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Sensitivity analysis of key operating parameters of combine harvesters

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Abstract

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The sensitivity analysis of key operating parameters on the average annual sub-profit in a group of three combine harvesters operating in companies providing agricultural services were analysed. Based on the results of the cost analysis, the following key operating parameters with the greatest influence on the costs were identified: the purchase price of the machine, the price of fuel, maintenance costs, personnel costs and annual performance. These parameters were used in the sensitivity analysis to investigate their effect on unit costs. Changing the above-mentioned parameters is calculated within ± 30% from their mean value. To perform a sensitivity analysis of the average annual sub-profit of combine harvesters, the unit price of mechanized work was additionally used. The results showed that greatest impact on both the average annual earnings of combines operation and on the changes in unit cost was those of the annual performance of the combine harvester, combine harvester purchase price and the cost of fuel. On the other hand, maintenance and personnel costs had a smaller influence concerning these changes of parameters.

Keywords: annual performance; costs optimization; unit costs; cost analysis; average annual sub-profit

The aim of the sensitivity analysis is to evaluate the impact of changes in key operational parameters for the planned result. Appropriate choice of key parameters has a great impact on achieving successful results. Sensitivity analysis aims at assessing the average annual sub-profit of harvesters as a result of changes in the values of key operating parameters or as a result of others factors, e.g. fuel prices on world markets. It is advisable to perform a sensitivity analysis already in the design stage of the project. Its implementation will identify potential risks and identify key operational parameters influencing profitability. According to Rataj (2005), the implementation of sensitivity analysis is necessary to determine the most probable size of the deviations for both optimistic and pessimistic trends. The estimates are based on the development of these parameters in the past. It identifies the impact of parameter changes on the size of the output (or a project result). As reported by Fotr and Kislingerova (2009), the experience of business practice and empirical research findings show that optimistic distortions dominate strategic financial plans and the resulting values of cash flow. This leads to lower performance achieved by individual pro-

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jects and entire companies. This is confirmed e.g. by the results of research conducted by Mankind and Steele (2005). Therefore, Lovallo and Kahneman (2003) recommend comparing the completed project with a group of projects already implemented in the past. Comparison of the results actually achieved by the projects implemented in the past should provide a benchmark for better estimation of the project under consideration (Fotr, Souček 2005). For flexible projects with a high degree of variability, Scholleová (2007) recommends to use the combination of award projects using discounted cashflow and real options, that is a risk analysis based on application of scenarios and simulations. Schoemaker (2002) summarizes the process of creating scenarios in the following steps: defining the scope of scenarios, identifying any issues that scenario has to answer, gathering information, defining the main external parameters, determining important trends and uncertainties, building scenario and evaluating scenario consistency.

According to Goodwin and Wright (2004), it is necessary to establish certainty equivalent cash flow in relation to the utility function, which expresses quantitatively the relation of the subject to the risk. Utility function in terms of the relation between the security equivalent and the set is different for each individual subject; therefore, this is not objective. Concerning probabilistic models that are difficult to solve analytically, it is possible to use Monte Carlo simulations as a tool. However, this method has not been used much in investment decision-making, yet. Monte Carlo simulation in the field of practice was applied by Mun (2004, 2006): it was used for the probability distribution of the net present value of cash flows simulation of discount rate including a risk premium. Utilization rate scenarios for modelling are considerably higher than the rate of use of simulations.

