Evaluation of the technical and economical effects of the using of machinery system for processing of straw for energy purposes

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Abstract: In conditions of the agriculture in Slovak republic the straw, obtained as a by-product from cereals cropping systems, has a growing potential to be used as an important renewable energy source. This trend is fully consistent with the energy policy of the European Union, which aims to reduce the negative environmental impacts of fossil fuel use. The aim of the presented paper was to evaluate technical and economic effects of the using of the system for processing of straw including straw baling, transport and handling of the straw bales. During the years 2010-2012 the field experiments have been conducted in conditions of the large-scale farm (2770 ha of arable land). For the straw baling, transport and handling of the straw bales there is used a machinery line consisting of the machines having a different performance and capacity. There was formulated a scientific hypothesis: capacity and economic efficiency of the machine line depend upon the technical parameters and operational management. During field experiments there were obtained information characterizing straw yield, weight, size and density of the straw bales, as well as data characterizing the used machines performance. In the next step there was prepared the input data for database and computer calculation has been conducted. Results obtained have allowed to know the effects of transport distance on the fuel consumption during straw harvest, baling and bales transport and level of costs for different carrying capacity of the trailers used for straw bales transport. The results confirmed the validity of the hypothesis and has allowed to know the technical and economic effects of the using of the system for processing of straw for energy purposes used in given production conditions.

Keywords: straw for energy purposes, straw baling, transport, handling, economical effects

Citation: Nozdrovicky L., M. Macak, and J. Maga. 2015. Evaluation of the technical and economical effects of the using of machinery system for processing of straw for energy purposes. Agric Eng Int: CIGR Journal, Special issue 2015: 18th World Congress of CIGR: 200-207.

1 Introduction

Due to the global climatic changes the importance of the using of renewable energy sources is increasing. These significant changes are reflected in the energy policy of the European Union as well as in individual EU member countries. In conception of the energy policy of the Slovak republic are defined main types of the renewable energy sources, which have to be used in order to cover the energy requirements of the national economy (Maga, 2011). Among the main types of the renewable energy sources the straw coming from cereals cropping systems plays an important role. According to Maga and Piszczalka (2006) in conditions of the Slovak Republic there are 719 200 ha of cereals cropping systems (wheat, barley and grain maize) producing a 2760052 tons of the straw of the which more than 1 million tons can be used for burning as a fuel for energy purposes without negative effect on the livestock production and soil.

For harvesting of the straw for energy purposes there are used different technologies.

In most cases there is used field technology based on using of square balers, which collect the straw windrowed by combine harvesters. Square straw balers are producing the bales which are located on the field surface. By using of automatic self-picking bale stacker the bales are picking, transported and stacking at the field headland

Received date: 2014-10-28 **Accepted date:** 2014-12-21

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and later they are transported to the storage place. In connection with the using of straw for energy purposes Hussein et al. (2012) has mentioned the fact that straw after harvest and windrowing has a very low bulk density. Baling of the straw to the square bales the straw bulk density increases up to 120 -170 kg m^{-3}.

According to Soucek, 2005, the straw harvesting, baling and bales transport can be considered as an introductory technological operations used in technological system focused on of the using of straw for energy purposes. Machinery used in above mentioned operations significantly effect the total efficiency of the system as a whole. Rationalization of the harvest and transport of the grain and straw (especially in the form of bales is based on implementation of the intelligent solutions on the machines allowing to obtain higher machine capacity (Barkoczi et al, 2012).

2 Material and methods

Field experiments have been conducted during years 2010 – 2012 AGRO Division Ltd, Selice, district Sala, south-west of Slovakia. Farm has 2900 ha of agricultural land of which 2770 ha is arable land. Grain maize is a main crop (1133 ha). Maize for silage is grown on 203 ha, lucerne 218 ha, winter wheat 597 ha and spring barley 274 ha. On the farm there was built a complete system for grain draying based on burning of straw to obtain heat necessary for grain drier. For burning of straw there is used a special boiler BIOLANG Kft. This boiler is specially designed for the heating of grain driers and other farm facilities.

