Grain combines productivity according to various unloading methods – in the field and at the edge of the field

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Grain combines productivity according to various unloading methods – in the field and at the edge of the field

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Abstract. *Grain tank unloading is usually done at a standstill. In some cases the combine has to leave the processed strip and to unload in a vehicle located outside the field. The publication analyses the reasons for unloading grain tanks by leaving the processed strip and the impact of this type of unloading on the combine productivity compared to unloading the grain tank in the field itself. A study has been performed in Bulgarian farms using different ways of unloading and the results of time measured for unloading grain tanks in and at the end of the field have been given when harvesting various agricultural crops. The combine productivity when unloading in the field and at the edge of the field has been compared. It has been determined that when unloading at the edge of the field the productivity is approximately 11% lower than the productivity during unloading at a standstill in the field.*

Keywords: combines, productivity, grain tank unloading, time for grain tank unloading

Introduction

Harvesting crops is the final stage of all activities related to their cultivation and is characterized by seasonality, high energy consumption, yield losses and multi-variability (Ishpekov, 2013). The harvest of cereals is one of the main activities in agriculture and it should be done within a shorter period - maximum 10 – 12 days, in order to avoid high losses of grain spillage and to reduce the risk of crop damage due to environmental conditions (Nikolov et al., 1974).

Cereals account for the largest percentage of arable land in the country. The process of their harvesting is fully mechanized and is characterized by simultaneous operation of harvesters, vehicles and other machines that ensure this process. Of great importance is the overall logistics of the process, which is associated both with the proper organization and selection of a variety of ways and means to perform the processes. The improper method of harvesting, delaying the harvesting campaign or poor organization can result in substantial material losses (Mandradzhiev, 2006; Li et al., 2013; Delchev and Trendafilov, 2013; Petrovna, 2014). Important for both the organization and the combine productivity is the method of unloading the grain tanks.

There are two main ways of unloading grain tanks: unloading on the go and unloading at a standstill. In terms of the organization of transport, the means of unloading can be classified as direct and indirect transport services (Vezirov et al., 2009; Scheuren et al., 2013). In relation to the optimization of grain tank unloading and the coordination between combines and vehicles, some authors (Ali et al., 2009) examined two scenarios of unloading: continuous and interrupted harvest. During continuous harvest, unloading is done on the move or at a standstill and the combine does not leave the processed strip. During interrupted harvest the combine leaves the strip and moves to the vehicle.

In our country, in about 90% of agricultural farms unloading is performed at a standstill. In some of them (about 13%) the combines leave the processed strip, move to the edge of the field and unload into vehicles (tractor vehicles or road vehicles) located outside it (Delchev et al., 2016). The reasons for this are as follows:

- when harvesting rice - it is practically impossible for a vehicle to enter into the rice "cells" (Delchev and Trendafilov, 2015);
- when harvesting sunflower – the sunflower stubbles intensively destroy the vehicle tyres;
- waterlogged soil, presence of a deep drainage ditch between the road and the field or undersized area;
- use of road vehicles that are not suitable for movement onto stubbles.

It should be noted that the latter reason is becoming more relevant with the construction of highways in the country and the separation of arable land in the farms, which determines the use of road vehicles with large capacity and high transport speed.

Unloading the grain tanks and moving the combines to the transport vehicles outside the field in most cases is necessary and appropriate, but it is associated with additional operations, which extend the total unloading time. This, in turn, results in a decrease in productivity (hourly, daily, seasonal) and in extending the harvest term. It is known that the combine productivity depends both on the technical parameters of the machine, and on the logistics factors. Such a factor is the place of unloading the full grain tanks.

The objective of this article is to investigate how the unloading time affects the performance during unloading at a standstill without leaving the processed strip and when going to the edge of the field.