The analysis of expenses using mechanized work in robotic citrus harvesting was dealt by Harrell (1987). As a result, the most important parameters affecting the cost of harvesting were identified: the inefficiency of the harvesting of the fruit, followed by the price of the harvester, the average cycle time for harvesting the fruit and the repair costs of harvester. In a further development, Harrell advised to focus on improving work efficiency of the harvester, reducing the price of the harvester, increasing reliability and modification of work tools which should lead to an improved performance of robotic harvesting. Pelesaraei et al. (2013) identified the following as the most important parameters affecting the economy of production of peanuts in Iran: labour, mechanization and seeds costs. Yousif et al. (2013) developed a computerized system for management and selection of appropriate agricultural technology, with regard to the selection of the suitable business operations for the relative cultivated crops. During the development and validation process of this system, it was discovered that the system is able to calculate and provide the required outputs immediately after entering the input data. Subsequently, the sensitivity of input parameters able to change the outputs was analysed. Based on the experience gained by this, the projected system was modified in order to enable converting the inputs to the required output parameters through the sensitivity analysis. Sensitivity analysis of shadow prices through linear programming methods was used by McCarl et al. (1990) to determine the key technology or alternative agricultural technologies, whose purchase or renewal must be considered carefully. The results of McCarl's et al. case studies show that his proposed algorithm identifies the benefits of changes in farming technology quite precisely, with an error quote of less than 10%.

The goal of the presented sensitivity analysis is to determine how to change the average annual subprofit of combine harvesters by changing key operating parameters. In particular, input prices change over time in the market and affect cost items. These market changes can be simulated by changes in key operating parameters when performing a sensitivity analysis, and thus, it is also possible to determine their impact on the average annual earnings of harvesters.

MATERIAL AND METHODS

This sensitivity analysis was performed with a group of three combine harvesters John Deere (Deere & Company, Zweibrücken, Germany) (hereinafter referred to as "CH"), namely models: John Deer 9880i STS, John Deer S 690i and John Deer JD 9660 WTS. They are operated all year round in a company providing agricultural services. The reported calculations and subsequent results are based on the average annual values that were determined for individual harvesters. Monitoring of operational parameters of harvesters was carried out between 2009 and 2012.

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Based on the cost analysis of individual cost items according to the methodology of cost calculation by Eq. (1) (Kavka 1997), key operating parameters that have the greatest impact on the costs were identified. For unit costs of harvesters, they are as follows: purchase price of the machine, price of fuel, maintenance costs, personnel costs and annual performance. For sensitivity analysis of the average annual sub-profit of harvesters Eq. (2), the price of mechanized work of harvesters was calculated, beside the above-mentioned key operational parameters. The calculated average annual sub-profit from harvesters' operation does not include overhead costs or income tax:

$$uCt = \frac{yCf}{yWm} + uCv \qquad (1)$$

$rCf = yCa + yCioc + yCibl + yCai + yCci + yCrt + yCg$
$uCv = uCmt + uClf + uCpc + uCam$

$$yP = (Pw - uCt) \times yWm \qquad (2)$$

where:

uCt – total unit operating costs (CZK/ha)
yCf – annual fixed operating costs (CZK/year)
yWm – annual performance (ha/year)
uCv – variable unit operating costs (CZK/ha)
yP – annual partial profit (CZK/year)
Pw – price of work of services combine harvester (CZK/ha)
yCa; *ioc*; *ibl*; *ai*; *ci*; *rt*; *g* – annual: amortization costs (*a*), interest of own capital (*ioc*), interest bank loan (*ibl*), accident insurance (*ai*), MTPL (*ci*), road tax (*rt*), garage (*g*) (CZK/year)
uCmt; fl; *pc*; *am* – unit costs: maintenance (*mt*), fuel and lubricants (*fl*), personal (*pc*), auxiliary material (*am*) (CZK/ha)

The limits of the expected changes in the key operating parameters in the sensitivity analysis were performed within ± 30% and for this interval, alternative outcomes were calculated.

The actual sensitivity analysis measures the impact of changes in key operational parameters on the unit cost and on the average annual sub-profit of harvesters' work. Calculations were obtained using tables created in MS Excel; these were generated by the positive and negative percentage change in key parameters which are calculated for the resulting effects. As reported by Fotr (1992), a visual representation of the results makes them more intelligible, therefore here, the results are also shown using graphs in order to better illustrate the effect and impact of various operating parameters.

RESULTS AND DISCUSSION

Purchasing and maintaining agricultural machines are two of the most considerable costs of the agricultural sector (Buckmaster 2003). Based on the cost analysis, average percentage of individual components of the cost of the monitored group of harvesters was calculated. The values are shown in Table 1 and Fig. 1.

