frac{t_p + t_p}{t_p} \cdot 100\%
\]  

(3)

Where: \(T_{\text{пс}}\) is the time for processing an area unit when unloading at a standstill, ha/h;

\(T_{\text{пм}}\) – time for processing an area unit when unloading on the move, ha/h.

The percentage change of productivity when unloading at a standstill compared to unloading on the move is:

\[
W_{\text{пс}} = \frac{W_{\text{пм}} \cdot 100}{W_{\text{пм}} \cdot 100} = \frac{t_p + t_p}{t_p} \cdot 100\%\]

(4)

Where: \(W_{\text{пс}}\) is productivity when unloading at standstill, ha/h;

\(W_{\text{пм}}\) – productivity when unloading on the move, ha/h.

When calculating the actually needed days for harvesting the wheat crop and unloading at standstill the following formula is used:

\[
D_{\text{пс}} = \frac{S}{W_{\text{пм}} \cdot T_{\text{пс}}} \cdot \text{days}
\]  

(5)

Where: \(D_{\text{пс}}\) are the days needed for harvesting the crop
when unloading at standstill, days;

\[ S \] – area occupied by the harvested crop, da;

\[ W_{\text{possible}} \] – actual hourly output of the harvester when unloading at standstill, da/h;

\[ T \] – shift duration, h. The shift duration was 11 hours;

\[ k \] – number of shifts, pcs. In this case the grain harvester was harvesting at a single shift.

Similarly, the days needed for harvesting the crop when unloading the harvester hopper on the move were determined by the formula:

\[ D_{\text{move}} = \frac{S}{W_{\text{possible}} \cdot T \cdot k}, \quad \text{days} \]  

(6)

**Results and discussion**

Table 1 shows the average time duration for unloading a full hopper into the transport vehicle \( t_p \). It is evident that its average output is \( t_p = 237.4 \text{s} \) (0.0659h). The coefficient of variation factor is 12.35, where the relative error at \( \gamma = 0.9 \) is within the permissible limits. The confidence interval in which the unloading time \( t_p \) is from 218.04 s to 253.42s.

**Table 1. Time duration for unloading one hopper into the transport vehicle**

<table>
<thead>
<tr>
<th>Indicator</th>
<th>Average unloading time, ( \bar{t} ), s</th>
<th>Corrected mean square deviation, ( S ), s</th>
<th>Variation factor, ( \beta )</th>
<th>Reliability interval ( t_{\bar{t}, \alpha} )</th>
<th>Limit relative error ( \Delta_{t, \alpha} ), %</th>
</tr>
</thead>
<tbody>
<tr>
<td>( t_p ), s</td>
<td>237.4</td>
<td>29.13</td>
<td>12.35</td>
<td>218.04; 253.42</td>
<td>7.54</td>
</tr>
</tbody>
</table>

From a logistics point of view, the time differences for unloading the full hoppers – \( t_p \) are due to inconsistency in the actions of the operators of harvesters and transport vehicles and the incorrect setting of the first level hopper filling signaling sensor. Higher values of time duration \( t_p \) result in lower output. From this point of view, the subjective factors (operators) seriously affect the unloading time of the full hopper on the field and, respectively, on the grain harvester output.

The bills of lading show that the transport vehicles serving the harvester at each course carried an average of 6385kg. At volumetric weight of wheat 720 kg/m³, this is volume of 8.87m³. Given that the volume of the harvester grain hopper is 10m³, it is evident that about 1m³ of it has not been used. In practice, this also results in a decrease in the grain harvester output. When using the obtained average results from the study on the unloading time \( t_p \) and the equal time for filling the tank in the harvester \( t_z = 16 \text{min} = 960 \text{s} \), the result is as follows:

\[ W_{100} = \frac{t_z}{t_z + t_p} \cdot 100 = \frac{960}{960 + 237.4} \cdot 100 = 84.03\% \]  

(7)

\[ T_{100} = \frac{t_z}{t_z + t_p} \cdot 100 = \frac{960 + 237.4}{960} \cdot 100 = 118.99\% \]  

(8)

The results show that upon stopping for unloading in the field, 16% of the harvester productivity is not achieved. The processing time per area unit increases by 19%, respectively, compared to unloading on the move.