Material and methods

A study has been conducted on the time for unloading grain combines in nine farms during wheat harvesting. In each farm one combine was selected with technical parameters within the following values: header working width - 6.1-7.2 m; grain tank volume – 8.6-

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9.0 m^3; unloading auger flow 105-130 l/s. When comparing the productivity of the various ways of grain tank unloading, only the cases when pure time to fill the grain tank (without stopping for technological reasons) is close have been taken into account. It has been conditionally accepted that it is the same for different combines *Tw*=20 min=1200 s. All combines have two levels of signaling for a full tank. In all five farms (A1, A2, A3, A4 and A5) the combines stopped in the field, having filled the grain tank (second level of signaling), without leaving the processed strip, and waited for the vehicles (announced by the first level of signaling) to unload their tanks therein. In the other four farms (B1, B2, B3 and B4) the combines left the processed strip, having filled the tanks (second level of signaling), and moved to the edge of the field, unloading their tanks into the waiting vehicles. By timing the following has been measured:

- T_s - grain tank unloading time, s. This is the time from stopping the harvesting process for unloading until the start of harvesting after the tank had been emptied, that is the time during which no productivity is achieved;

- T_t - time for emptying the full grain tank, s;

- T_g – the time it takes the combine to move from the location in the field where the tank had been filled to the edge of the field where unloading takes place, s;

- T_r – the time it takes the combine to move from the location of unloading at the edge of the field to the point in the field where the next operation starts, s.

When unloading the combines outside the field, the time for grain tank unloading is as follows:

$$T_s = T_g + T_t + T_r, \text{ s} \quad (1)$$

The arithmetic mean of the above time intervals has been calculated for each combine following the equation

$$\overline{X}_j = \frac{1}{n_j}\sum_{i=1}^{n_j} x_{ij} \quad (2)$$

where x_{ij} is the *i*-th experimental value for the *j*-th combine;

n_j – the number of measurements for the *j*-th combine.

For the two groups of combines (unloading in the field and at the edge of the field) the total (weighted) arithmetic mean has been calculated:

$$\overline{X} = \frac{1}{\sum_{j=1}^{m} n_j}\sum_{j=1}^{m} n_j.\overline{X}_j \quad (3)$$

where *m* is the number of combines in the group.

For each combine the following has been determined:

- corrected mean square deviation

$$s = \sqrt{\frac{1}{n_j - 1}\sum_{i=1}^{n_j}\left(x_{ij} - \overline{X}_j\right)^2} \quad (4)$$

- variation coefficient

$$\hat{V} = \frac{s}{\overline{X}_j}.100, \quad \% \quad (5)$$

- trust interval of the mean value

$$I_{\gamma;k}^{E[X]} = \left(\overline{X}_j - t_{\gamma;k}\frac{s}{\sqrt{n_j}}; \overline{X}_j + t_{\gamma;k}\frac{s}{\sqrt{n_j}}\right) \quad (6)$$

- relative error limit

$$\Delta_{\gamma;k} = \frac{t_{y;k}.s}{\sqrt{n_j}.\overline{X}_j} \quad (7)$$

The criterion of Student $t_{\gamma;k}$ has been defined in trust probability γ = 0.9 and degrees of freedom $k=n_j-1$. All calculations have been done by the methodology described by Mitkov and Minkov (1989). According to the same authors, when studying agricultural machinery trust probability can be assumed to be 0.9 and the relative permissible error can be within the range 5-10%. We have accepted these values when evaluating and analysing the experimental results.

In order to analyze the effect of the unproductive time connected with grain tank unloading on its productivity, the following equation is used to determine the combine productivity for operational time

$$W = \frac{S}{T_o} = \frac{S}{T_w + T_s}, \quad \frac{ha}{h} \quad (8)$$

where *S* is the harvested area that fills the entire tank, *ha*;

T_o – the time for performing a cycle of filling and unloading of the grain tank (operational time),

T_w - time for filling the grain tank, *h*.

The use of this equation to determine the combine productivity is in order to eliminate the factors that affect the productivity, but are not related to the way of grain tank unloading, such as the idle time due to technical or other reasons.

The processing time per area unit is inversely proportional to productivity, i.e.

$$T_1 = \frac{1}{W} = \frac{T_w + T_s}{S}, \quad \frac{h}{ha} \quad (9)$$

By using the results from the timing, the change in productivity and processing time per area unit has been calculated for the various methods of grain tank unloading at a standstill compared to grain tank unloading in motion. Another comparison has been made between unloading in the field and at the edge of the field.