The percentage share of the cost for each combine harvesters corresponds to the average values of all combine harvesters. As shown in Table 1 and

Table 1. Structure of the average cost of combine harvesters

Cost item	Annual total costs (CZK/year)	Total unit costs (CZK/ha)	Share of costs (%)
Amortization	1,011,807	1,154	53.63
Interest of own capital	113,753	125	5.81
MTPL insurance	842	1	0.05
Accident insurance	90,171	104	4.85
Garaging	2,927	3	0.15
Personal costs	50,790	56	2.62
Maintenance	178,315	182	8.46
Fuel and lubricants	495,914	526	24.43
Fixed costs	1,219,500	1,388	64.49
Variable costs	725,019	764	35.52
Total costs	1,944,519	2,152	100.00

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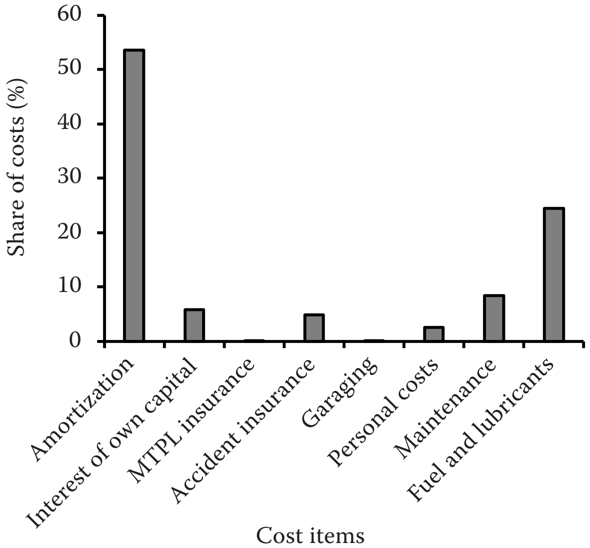

Fig. 1. Graphical representation of the structure of the average cost of combine harvesters

Fig. 1 shows the fixed costs involved in 64.49% of average total cost. The proportion of variable costs amounts to 35.52% of the total costs. The largest proportion of the average cost is occupied by amortization costs, which represent 53.63%. In the second place there is the average cost of fuel with a share of 24.43%. Their amount is influenced by global factors such as oil price and volume of its production. In the third place there are the average maintenance costs with a share of 8.46%. The following figure (Fig. 2) shows the typical range of five items with the highest share of costs provided through cost analysis. According to the research results of Rotz (1987, 1991), high variability of analysis results is in normal range.

Costs for maintenance and repairs of combine harvesters are one of the major components of variable costs. These costs are very individual for each machine. Fig. 3 shows the trend in the average cost of combine harvesters repairs in the years 2009 to 2012, observed from the accounting records of the company. In part, repair costs include worn working parts of the machine, which depends on the time of utilization of the machine. Other parts are dependent on random disturbances. Due to the seasonal deployment combine harvester's enterprise must wear the working parts of the machine to keep the store in case of failure. This increases the capital liability in inventories. From Fig. 3, it is evident that there is a gradually growing trend in the time of as the machine usage time.

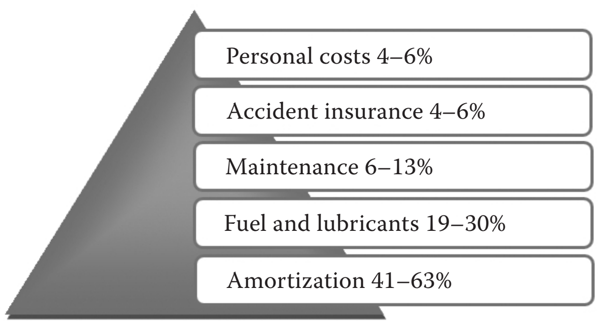

Fig 2. Five items with the largest share of the total cost of combine harvesters (%)

Sensitivity analysis of average unit cost

The results of the sensitivity analysis of the average unit costs monitored on the combine harvester John Deere are listed in the Table 2 and graphically displayed in Fig. 4. The average unit cost for combine harvesters is 2,152 CZK/ha.