For the straw baling, transport and handling of the straw bales there is used a machinery line consisting of the machines having a different performance and capacity. There was formulated a scientific hypothesis: capacity and economic efficiency of the machine line depend upon the technical parameters and operational management.
Based on defined aims and objectives our attention was focused on the following topics:

- Evaluation of the performance of the machines used for wheat straw baling, straw bales collection and straw bales transport from the field to the farm.
- Analysis of the effects of the transport distance on the performance of the transport unit based on using of information advisory system AgroConsult being a part of the higher Computer-Aided Machinery Management System C.A.M.M.S.

As it was above mentioned the direct operational costs related to individual field operation were considered as a main indicator allowing evaluating the efficiency the used machines. For each operation realized on the field (baling of a wheat straw, bales collection and their transport to the stock, straw bales handling, loading and transport from the field).

2.1 Characteristics of the field experiments (Table 1)

Table 1 Machines used in field experiments

Operation	Year 2010 (194,34 ha)	Year 2012 (66,01 ha)
Straw baling	JCB Fastrac 3200 Tractor + Krone Big Pack 1290 XC square baler	John Deere 7200R Tractor + Krone Big Pack 1290 XC square baler
Wheat straw bales picking and bales stacking on the field headland	John Deere 6920 Tractor + Arcusin F 54. 63 self-picking bale stacker	John Deere 6920 tractor + Arcusin F 54.63 self-picking bale stacker
Bales transport from the field to the farm	MF 69.99 Tractor + semi-trailer	John Deere 7830 Tractor, +Wielton RS–3S/S14 semi-trailer
Loading and unloading of the bales	John Deere 3400 Loader John Deere 3400 Loader	John Deere 3400 Loader Fastrac 536 - 60 Loader

2.1.2 Methodology of the calculation of the costs related to the machinery operation by using of programmed module AgroConsult - C.A.M.M.S.

Direct costs related to individual operation provide by individual machine or tractor-machine set were considered as a basic indicator allowing to evaluate the effectively of the used machinery. For each operation provided on the field – straw baling, straw bales picking and their transport to stocking with subsequent bale s transport from the field to storage we have calculated the operational costs. In case of bales transport from the field to the storage we have focused our attention on the technology of transport and we have simulated possible variants of the tractor-machine sets with different pay-load of the semi-trailers, which have been used for transport of wheat straw bales for different transport distance. The calculations have been done by using of Computer-Aided Machinery Management System C.A.M.M.S. (Kavka, 2007). Obtained results we have processes in the form of tables and graphs by using of MS Excel.

According to character of our task we have used a programed module AgroConsult (C.A.M.M.S.) and in the block, Catalogue", which is determined for the recording of the technical parameters and input data of the used machines, we have entered data characterizing tractor-machine sets, which have been used for work on the field. Under the term, tractor-machine set"we understand a particular tractor assembly with the appropriate implement or machine, for example: John Deere 7200R Tractor + Krone Big Pack 1290 XC square baler.

By means of the form, Machine card"the program has allowed entering input technical and economical data: weight of the tractor/machine, tractor/machine dimensions (height, length, width), repair coefficient, recommended annual use of the tractor/machine, acquisition price of the tractor/machine and strategy of the tractor/machine depreciation.

After completing tractor-machine sets we have provided the calculations of the operational indicators of the tractor-machine set for a given working operation. Thanks to the calculations we have obtained clear information about the constant and variable costs for whole tractor-machine set. In case of transport of the wheat straw bales in the section, Economics of technological transport we have used the form, Economic considerations on tractor-machine sets and we have entered the appropriate data in order to evalaute the effect of changes of transport unit pay-load due to the increasing of transport distance. Due to the changes of transport unit pay-load in both years of experiments we have to change the input data and it had the affect on results of calculations.

3. Results and discussion

Wheat straw was baled to the form of large square bales having dimensions 2200 x 1200 x 900mm and weight 270 kg. It was possible to change these dimensions and weight of the bales according to the requirements given by storage conditions. There were carried out 40 working time analysis and it has allowed to know the time of baling of one bale (Table 2).