Results and discussion

The results from the time measurement for grain tank unloading in the field without leaving the processed strip are shown in Table 1 and Figure 1. The average duration of the time T_s is 189.56 *s*, and it varies between 129.47 *s* and 216.88 *s* in each individual farm. The relative error γ=0.9 is within the acceptable limits. It is noteworthy that the average unloading time in the four farms (A1, A2, A4 and A5) is almost equal - between 204.67 and 216.88 *s*. In one of the farms (A3) that time is significantly different – 129.47 *s* or between 36.74% and 40.3% less in comparison to the rest. This great time difference T_s is due mainly to the less waiting time of the vehicle in that farm. For logistical reasons the differences in unloading time are due to incoherence in the actions of the combine operators and vehicle drivers and to incorrect setting of the grain tank full level sensor. The greater the values of T_s, the lower the productivity. With the same objective factors (technical parameters of the grain combines), the subjective factors (operators) have serious effect on the unloading time in the field, respectively the grain combine productivity.

When unloading grain tanks by moving the combines towards the edge of the field and unloading into vehicles located outside the field, the unloading time is formed by the duration of the following operations: time for the combine to move to the edge of the field; time for emptying a full tank; time for the combine to return to the field and this is determined by the equation (1). Table 2 shows the results of the grain tank unloading time T_s when going to the edge of the field

Table 1. Unloading time of grain combines in the field

Farm	Number of measurements, n	Mean unloading time in the field, T_S, s	Corrected mean square deviation, S	Variation coefficient, $\hat{V}$, %	Trust interval $I_{\gamma;k}^{E[X]}$	Relative error limit $\Delta_{\gamma;k}$, %
A1	17	216.88	39.6	18.26	200.11; 233.63	7.73
A2	19	210.42	32.6	15.49	197.45; 233.29	6.16
A3	19	129.47	27.28	21.07	118.62; 140.32	8.38
A4	12	204.67	37.04	18.1	184.61; 224.73	9.80
A5	6	206.17	23.32	11.31	186.94; 225.4	9.33
Average idling time when unloading, s		189.56				

Table 2. Unloading time for grain combines at the edge of the field

Combine	Number of measurements, n	Mean unloading time at the edge of t he field, T_S, s	Corrected mean square deviation, S	Variation coefficient, $\hat{V}$, %	Trust interval $I_{\gamma;k}^{E[X]}$	Relative error limit $\Delta_{\gamma;k}$, %
B1	8	388.63	50.32	12.95	354.92; 422.34	8.67
B2	7	299.86	40.30	13.44	270.02; 329.53	9.90
B3	8	351.25	26.99	7.68	333.17; 369.33	5.15
B4	7	383.86	55.80	14.54	342.02; 425.70	10.90
Average idling time during unloading, s		356.84				

