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Assessment of the harvesting costs of different combine harvester fleets

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Abstract: This study discusses practical collection methods of cereal harvesting costs in different agricultural holdings in order to effectively manage combine harvester fleets, make economically reasoned decisions on the exploitation of combine harvesters, reduce harvesting costs and consequently the cost price of cereals. For this purpose, the author used work results of combine harvesters monitored by three randomly selected agricultural holdings, collected practical information on harvesting, analysed this information and provided assessments on the effectiveness of their combine harvester fleet. Evidently, not all combine harvester fleets and combines operate with the same efficiency, as their harvesting costs are different.

Keywords: combine harvester performance; fixed and variable cost; cereal harvesting unit cost; fuel consumption

A combine harvester is a technical device that affects the technological development trends of agriculture just like a tractor (Kutzbach 2000). There are many known methods for selecting combine harvesters and designing combine harvester fleets. It is possible to design a fleet analytically by considering the technical and technological parameters of the machines. In order to model a combine harvester fleet, for example, a mathematical model has been prepared (Bulgakov et al. 2015) for determining the composition of a combine harvester fleet with the purpose of ensuring the performance of all the harvesting related operations according to the structure of the grown cereals, agro-technically optimal times, optimum material costs and working time.

Machine fleets are designed also based on other practical factors such as the location of the machine dealership and technical assistance, i.e. distance from the client etc. As a result of technological developments the combine harvester and tractor fleets and in particular their capability has changed over the years (Kutzbach 2000; Miu 2015), but they have also changed due to social-economic developments of countries over the years (Pawlak et al. 2002; Olt et al. 2010; Olt, Traat 2011; Viesturs, Kopics 2016). The general trend is that since 1965, when a record number of combine harvesters (over 60,000 machines) were manufactured and commissioned in Western Europe, the engine power (kW) and throughput ($t \cdot h^{-1}$) of combine harvesters has increased every year and their yearly sales quantity has decreased accordingly (Kutzbach 2000).

The formation of harvesting costs of combine harvesters has been studied by many authors (Gunnarson et al. 2009; Hanna, Jarboe 2011; Spokas, Steponavicius 2011; de Toro et al. 2012; Singh et al. 2012; Vladut et al. 2012; Findura et al. 2013; Nozdrovický et al. 2013; Prístavka et al. 2013, 2017; Benes et al. 2014; Bochtis et al. 2014; Prístavka, Bujna 2014; Mašek et al. 2015, 2017). Some of them have focused on the characterisation of specific machines from different manufacturers, such as John Deere (Benes et al. 2014; Prístavka et al. 2017) and New Holland (Mašek et al. 2017). For example, Prístavka et al. (2013) studied the harvesting costs of combine harvesters John Deere CTS 9780 and Z2264 in their work during a period of three years (2010 to 2012). Prístavka et al. (2017)

https://doi.org/10.17221/98/2017-RAE

have also monitored the combine JD 9660 WTS for three years (2013–2015) and presented the harvester's actual harvested area performance (2.2 and 2.6 ha·h^{-1}), various harvesting costs, fixed and variable costs, including fuel consumption (16–17 l·ha^{-1}). Benes et al. (2014) have studied the harvesting costs of JD tangential-flow and axial-flow combines and discovered, that the harvesting costs of an axial-flow combine are slightly lower comparing to a regular combine. Mašek et al. (2017) have studied the performance, fuel consumption and maintenance costs of NH tangential-flow (CX) and axial-flow combines (CR). All these studies provide an overview of the amount of harvesting costs of different combine harvesters per season or year, but they do not specify the operational efficiency of these machines. This raises a question whether the harvested area performance of combine harvesters depends on the year and if so, then how and what are the main influences? Additionally, are the harvesting costs of similar combines always the same?