The values in Table 2 and Fig. 4 also show that the greatest impact on the average unit cost is that of the annual performance. A decrease of 30% (the value of 920 ha/year to 645 ha/year) in the annual performance is causing an increase in average unit cost of 2,152 CZK/ha to 2,817 CZK/ha. This change represents an increase of the average unit costs by 30.9%, i.e. about 665 CZK/ha. Conversely, by an increase of 30 % (the value of 920 ha/year to 1,196 ha/year) in the average annual efficiency, there is a drop of the average unit costs from 2,152 CZK/ha to 1,794 CZK/ha. This change represents a reduction of 16.64 %, i.e. 358 CZK in average unit cost.

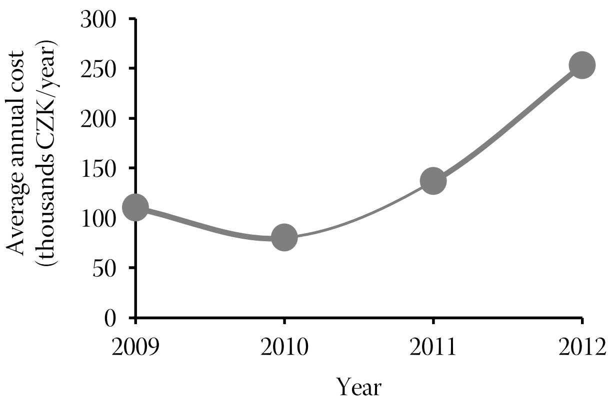

Fig. 3. Evolution of the average annual cost of maintenance and repairs of combine harvesters between 2009 and 2012 (in thousand CZK/year)

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Table 2. Results of the sensitivity analysis for John Deere combine harvester

Parameter change (%)	–30	–25	–20	–15	–10	–5	0	5	10	15	20	25	30
Average unit costs (CZK/ha)													
Annual performance	2,817	2,669	2,540	2,426	2,324	2,234	2,152	2,078	2,011	1,949	1,893	1,841	1,794
Purchase price	1,768	1,832	1,896	1,960	2,024	2,088	2,152	2,216	2,280	2,343	2,408	2,472	2,536
Price of FL	1,994	2,021	2,047	2,073	2,099	2,125	2,152	2,178	2,204	2,231	2,257	2,283	2,309
Maintenance costs	2,112	2,119	2,126	2,132	2,139	2,145	2,152	2,159	2,165	2,171	2,178	2,185	2,191
Personnel costs	2,135	2,138	2,141	2,143	2,146	2,149	2,152	2,155	2,158	2,160	2,163	2,166	2,169
Average unit costs (% CZK/ha)													
Annual performance	30.90	24.02	18.03	12.73	7.99	3.81	0.00	–3.44	–6.55	–9.43	–12.04	–14.45	–16.64
Purchase price	–17.84	–14.87	–11.90	–8.92	–5.95	–2.97	0.00	2.97	5.95	8.88	11.90	14.87	17.84
Price of FL	–7.34	–6.09	–4.88	–3.67	–2.46	–1.25	0.00	1.21	2.42	3.67	4.88	6.09	7.30
Maintenance costs	–1.86	–1.53	–1.21	–0.93	–0.60	–0.33	0.00	0.33	0.60	0.88	1.21	1.53	1.81
Personnel costs	–0.79	–0.65	–0.51	–0.42	–0.28	–0.14	0.00	0.14	0.28	0.37	0.51	0.65	0.79
Average operating profit (thousands of CZK/year)													
Annual performance	–144.287	–55.910	32.470	120.853	209.233	297.613	386.003	474.373	562.757	651.137	739.517	827.900	916.280
Purchase price	723.663	667.387	611.107	554.830	498.553	442.273	386.003	329.720	273.437	217.160	160.883	104.603	48.327
Price of FL	329.037	338.530	348.023	357.517	367.007	376.500	386.003	395.490	404.987	414.473	423.967	433.463	442.957
Maintenance costs	424.547	418.123	411.697	405.270	398.847	392.420	386.003	379.567	373.147	366.720	360.293	353.870	347.443
Personnel costs	401.233	398.693	396.153	393.613	391.077	388.533	386.003	383.457	380.913	378.377	375.837	373.300	370.743
Price of mechanized work	–313.160	–196.637	–80.110	36.417	152.943	269.470	386.003	502.523	619.047	735.573	852.097	968.623	1,085.150
Average operating profit (% of thousands CZK)													
Annual performance	–137.38	–114.48	–91.59	–68.69	–45.80	–22.90	0.00	22.89	45.79	68.69	91.59	114.48	137.38
Purchase price	87.48	72.90	58.32	43.74	29.16	14.58	0.00	–14.58	–29.16	–43.74	–58.32	–72.90	–87.48
Price of FL	–14.76	–12.30	–9.84	–7.38	–4.92	–2.46	0.00	2.46	4.92	7.38	9.84	12.30	14.76
Maintenance costs	9.99	8.32	6.66	4.99	3.33	1.66	0.00	–1.67	–3.33	–4.99	–6.66	–8.32	–9.99
Personnel costs	3.95	3.29	2.63	1.97	1.32	0.66	0.00	–0.66	–1.32	–1.97	–2.63	–3.29	–3.95
Price of mechanized work	–181.13	–150.94	–120.75	–90.56	–60.38	–30.19	0.00	30.19	60.38	90.56	120.7	150.94	181.13