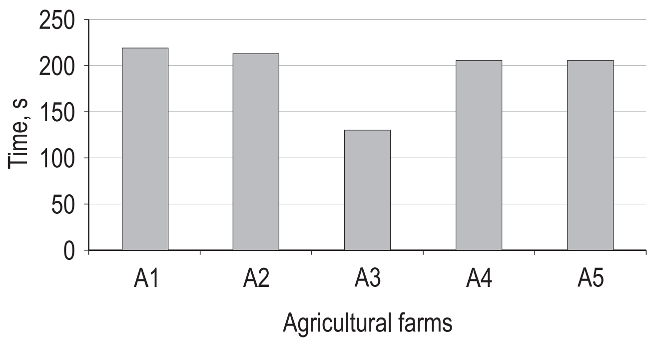

Figure 1. Unloading time of grain combines in the field

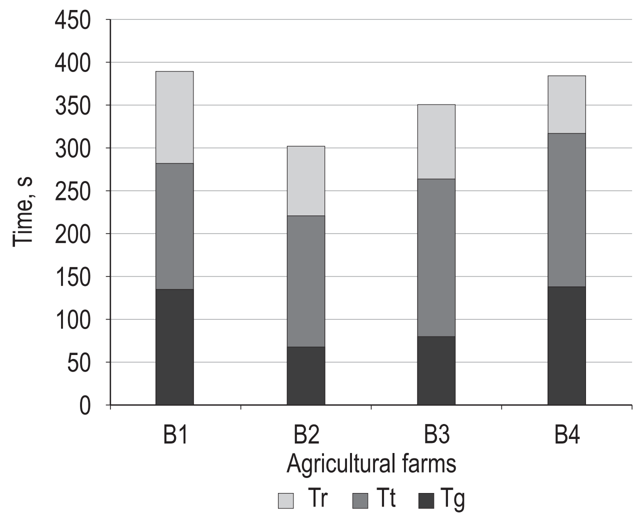

Figure 2. Unloading time of grain combines at the edge of the field

for the four farms, and its graphical representation is shown in Figure 2.

The average duration of unloading time by moving the combine to the edge of the field is T_s 356.84 *s*, as it varies between 299.86 and 388.63 s in each farm. In one farm the relative error limit exceeds 10%. The graph on Figure 2 shows that the differences in the time duration of T_s in each farm are mainly due to differences in the duration of operations relating to movement of the combine T_g and T_r.

Table 3 shows the results in time to empty full tanks T_t. The average time for that group of combines is 166.17 *s*, as it varies between 146.75 *s* to 185.13 *s* in each farm. The difference between two of the farms (B1 and B3) is around 21% and it is quite unexpected since the technical parameters of the combines affecting that time are very close. Our observations determined that the main reason for the difference is that the maximum flow rates of

Table 3. Time for emptying a full bunker

Farm	Number of measurements, n	Unloading time for a full tank, Tt, s	Corrected mean square deviation, S	Variation coefficient, $\hat{V}$, %	Trust interval $I_{\gamma;k}^{E[X]}$	Relative error limit $\Delta_{\gamma;k}$, %
B1	8	146.75	15.59	10.62	136.3; 157.2	7.12
B2	7	154.29	13.00	8.42	144.72; 163.86	6.20
B3	8	185.13	18.77	10.14	172.55; 197.71	6.80
B4	7	178.57	20.6	11.53	163.40; 193.74	8.50
Average time for emptying a full bunker, s		166.17				

the discharging augers are not used. Usually, unloading is done at lower engine speed, respectively of the auger (the discharge system). Also, the tank valves regulating the flow of grain to the discharge system are not calibrated for the respective crop.

The time T_g for moving the combine to the edge of the field is indicated in Table 4. Its average value for the group of farms is 104.53 s and it varies considerably - between 66.43 s and 136.71 s. The variation coefficient is high, especially in the last farm, where the relative error is significantly higher than the permissible one. Similar results were obtained for the time it takes the combine to return from the edge of the field to the place of harvest T_r (Table 5). These variations in results can be considered expected. The duration of both time intervals depends entirely on the distance between the location in the field where the tank is being filled and the location of the vehicles waiting right outside the field. These distances are greater in fields with a larger area, irregular shape and smaller length of the border with their service road on which of the vehicles wait.

Table 4. Time for movement of the combine from the inside of the field to the unloading point at the edge of the field

Farm	Number of measurements, n	Mean time for movement to the edge of the field, Tg, s	Corrected mean square deviation, S	Variation coefficient, $\hat{V}$, %	Trust interval $I_{\gamma;k}^{E[X]}$	Relative error limit $\Delta_{\gamma;k}$, %
B1	8	135.25	26.7	19.74	117.36; 153.14	13.23
B2	7	66.43	12.66	19.06	55.11; 75.75	14.03
B3	8	79	13.73	17.38	69.8; 88.2	11.65
B4	7	136.71	60.66	44.35	92.07; 181.35	32.65
Average time for movement to the edge of the field, s		104.53				

Table 5. Time for movement of the combine from the edge of the field to the place of harvest