Using the obtained results, established study data and the adopted working width utilization factors \( \beta = 0.93 \) and the working time utilization factor \( \gamma = 0.71 \), the following grain harvester hourly outputs have been obtained, presented in Table 2, and their graphic image is given on Figure 1.

The results obtained and presented in Table 1 and Figure 1 shows that only the incorrect setting of the harvester hopper levels results in a 1% reduction of the output (17.15 t/h vs. 17.51 t/h, respectively 25.22 da/h vs. 25.73 da/h) when unloading at standstill. Much more significant impact on the output has the method of hopper unloading. In this case, the actual output is 17.15 t/h (25.22 da/h), and the actually possible output, if the harvester works with the same indicators and unloads on the move, will reach an output of 20.91 t/h (30.74 da/h), that is, it will harvest at 18% higher output.

The actual and actually possible output when unloading at standstill and on the move can be significantly higher. This statement is based on the fact that the harvester was harvesting at a relatively low operating speed (4.85 km/h) and the unofficial data for this harvester and harvesting yield at this value is that a speed of between 6 and 7.5 km/h is used.

<table>
<thead>
<tr>
<th>Output Harvester</th>
<th>( W_{\text{act}} ), t/h</th>
<th>( W_{\text{act}} ), da/h</th>
<th>( W_{\text{act, possible}} ), t/h</th>
<th>( W_{\text{act, possible}} ), da/h</th>
<th>( W_{\text{possible}} ), t/h</th>
<th>( W_{\text{possible}} ), da/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Claas Lexion 660</td>
<td>17.15</td>
<td>25.22</td>
<td>17.51</td>
<td>25.73</td>
<td>20.91</td>
<td>30.74</td>
</tr>
</tbody>
</table>
The investigations revealed that there is a significant difference between the actual output at which the harvester had been harvesting and the actually possible one if it unloads on the move. For this purpose, the days needed for harvesting the crop with the two unloading methods have been calculated by using the following dependencies:

- Actual days needed for harvesting the wheat when unloading the grain hopper at standstill:
  \[ D_{act} = \frac{S}{W_{\text{wheat}} \cdot T_k} = \frac{800}{25,22,11,1} = 2,88 \text{ days} \] (9)

- Actually possible days for harvesting the wheat when unloading the grain hopper on the move:
  \[ D_{\text{mov}} = \frac{S}{W_{\text{possible}} \cdot T_k} = \frac{800}{30,74,11,1} = 2,36 \text{ days} \] (10)

The results show that crop harvesting times can be shortened if unloading on the move is used, by about one day, respectively, when harvesting the wheat crop. In fact, reducing harvest days will be more, given that the conditions of harvest within the agro-technical period are often changing and there are days when no harvest takes place or the harvesting is only for a few hours. It is known that every day during the harvesting campaign is particularly important.

The days designated for harvesting the crop are working days and can be considered as term for crop harvesting. Practically, the days during which it was not possible to harvest due to rainfall or other force majeure have not been taken into account in the present case.

**Conclusion**

It was found that: a) the average unloading time of the grain harvester hoppers with stopping for unloading on the field is 237.4s; b) about 1 m³ of the harvester hopper was not in use and the number of its stops increased; in practice, this results in reducing the grain harvester output; c) the actual grain harvester output when unloading at standstill is 17.15 t/h (25.22 da/h), and the actually possible output if the harvester operates with the same indicators and unloads on the move will reach an output of 20.91 t/h (30.74 da/h), that is, it will harvest at 19% higher output; d) the crop harvesting times can be shortened by about one day if the method unloading on the move is used.

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