According to Sopegno et al. (2016) the main operating costs of a machine fleet are spare part, machine repair and fuel costs. The article explains that the freely usable application AMACA (Agricultural Machine App Cost Analysis) is intended for analysing the operating costs of a machine fleet. The user of this app must enter input parameters such as purchase price of fuel (varies by country and changes daily), interest rate of the machine, field parameters, engine power of the machine etc. This raises a question whether the input parameters in this calculation model are sufficient for analysis.

The objective of this study was to compare data collection methods for calculating the harvesting costs of various cereal growers and the collected data as well as analyse whether it is possible to make assessments about the efficiency of a combine harvester fleet based on the collected data and make practical, economically reasoned decisions to improve the efficiency of operations of this combine harvester fleet. For this purpose, the term cereal harvesting unit cost was used.

MATERIAL AND METHODS

Cereal harvesting unit cost (e_A) includes fixed and variable costs of cereal harvesting (Fairbanks et al. 1971; Ammann 1999) and it is inversely proportional to the performance of a combine harvester (W) and it represents harvesting costs per hectare or field area unit (EUR·ha^{-1}) or a ton of harvested cereals (EUR·t^{-1}) based on the following calculation method (Eq. 1):

$$e_A = \frac{1}{W}\left(C_{\mathrm{F}} + C_{\mathrm{V}}\right) \tag{1}$$

where: C_{F} – fixed cost (EUR·h^{-1}); C_{V} – variable cost (EUR·h^{-1})

The fixed cost C_{F} is calculated as follows (Eq. 2):

$$C_{\mathrm{F}} = \frac{1}{T}\left(C_{\mathrm{d}} + C_{\mathrm{l}} + C_{\mathrm{i}} + C_{\mathrm{g}}\right) \tag{2}$$

where: T – combine harvester seasonal workload, i.e. total seasonal working time (h); C_{d} – combine harvester depreciation (EUR); C_{l} – combine harvester financial lease or operating lease annual fee – for leased machines (EUR); C_{i} – combine harvester annual insurance cost (EUR); C_{g} – combine harvester total garage cost (EUR)

Whereby the combine harvester depreciation C_{d} is calculated as follows (Eq. 3):

$$C_{\mathrm{d}} = \frac{C_b \times a_c}{100} \tag{3}$$

where: C_b – carrying amount of the combine harvester (EUR); a_c – depreciation rate (%), i.e. accounting rate, which can vary for each agricultural holding

The variable cost C_{V} is calculated as follows (Eq. 4):

$$C_{\mathrm{V}} = \frac{C_{\mathrm{m}}}{T} + C_{\mathrm{f}} + C_{\mathrm{l}} \tag{4}$$

where: C_{m} – combine harvester annual maintenance costs – service and repair (EUR); C_{f} – special fuel charge – including lubricant costs (EUR·h^{-1}); C_{l} – labour costs – salary plus taxes (EUR·h^{-1})

The special fuel charge C_{f} (EUR·h^{-1}) is calculated as follows (Eq. 5):

$$C_{\mathrm{f}} = Q_{\mathrm{f}} \times r_{\mathrm{f}} \tag{5}$$

where: Q_{f} – hourly fuel consumption (l·h^{-1}); r_{f} – fuel purchase price (EUR·l^{-1})

Whereby the hourly fuel consumption Q_{f} is calculated as follows (Eq. 6):

$$Q_{\mathrm{f}} = \frac{k_1 \times q_{\mathrm{f}} \times P_{\mathrm{n}}}{\rho} \tag{6}$$

where: k_1 – engine load factor; q_{f} – special fuel consumption (kg·kWh^{-1}); P_{n} – engine nominal power (kW); ρ – fuel density (kg·l^{-1})

https://doi.org/10.17221/98/2017-RAE

Labour costs C_l are calculated as follows (Eq. 7):

$$C_l = M_c \times q_p \times k_p \quad (7)$$

where: M_c – amount of crops harvested by combine harvester (t·h^{-1}); q_p – piecework pay, i.e. fee for harvesting 1 t of cereals (EUR·t^{-1}); k_p – factor considering labour costs