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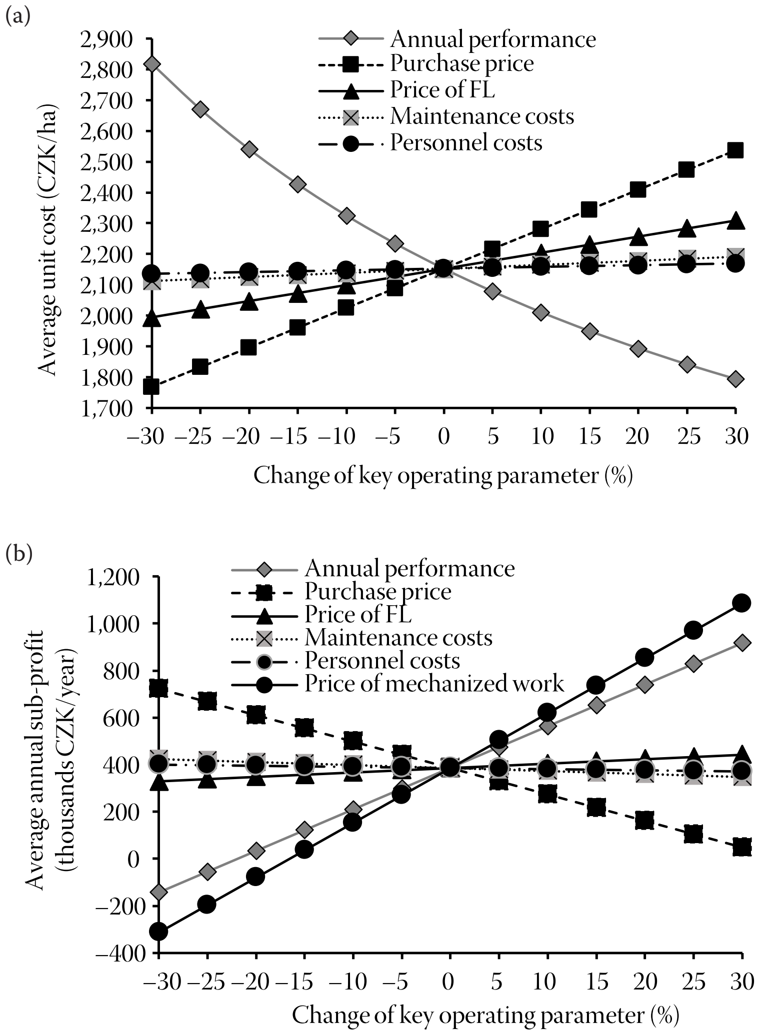