Farm	Number of measurements, n	Mean time of movement from the edge of the field to the place of harvest Tr, s	Corrected mean square deviation, S	Variation coefficient, $\hat{V}$, %	Trust interval $I_{\gamma;k}^{E[X]}$	Relative error limit $\Delta_{\gamma;k}$, %
B1	8	106.63	30.59	28.69	86.14; 127.12	19.22
B2	7	79.14	20.19	25.52	64.27; 94.01	18.79
B3	8	87.13	13.23	15.18	78.27; 95.99	10.17
B4	7	68.57	21.90	31.94	52.45; 84.69	23.51
Average time for movement from the edge of the field to the harvesting location, s		86.14				

The average time for moving the combine from inside the field to the unloading location at the edge of the field (T_g=104.53 s) is greater than the travel time of the combine from the edge of the field to the place of harvest (T_r=86.14 s). This seems natural and can be explained with the varying combine speed with a full or an empty tank, respectively lower and higher. It is noteworthy that in two of the farms the time T_g is less than T_r, i.e. the speed of the combine with an empty tank was lower. In our observations, the combine operators lowered the speed to provide "softer" movement and to reduce the header "bounce", when the tank of the combine is empty and, therefore, the total mass of the machine is lower. Eventually, these times are affected by numerous external factors - the state of the stubbles, the air pressure in tyres, the machine mass, the fixing of the header (the distance from the front axle of the machine), etc.

The total average time of moving operations from inside the field to the unloading point at the edge of the field and return from the edge of the field to the harvesting point is $T_g + T_r$ = 190.67 s and exceeds the average time for emptying the full tank – 166.17 s. The ratio $T_g + T_r : T_t$ is 53.44% : 46.56%. In other words, the time for unloading combines at the edge of field T_s is formed to a greater extent by the movement times of the combine to the vehicle and its return back, rather than the tank emptying time.

The results on Table 1 and Table 2 show that the average unloading time of the grain tanks T_s in the field is 3.16 min and it is significantly less than the average unloading time T_s in a vehicle located outside the field – 5.95 min. This is unproductive time and affects both the productivity and the duration of time for processing area unit. In order to calculate its effect, the following equations (8) and (9) were used, and the duration of the processing time per area unit and productivity were compared with unloading on the move. That is, when there is no unrealized productivity connected with stopping for grain tank unloading.

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

$$T_{1\%} = \frac{T_{1S}}{T_{1M}}.100 = \frac{\frac{T_w + T_s}{S}}{\frac{T_w}{S}}.100 = \frac{T_w + T_s}{T_w}.100, \quad \% \tag{10}$$

where T_{1S} is the time for processing an area unit when unloading at a standstill, ha/h;

T_{1M} – 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:

$$W_{\%} = \frac{W_S}{W_M}.100 = \frac{\frac{S}{T_w + T_s}}{\frac{S}{T_w}}.100 = \frac{T_w}{T_w + T_s}.100, \quad \% \tag{11}$$

where W_S is productivity when unloading at standstill, ha/h;

W_M – productivity when unloading on the move, ha/h.

When using the obtained average results from the study on the unloading time and the adopted equal time for filling the tank in the various combines T_w=20 *min*=1200 *s* the result is as follows:

- for unloading in the field (T_s = 189,56 *s*)

$$W_{\%} = \frac{T_w}{T_w + T_s}.100 = \frac{1200}{1200 + 189{,}56}.100 = 86{,}36\% \qquad (12)$$

$$T_{1\%} = \frac{T_w + T_s}{T_w}.100 = \frac{1200 + 189{,}56}{1200}.100 = 115{,}8\% \qquad (13)$$

- for unloading at the edge of the field (T_s =356,84 *s*)

$$W_{\%} = \frac{T_w}{T_w + T_s}.100 = \frac{1200}{1200 + 356{,}84}.100 = 77{,}08\% \qquad (15)$$

$$T_{1\%} = \frac{T_w + T_s}{T_w}.100 = \frac{1200 + 356{,}84}{1200}.100 = 129{,}74\% \qquad (16)$$

The results show that upon stopping for unloading in the field, 14% of the combine productivity is not achieved, and when unloading at the edge of the field - 23%. The processing time per area unit increases with 15% and 30%, respectively, compared to unloading on the move.