Performance W of a combine harvester can be divided in two: harvested area and harvested weight performance, where harvested area performance W_A (ha·h^{-1}) is calculated as follows (Eq. 8):

$$W_A = 0.1 \times v_k \times B_h \times \beta \quad (8)$$

where: v_k – combine harvester working speed (km·h^{-1}), $v_k = v_b(1 - \delta)$; B_h – header working width (m); β – use factor of header working width (β ≤ 1, usually β = 0.9 ... 1.0); v_b – speed according to on-board computer; δ – slip factor

Work of an operating combine is better characterised by daily performance, which is calculated as follows (Eq. 9):

$$W_{A,d} = 0.1 \times v_k \times B_h \times \beta \times T_d \times \tau \quad (9)$$

where: T_d – total length of workday on field (h), including time on empty runs on field (i.e. maneuvering), passing from one lane to another, adjusting the combine harvester, technological and organisational and other time-consuming aspects; τ – use factor of working time

Whereby the use factor of working time τ is calculated as follows (Eq. 10):

$$\tau = \frac{T_e}{T} \quad (10)$$

where: T_e – combine harvester effective working time (h), i.e. time, when combine is harvesting cereals and when header is in lowered position and operating

Combine harvester harvested weight performance W_m, i.e. the amount of harvested crops in time unit (t·h^{-1}), which is more characteristic and comprehensive than harvested area performance, is calculated as follows (Eq. 11):

$$W_m = 0.1 \times v_k \times B_h \times \omega \quad (11)$$

where: ω – cereal yield (t·ha^{-1})

When calculating cereal harvesting unit cost e_Y per harvest weight (t), fixed and variable costs must be determined per harvest ton (EUR·t^{-1}).

This study analysed the harvesting costs of combine harvester fleets of three randomly selected agricultural holdings who apply different methods for collecting and using data. These holdings are referred to in this article as the first, the second and the third agricultural holding. The first holding has 2,044 ha of cultivated area, 1,000 ha of which is used for the production of cereals. The holding uses three Claas Lexion 670 combine harvesters, all of which are the same age and were purchased in 2016 with engine power of 320 kW/435 hp and header width of 7.7 m. All three combines worked mainly on the same fields and therefore experienced similar working conditions. A harvesting area of 1,000 ha is clearly insufficient for these three combines, which is why two of them (No. 3450 and 3459) were used to provide harvesting service for other neighbouring cereal growers. The daily harvesting data is collected from the on-board computer of the combine harvester in form of printouts and then entered into a summary table for subsequent analysis. This holding keeps separate records of the fuel consumption, salaries, maintenance and repair costs, depreciation, lease payments and insurance of the machines. This data is also added to the summary table. One of the sub-objectives of this study was to compare and analyse agro-technical characteristics and harvesting unit cost of similar combine harvesters.

The second agricultural holding has 4,000 ha of cultivated area, 1,452–1,701 ha of which has been used for the production of cereals during the last three years. The holding has one older combine Claas Lexion 460 (purchased in 2003) with engine power 230 kW and header width of 6.6 m and one newer combine Claas Lexion 670 (purchased in 2015) with header width of 7.7 m. This holding does not extract individual records of the work performed by combine harvesters every day or week. In case of fuel consumption and harvested crops general records are kept for combine harvester fleet and this data is not presented individually for each combine.

The third agricultural holding has 7,000 ha of cultivated area, 4,003 ha of which is used for growing cereals and oilseed crops. The holding has six combine harvesters: three New Holland CX 8080 and one New Holland CX 8090 with header width of 7.5 m, one Case 9230 and one Case 9240 with header width of 10.5 m. All the combines are leased and yearly operating lease is paid for all of them.

https://doi.org/10.17221/98/2017-RAE

The holding uses a special program Terake for the collection of harvesting data, more specifically for the calculation of the working time of employees, fuel consumption, harvested field area and amount of crop and also maintenance costs. The results are transferred from Terake to MS Excel tables, which are then used for creating summary tables. Using this program allows monitoring fuel consumption and labour costs and reduces errors that occur upon information processing.