Fig. 4. Sensitivity analysis results calculating (a) the average unit cost (in CZK/ha) and (b) the average annual sub-profit of harvesters (in thousand CZK/year)
FL – fuel and lubricants

Second in the order of the key parameters that most affect the average unit cost is the purchase price of the combine harvester, which has also an effect on the depreciation and the interest of own capital. A decrease in the cost of a combine of 30% (value of 6.046 mil. CZK to 4.232 mil. CZK) would reduce the average unit cost of 2,152 CZK/ha to 1,768 CZK/ha. This change represents a reduction in average unit cost of 17.84%, i.e. 348 CZK. An increase of the cost of the combine by 30% (from an average of 6,046 mil. CZK to 7,860 mil. CZK) would increase the average unit cost from 2,152 CZK/ha to 2,536 CZK/ha. This change implies an increase in average unit cost of 17.84%, i.e. 384 CZK/ha. For agricultural companies (farmers) mechanization costs can constitute 15–50 % on the total costs of crop production (mean data related to field crops (Anderson 1988).

The third key parameter with the largest impact is the cost of fuel and lubricants (hereinafter "FL"). With the drop in fuel prices, i.e. a complex price of diesel by 30% (from 35.28 CZK/l to 24.69 CZK/l) there is a decrease of the average unit costs to 1,994 CZK/ha. This change represents a reduction in average unit cost of 7.34%, i.e. 158 CZK/ha. If the fuel prices increased by 30 % (from 35.28 CZK/l to 45.86 CZK/l), it would increase the average unit cost of 2,152 CZK/ha to 2,309 CZK/ha. This change represents an increase in average unit cost of 7.30%, i.e. 157 CZK/ha.

The impact of a 30% reduction in maintenance costs represents the change in average unit cost of 1,85% to 2,112 CZK/ha, i.e. about 40 CZK/ha; an increase of 30% means that the average unit cost increases by 1.83%, i.e. 39 CZK/ha.

Regarding personnel costs, a reduction of 30% represents the change in average unit cost of 0.79% to 2,135 CZK/ha, i.e. about 17 CZK/ha; with an increase by 30% , the average unit costs increased by 0.77% to 2,169 CZK/ha, i.e. 17 CZK/ha.