Table 2 Basic data of the working operation – wheat straw baling

Parameter	Year	
	2010	2012
Tractor-machine set (tractor + baller)	JCB Fastrac 3200 + Krone Big Pack 1290 XC baler	John Deere 7200R + Krone Big Pack 1290 XC baler
Field acreage, ha	194,34	66,01
Harvested amount of straw, t	212	113
Amount of bales, pcs	787	420
Weight of bale, kg	270	270

The amount of the straw in the windrow was considered as a most important indicator. This indicator

had direct effect on the final result as the sufficient amount of the straw in the windrow has allowed fast bale creation (baling) with required parameters and did not decelerate of working process as a whole.

In the year 2010 for the straw baling there was used tractor –machine set JCB Fastrac 3200 tractor + Krone Big Pack 1290 XC baler. The baling of 40 bales lasted 37 min and 52 s, and it means that baling of one bale took an average 57 s.

In the year 2012 for the straw baling there was used different tractor –machine set based on John Deere 7200R tractor. For straw baling there was used the same square baler Krone Big Pack 1290 XC. The baling of 40 bales lasted 1 h 19 min and 33 s. Compared to the previous results the same amounts of bales were produced during working time increased by 41 min and 41 s. The main reason of the increased working time consumption was smaller field acreage as there were more time loses due to the more frequent machine turning on the field headlands.

On Figure 1 and Figure 2 there are shown histograms with cumulative frequency distribution curve of the time

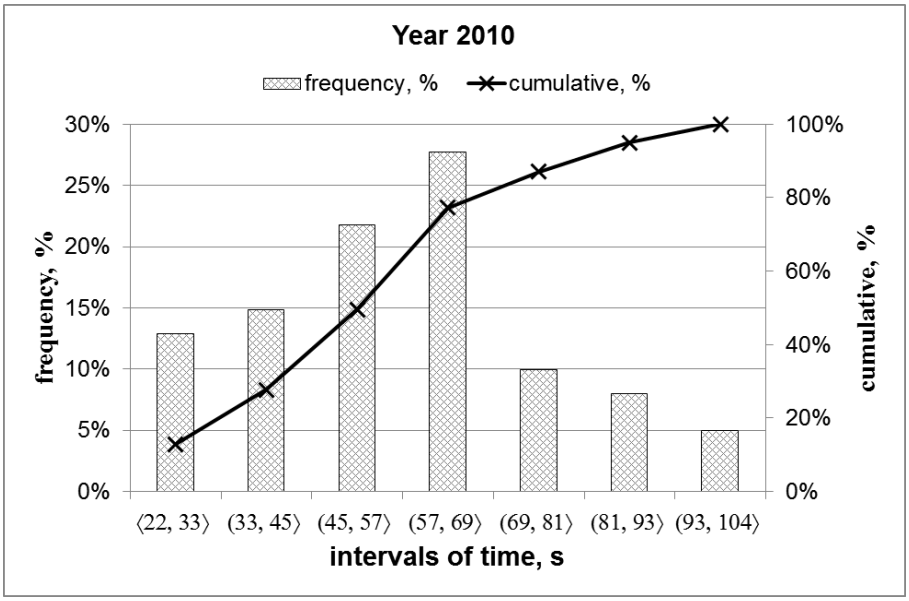

Figure 1 Histogram with cumulative frequency distribution curve of the time values characterizing baling of one bale, tractor-machine set JCB Fastrac 3200 tractor + Krone Big Pack 1290XC square baler