RESULTS AND DISCUSSION

Exported data from the on-board computers of the combine harvesters of the first and second agricultural holdings are presented in summary in Table 1, agro-technical characteristics in Table 2 and economical characteristics in Table 3. Data of the combine harvesters Lexion 670 (No. 3450, 3459, 3449) of the first holding as well as the combine harvester of the second holding refer to the harvesting season of 2016, in case of combine harvester Lexion 460 (No. 3948) of the second agricultural holding average annual data of 11 years (2004–2014) has been provided.

Total working time in Table 2 represents the time when the combine harvester engine was turned on and running (h). Field working time represents the time when the threshing machine was operating (h). Effective working time represents the time when the header was in operating position and all the combine harvester attachments were operating. Straw chopper working time represents the time when the straw chopper of the combine harvester was operating. The observable agricultural holdings did not chop all the straw nor spread it on the field.

Table 1 shows that the combine harvester No. 3450, which has performed the most service work,

Table 1. Summary table of the data exported from on-board computers of the combine harvesters of the first and second agricultural holding

	1st holding, Lexion 670			2nd holding, Lexion 460	2nd holding, Lexion 670
	No. 3450	No. 3459	No. 3449	No. 3948	No. 2488
Total annual working time (h)	323.89	301.42	267.50	384.45	411
Field annual working time (h)	197.47	196.67	152.20	250.09	260
Effective working time (h)	167.18	176.22	134.90	218.58	231
Straw chopper working time (h)	60.20	106.81	47.46	83.82	176
Harvested annual area (ha)	752.97	964.76	731.08	744.55	859
Total distance travelled (km)	1,758.697	1,912.051	1,575.707	2,104.73	2,271
Distance travelled on road (km)	412.674	405.852	257.588	637.46	744
Distance travelled on field (km)	1,326.534	1,506.201	1,318.120	1,467.27	1,527
Total fuel consumption (l)	10,027.70	10,439.65	8,252.51	–	–
Fuel consumption on road (l)	456.20	369.65	330.51	–	–
Fuel consumption on field (l)	9,571.70	10,070.15	7,922.01	–	–

Table 2. Agro-technical characteristics of combine harvesters of the first and second agricultural holding

	1st holding, Lexion 670			2nd holding, Lexion 460	2nd holding, Lexion 670
	No. 3450	No. 3459	No. 3449	No. 3948	No. 2488
Harvested weight performance ($t \cdot h^{-1}$)	17.51	17.52	21.98	11.07	15.96
Harvested crops (t)	3,457.55	3,445.73	3,345.72	2,768.53	4,150.00
Harvested area performance ($ha \cdot h^{-1}$)	3.81	4.91	4.80	3.10	3.30
Total fuel consumption per hour ($l \cdot h^{-1}$)	30.96	34.63	30.85	-	-
Fuel consumption per hour on field ($l \cdot h^{-1}$)	48.47	51.20	52.05	-	-
Fuel consumption per area unit ($l \cdot ha^{-1}$)	13.32	10.82	11.29	-	-
Fuel consumption per harvest ($l \cdot t^{-1}$)	2.90	3.03	2.47	-	-

https://doi.org/10.17221/98/2017-RAE

Table 3. Economical characteristics of the combine harvesters of the first agricultural holding