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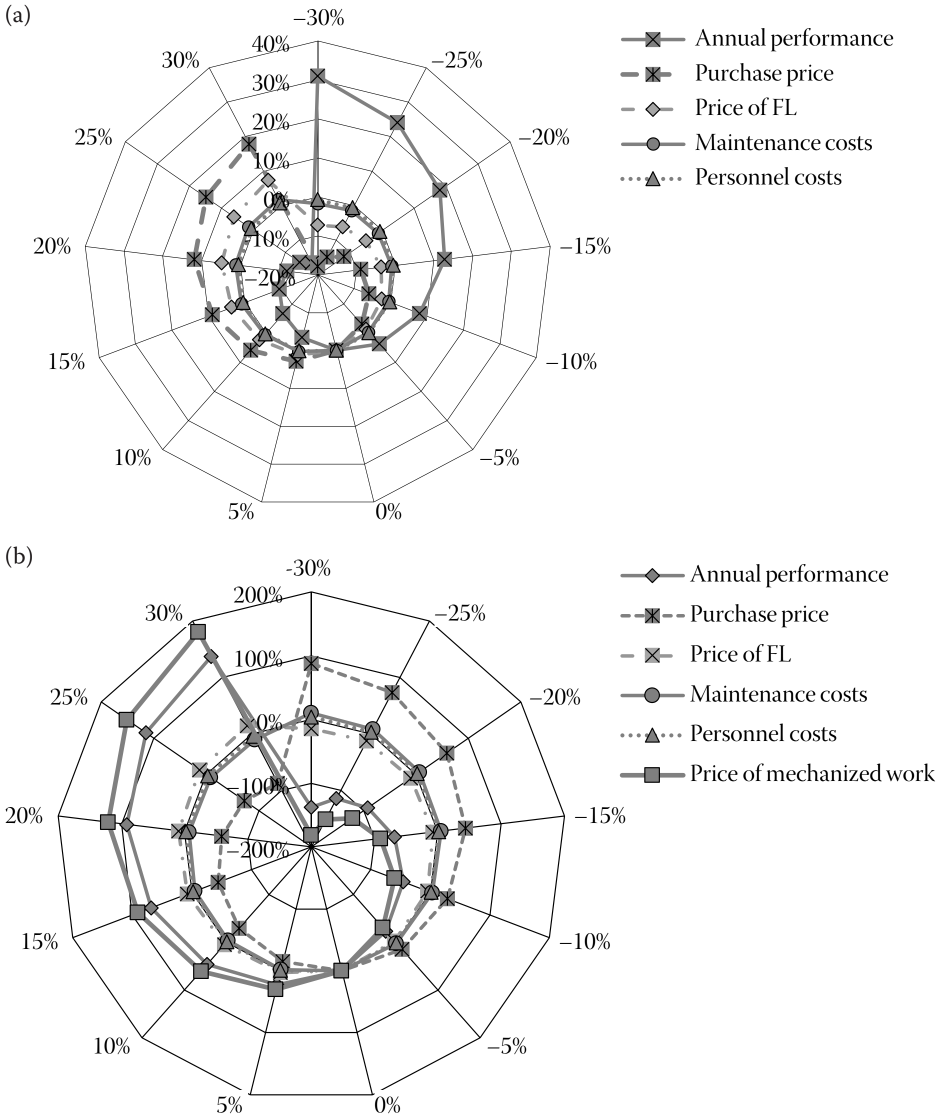

Fig 5. Sensitivity analysis results calculating (a) the average unit costs (in % of CZK/ha) and (b) the average annual sub-profit of harvesters (in % of thousand CZK/year)
FL – fuel and lubricants

Sensitivity analysis of the average annual sub-profit of harvesters

The results of the sensitivity analysis of the average annual sub-profit of harvester John Deere are listed in Table 2 and graphically described in Fig. 5. Average unit costs for harvesters are 2,152 CZK/ha.

The average annual sub-profit of harvesters calculated on the basis of cost analysis is 386,003 CZK/year. In sensitivity analysis, the average annual sub-profit calculations are carried out with six parameters, as it is also influenced by the price of mechanized work. The price of mechanized work including the cost of fuel is 2,509 CZK/ha.

The biggest impact on the average annual sub-profit of harvesters has the change of the price for mechanized work. When it drops by 30% (of the value of 2,509 CZK/ha to 1,757 CZK/ha), the average annual sub-profit decreases to –313,160 CZK/year, which means that it changes from profit to loss. This represents a change of 181.13%, i.e. 699,163 CZK. If the price increases by 30% (from 2,509 CZK/ha on 3,262 CZK/ha), the average annual sub-profit increased to 1,085,150 CZK/year. This represents an increase of 181.13%, i.e. an increase of 699,163 CZK/year.

The second key parameter, which has the largest impact on the average partial annual profit, is the annual performance of the harvester; the third parameter is the cost. These operating parameters also imply the highest influence in the sensitivity analysis of unit costs. The decline in the annual performance by 30% (value of 911 ha/year at 638 ha/year), makes the average annual sub-profit decrease to

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144,287 CZK/year, i.e. it changes from profit to loss, which represents a change of 137%, i.e., a difference of 530,290 CZK/year. An increase of the annual harvester's performance by 30% (from 911 ha/year to 1,184 ha/year) increases the average annual profit to 916,280 CZK/year. This represents a difference of 137%, i.e. 530,277 CZK/year. Reduction of the cost of the combine by 30% increases the average annual sub-profit to 723,663 CZK/year, which represents a change of 88%, i.e. 337,660 CZK/year. Increase in the cost of the combine by 30% decreases the average annual sub-profit to 48,327 CZK/year. The cost of the combine must be in relation to its annual performance.