The unrealized productivity and the increase of the harvest work time per area unit when unloading the grain tank at a standstill can be determined by using the graph shown on Figure 3. On the abscissa is the ratio *Ts/Tw*, and on the ordinate are the values *W%* and *T1%*. During harvest without stopping the combine for unloading (Ts = 0), 100% of its productivity is used. If the unloading time is equal to the harvest time (Ts/Tw=1), as seen from the figure, the combine productivity decreases twice, and the time required for processing an area unit increases twice. For the experimentally obtained data when stopping in the field for unloading, we get Ts/Tw=189.56/1200=0.158, and for unloading at the edge of the field - Ts/Tw=356.84/1200=0.3. After plotting the graphs of W% and T1% along the ordinate the percentage of the used productivity can be directly reported, and also the increased time for harvesting per area unit, that coincide with the above calculations.

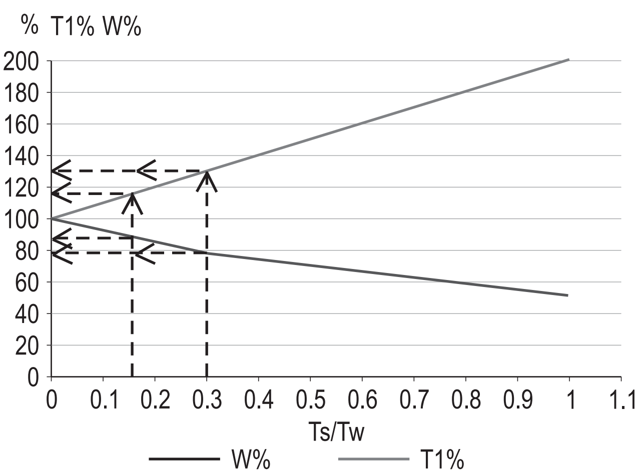

Figure 3. Diagram for reporting change of productivity W% and time for processing an area unit T1% when unloading at a standstill depending on the relationship between combine idling time for unloading Ts and the time for filling the tank Tw

When comparing the variants for unloading at a standstill (unloading in the field compared to unloading at the edge of the field) we obtain:

$$W_{\%} = \frac{T_w + T_s}{T_w + T_g + T_t + T_r}.100 = \frac{1200 + 189{,}56}{1200 + 104{,}53 + 166{,}17 + 86{,}14}.100 = 89{,}26\% \qquad (16)$$

$$T_{1\%} = \frac{T_w + T_g + T_t + T_r}{T_w + T_s}.100 = \frac{1200 + 104{,}53 + 166{,}17 + 86{,}14}{1200 + 189{,}56}.100 = 112{,}04\% \qquad (17)$$

The results show that when unloading at the edge of the field the combine productivity is nearly 11% lower if compared to the productivity when unloading in the field. Respectively, processing time per area unit increases by about 12%.

Conclusions

It has been determined that: the average time for grain tank unloading with stopping of the combines in the field is 3.16 min, and the average time for going to the edge of the field and unloading into a vehicle located outside it – 5.95 min; 53% of the grain tank unloading time at the edge of the field (from the total 5.95 min) is used for moving the harvester to the transport vehicle, and back; when combines unloading at the edge of the field their productivity is approximately 11% lower than the productivity during unloading at a standstill in the field, respectively, the time for harvesting an area unit increases with about 12%; when combines stopping for unloading in the field the combine productivity decreases with 14% and when unloading at the edge of the field it decreases with 23% compared to unloading on the move; the processing time per area unit increases with 15% and 30%, respectively.

A diagram has been developed for reporting changes in productivity and time for harvesting an area unit when unloading at a standstill compared to unloading on the move, depending on the ratio between the combine idling time for unloading and the time for filling the tank (operation of the combine).

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Thesis:

Hristova D, 2013. Investigation on genetic diversity in local sheep breeds using DNA markers. Thesis for PhD, Trakia University, Stara Zagora, Bulgaria, (Bg).

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