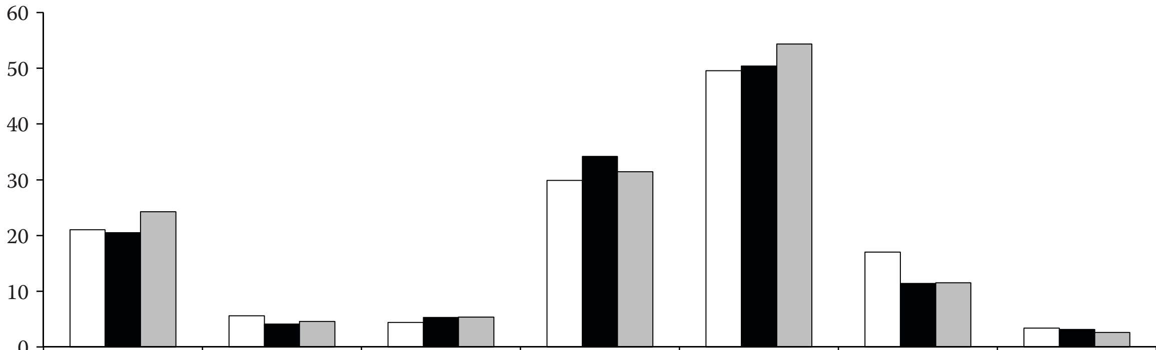
	Lexion 670		
	No. 3450	No. 3459	No. 3449
Fixed cost (EUR·h^{-1})	27.50	35.21	42.73
Variable cost (EUR·h^{-1})	55.88	54.14	58.20
– maintenance cost (EUR·h^{-1})	0.34	0.76	0.50
– fuel cost (EUR·h^{-1})	19.64	21.97	19.60
– labour costs (EUR·h^{-1})	31.87	23.47	27.61
Unit cost (e_A) (EUR·ha^{-1})	25.24	27.49	21.03
Unit cost (e_m) (EUR·t^{-1})	3.98	7.81	4.62

has the longest working time, longest distance travelled on road and therefore larger fuel consumption on road and also slightly smaller harvested area compared to the other combine harvester No. 3459 of the same agricultural holding, however the average workday length of the combine No. 3450 was 7.5 h, combine No. 3459 9.4 h and combine No. 3449 8.4 h. The average distance travelled on road was 9.6 km for combine No. 3450, 12.7 km for combine No. 3459 and 8.1 km for combine No. 3449.

The combine harvester Lexion 670 (No. 2488) of the second agricultural holding has shown the same level of capacity as the combine harvesters of the first agricultural holding. The combine harvester Lexion 460 (No. 3948) can also be considered efficient based on the harvested area. In 2008, it was used for harvesting crops from a field area of 805 ha. For the combine harvesters (No. 3948 and 2488) of the second agricultural holding there are many gaps in the fuel consumption records and therefore this data is not presented in the summary table.

In conclusion, it can be said that the combine harvester Lexion 670 is capable of harvesting crop from a field area of up to 1,000 ha during the season.

Table 2 shows that in case of the observable combine harvesters Lexion 670 the harvested area performance (e_A) was 3.81–4.91 ha·h^{-1} and the harvested weight (t) performance (e_m) was 17.51 to 21.98 t·ha^{-1}. However, if we look at average performances during the effective working time, then the best average harvested area performance (e_A) of 5.47 ha·h^{-1} was achieved by combine harvester No. 3459 and the best harvested weight performance of 24.80 t·h^{-1} by combine harvester No. 3449 (Fig. 1). The combine harvester Lexus 460 (No. 3948) also harvested on an average 3.1 ha·h^{-1} per year during 11 year period (2004–2014) and on an average 3.87 ha·h^{-1} during the best year (2007).



	Harvested weight (t) performance (t·h^{-1})	Harvested crops (t)	Harvested area performance (ha·h^{-1})	Total fuel consumption per hour (l·h^{-1})	Fuel consumption per hour on field (l·h^{-1})	Fuel consumption per area unit (l·ha^{-1})	Fuel consumption per harvest (l·t^{-1})
□ 3450	21.01	5.591	4.431	29.906	49.565	17.014	3.389
■ 3459	20.515	4.115	5.303	34.185	50.424	11.422	3.132
▩ 3449	24.235	4.57	5.371	31.417	54.364	11.541	2.58

Fig. 1. Comparison of the agro-technical characteristics of combine harvesters in the first company

https://doi.org/10.17221/98/2017-RAE

Table 4. Agro-technical and economical characteristics of the combine harvesters of the third agricultural holding