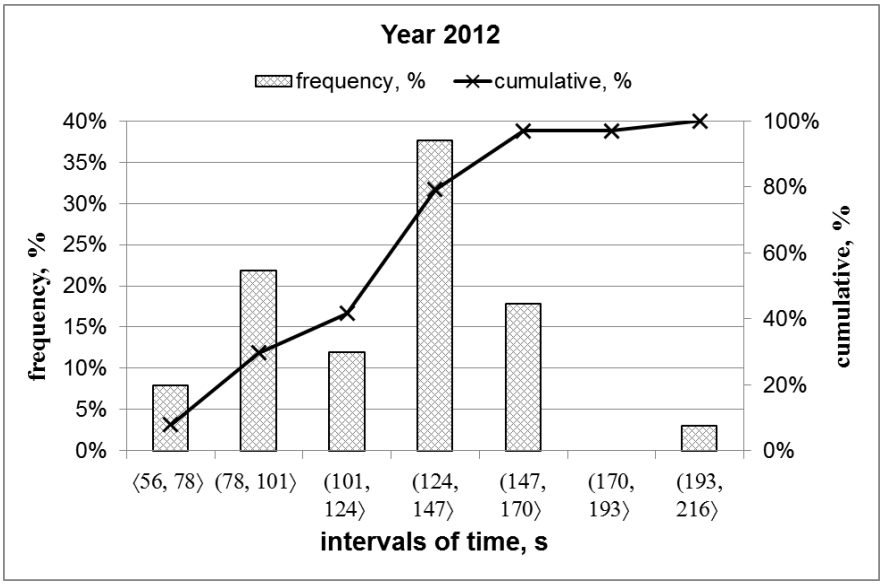

Figure 2 Histogram with cumulative frequency distribution curve of the time values characterizing baling of one bale, tractor-machine set John Deere 7200R tractor + Krone Big Pack 1290XC square baler

values characterizing baling of one bale.

Table 3 Economic evaluation of the working operation – bales baling

Input data	Year 2010		Year 2012	
	Tractor-machine set		Tractor-machine set	
BALES BALING	Tractor FASTRAC 3200	Machine KRONE BIG PACK 1290 XC baler	Tractor John Deere 7200R	Machine KRONE BIG PACK 1290 XC baler
Machine acquisition price without VAT:	138 000 €	150 000 €	230 000 €	150 000 €
Annual use:	1800 h yr^{-1}	600 ha yr^{-1}	1800 h yr^{-1}	600 ha yr^{-1}
Annual insurance:	74 € yr^{-1}	591 € rok^{-1}	74 € yr^{-1}	591 € yr^{-1}
Repair coefficient:	0,5	0,2	0,5	0,2
Rated engine power:	145 kW		158 kW	
Machine power requirement:	112 kW		112 kW	
Share of own resources:	100%		100%	
Type of depreciation:	4 yr, linear		4. r. line árne	
Number of operators:	1		1	
Labour costs:	6 € h^{-1}		6 € h^{-1}	
Fuel consumption:	3.5 L ha^{-1}		5.5 L ha^{-1}	
Fuel price:	1.50 € L^{-1}		1.50 € L^{-1}	
Machine performance:	15.6 ha h^{-1}		4.7 ha h^{-1}	
Total unit costs per tractor-machine set	**78.2 € ha^{-1}**		**90.3 € ha^{-1}**	

Table 4 Economic evaluation of the working operation – bales picking

Input data:	Year 2010		Year 2012	
	Tractor-machine set		Tractor-machine set	
BALES PICKING	Tractor John Deere 6920	Machine ARCUSIN F 54.63	Tractor John Deere 6920	Machine ARCUSIN F 54.63
Machine acquisition price without VAT:	136 000 €	110 000 €	136 000 €	110 000 €
Annual use:	1700 h yr^{-1}	800 h yr^{-1}	1700 h yr^{-1}	800 h yr^{-1}
Annual insurance:	74 € yr^{-1}	530 € yr^{-1}	74 € yr^{-1}	530 € yr^{-1}
Repair coefficient:	0,5	1	0,5	1
Rated engine power:	119 kW		119 kW	
Share of own resources:	100%		100%	
Type of depreciation:	4yr, linear		4yr, linear	
Number of operators:	1		1	
Labour costs:	6 € h^{-1}		6 € h^{-1}	
Fuel consumption:	11.8 L h^{-1}		11.6 L h^{-1}	
Fuel price:	1.50 € L^{-1}		1.50 € L^{-1}	
Machine performance:	70 bales per hour		70 bales per hour	
Total unit costs per tractor-machine set	113.2 € h^{-1}		109.8 € h^{-1}	

In Table 3, Table 4, Table 5 and Table 6 there are presented input data and results characterizing machinery used for individual working operations in years when field experiments were conducted. When comparing the values of the total unit costs per tractor-machine set related to wheat straw baling (Table 3) there is evident some differences. In the year 2010 the KRONE BIG PACK 1290 XC baler was used together with FASTRAC 3200 tractor and in the year 2012 the same baler was used with John Deere 7200 tractor. Higher rated power of the

John Deere 7200 tractor was not used optimally and effectively and this fact caused the increase of the fuel consumption. Total unit costs per tractor-machine set based on FASTRAC 3200 tractor were lower by 13.4% when compared with the tractor-machine set based on John Deere 7200 tractor. Rated power of the FASTRAC 3200 tractor fully matched the energy requirements of the KRONE BIG PACK 1290 XC baler.