Changes in the price of fuels and lubricants (FL) for 30% will reduce the average annual profit to 56,967 CZK/year, i.e. 14.76%. Furthermore, maintenance costs decrease at 30% changes the average annual profit by 38,543 CZK/year, i.e. 9.99%. Reducing personnel costs by 30 % will increase the average annual income of 15,230 CZK/year, i.e. by 3.95%. Increasing the above key parameters will lead to the opposite effect on the average annual profit.

CONCLUSION

The cost analysis shows that the largest share of total costs for combine harvesters is occupied by amortization costs, which range from 41–63%. In the second place it is the cost of fuel with a share of 19–30%, followed by maintenance costs with a share of 6–13%. These results confirm the research conducted by Calcante at al. (2013) who stated that repair and maintenance costs generally constitute 10–15% of the total costs related to the agricultural equipment and tend to increase with the age of the equipment; hence, an important consideration in farm management is the optimal time for equipment replacement. In fourth place is the cost of the return on equity 4–8%, followed by the cost of car insurance 4–6% and personnel costs with a share of 4–6 %. To evaluate the results obtained different procedures can be used. For example, O'Donnell (2012) used the total factor productivity (TFP) index, which is used in the evaluation of two separate components – the changes in technology and efficiency. The factor having the greatest share is the technical changes and the mix of factors influencing changes in efficiency. Therefore the technical factors must be taken into account when purchasing new machines. The goal may be to reduce the purchase price of machinery, which affects the amount of depreciation. Next, it is important to select the type of the machine, which will not require motor with higher performance and power consumption; it is also necessary to focus on the quality of the machine design and especially wearing parts, the availability and cost of service, not to increase the cost of maintenance and repairs. It is necessary to consider the appropriate form of financing the acquisition of machinery and equipment such as insurance options.

The results presented in Figs 6 and 7 show that both the annual use and purchase price have the substantial impact on the average unit cost and average annual sub-profit of combine harvesters. Annual performance in agricultural holdings is limited by their range of cropped area, seeding techniques, field crops and crops intended to be harvested with a combine. This is also the reason why many farms cannot achieve a higher utilization. Moreover, the harvester is often operated for several years exceeding the period of depreciation or the optimal time for its renewal. Another limiting factor is also timely execution of harvest, which can be of course affected by the weather. For this reason, many agricultural businesses prefer lower usage of combines and extend the period of their operation, which is then reflected in their technical deterioration and technological obsolescence. For companies providing agricultural services, there is a limiting range of services that can be implemented on the market. Therefore, many companies decided to start providing their services in those regions where crops ripen earlier and then to move gradually into higher areas. When considering an increase in the number of harvesters in the vehicle fleet, all undertakings providing agricultural services have to reflect upon ensuring an adequate yearly performance, too. The amount of the costs is considerably influenced by farm size and scope of the harvested area. As reported by Delbridge et all. (2013) estimated machinery costs per hectare are lower and whole-farm net returns are higher for larger farms.

Purchase price of a harvester is a very individual matter, which is influenced not only by the negotiating skills of the buyer or his good rapport with the vendors but also by several other operating parameters such as the period of the design, the method of financing the purchase or exchange-rate movements.

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Therefore, before buying, it is necessary to perform a separate analysis of the risk of changes in the purchase price and to eliminate changes in key operational parameters. And also, as stated in Cross and Perry (1996), the estimated life is highly variable for each type of machine, because it depends on its use.

An analysis of the economic result shows that it greatly affects the price of mechanized work and annual performance. Both of these components are related, since higher utilization reduces the amount of annual unit cost to enter the price of mechanized work, thereby increasing profits. Based on the results of individual analyses of the two combine harvesters an increase in their annual performance is recommended.

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