	New Holland CX 8080			New Holland CX 8090	Case IH Axial-Flow 9230	Case IH Axial-Flow 9240
	No. 2326	No. 3955	No. 3956	No. 3205	No. 3059	No. 3448
Harvested area (ha)	313.43	581.76	491.04	715.00	1,050.00	852.00
Total working time (h)	230	273	231	312	340	295
Harvested area performance (ha·h^{-1})	1.36	2.13	2.13	2.29	3.09	2.89
Total harvesting costs (EUR)	55,264	27,692	26,117	32,879	48,370	35,461
Harvesting unit cost (e_m) (EUR·ha^{-1})	176.32	47.60	53.19	45.98	46.07	41.62

Table 3 shows that in case of the same yearly operating lease the fixed cost (EUR·h^{-1}) of combine harvesters is different due to their varying yearly workload, i.e. number of working hours. Maintenance costs of the combine harvesters of the first agricultural holding are low during the first year, but practical use of Lexion combines has proven that these costs increase year by year.

The economical characteristics of combine harvesters of the second agricultural holding are not presented since gaps existed in the source data (lack of correctly fixed fuel consumption data). It is known that the fixed cost of combine No. 2488 is 87.59 EUR·h^{-1}, which refers to a not very user-friendly operating lease contract, and the maintenance costs of the second year were 4.59 EUR·h^{-1}. During the last year of use (2014) the maintenance costs of the combine harvester Lexion 460 were 15 EUR·h^{-1}.

The summary table of the agro-technical and economical characteristics of the combine harvesters of the third agricultural holding was created on the basis of data acquired from the program Terake.

Table 4 shows that the working load of the combine harvesters of the third agricultural holding was highly different. The harvested area differed by more than 3 times and the harvested area performance by 2.3 times, however these parameters do not reach the level of respective indicators of the combine harvesters of the first agricultural holding (Table 1).

Table 4 shows that the largest cereal harvesting unit cost 176.32 EUR·ha^{-1} was achieved when harvesting with combine harvester No. 2326 (New Holland CX 8080), which is abnormally large and caused by the restoration of the combine harvester's technical condition, i.e. increasing maintenance costs. This combine also showed lowest performance with its average harvested area performance of 1.36 ha·h^{-1} in 2016. Lowest harvesting unit cost (41.62 EUR·ha^{-1}) was achieved when harvesting with combine harvester No. 3448 (Case IH Axial Flow 9240). The average harvesting unit cost of the third agricultural holding was 63 EUR·ha^{-1}, which represented 13.4% of the holding's total costs regarding cereal growing.

Although the technical parameters of the combine harvesters of the first, second and third agricultural holding are different, their operational efficiency is comparable due to the harvesting unit cost. It appears that the most effective combine harvester fleet out of those of the three observable agricultural holdings belongs to the first holding due to its good combine selection, organisation of operations, collection of harvesting data and qualification of combine harvesters. In today's highly competitive market, it is essential to seek possibilities to minimize production costs and lower the cost price of products. The implementation of information technology and the complete automation of harvesting data collection and processing will probably help to reduce costs even further.

CONCLUSION

Based on the on-board computers of the combine harvesters and the collection and calculation of other cereal harvesting related data, it can be concluded that all the observable agricultural holdings collect and analyse harvesting data differently. Out of the three observable agricultural holdings in this study the first one has a complete overview of the combine harvester related operations and costs during harvesting season, but the collection of data requires great care and a lot of manual work. The best data collection and processing methods among the three observable agricultural holdings are implemented in the third holding, since they do

https://doi.org/10.17221/98/2017-RAE

not require various calculations and preparation of tables, which significantly reduces the possibility of errors. It also appeared that the combine harvester fleet of the third agricultural holding requires upgrading or restructuring. The study also showed that the unit costs of machines of the same type and make might vary (first holding). One of the reasons for this is the difference in qualifications and habits of the harvester operators, including the skills to make settings to the machines and adjust them during operation, select travelling path on the field and make optimum use of the working time. These influences should be further studied.

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