In case of picking and stocking of the bales (Table 4) there were not found significant differences between the years 2010 and 2012 (only 3%), as the harvest conditions were similar and in both years there was used the same tractor-machine set.

In case of bales transport (Table 5) we can state that increasing of the carrying capacity of the semi-trailers by 3 tons had a very small effect on the fuel consumption related to amount of transported material. Fuel consumption was nearly the same. Increasing of the carrying capacity of the semi-trailers has caused only the increase of fuel consumption of the tractor-machine sets related to one hour of operation. Fuel consumption was increased also due to the higher transport performance. Based on results obtained it is very important to make maximum use of carrying capacity of the semi-trailers in order to obtain maximum efficiency of the tractor power.

To author: please move Table 3 and Table 4 at this place.

Table 5 Economic evaluation of the working operation – bales baling

Input data:	Year 2010			Year 2012		
	Tractor-machine set			Tractor-machine set		
	Tractor	Machine		Tractor	Machine	
BALES TRANSPORT	**MF 69.99**	**Semi-trailer**		**John Deere 7830**	**Wielton PRS - 3S/S14**	
Machine acquisition price without VAT:	61 640 €	10 000 €		173 650 €	20 000 €	
Annual use:	1800 h yr^{-1}	800 h yr^{-1}		1800 h yr^{-1}	800 h yr^{-1}	
Annual insurance:	74 €. yr^{-1}	85 €. yr^{-1}		74 €. yr^{-1}	85 €. yr^{-1}	
Repair coefficient:	0,5	0,4		0,5	0,4	
Rated engine power:	169 kW			153 kW		
Share of own resources:	100%			100%		
Type of depreciation:	4 yr, linear			4 yr, linear		
Number of operators:	1			1		
Fuel price:	1.50 € L^{-1}			1.50 € L^{-1}		
Labour costs:	6 € h^{-1}			6 € h^{-1}		
Fuel consumption (L h^{-1}):	9.76	13.36	16.88	7.77	10.78	14
Machine performance (bales per hour):	45	62	78	41	57	74
Total unit costs per tractor-machine set, (€ h^{-1})	44.02	48.69	53.25	65.54	72.46	73.62

When evaluating the total unit costs per tractor-machine set related to loading and unloading of the bales (Table 6) we can see the in the year 2010 there was use the same machine for loading and unloading of the bales – John Deere 3400 loader. In the year 2010 for unloading was used JCB 536-60 loader, with fuel consumption at an average higher by 16.6%.

Table 6 Economic evaluation of the working operation - bales loading/unloading

Input data:	Year 2010			Year 2012					
	Machine for loading and unloading :			Machine for loading :			Machine for unloading :		
Bales loading/unloading	**John Deere 3400 loader**			**John Deere 3400 loader**			**JCB 536-60 loader**		
Machine acquisition price without VAT:	30 000 €			30 000 €			45 000 €		
Annual use:	800 h rok^{-1}			800 h rok^{-1}			800 h rok^{-1}		
Annual insurance:	70 € rok^{-1}			70 € rok^{-1}			70 € rok^{-1}		
Repair coefficient:	1			1			1		
Rated engine power:	74 kW			74 kW			74.2 kW		
Share of own resources:	100%			100%			100%		
Type of depreciation:	4 yr, linear			4 yr, linear			4 yr, linear		
Number of operators:	1			1			1		
Labour costs:	6 € h^{-1}			6 € h^{-1}			6 € h^{-1}		
Fuel price:	1.50 € L^{-1}			1.50 € L^{-1}			1.50 € Ll^{-1}		
Fuel consumption (L h^{-1}):	3	4.1	5.2	2.7	3.7	4.9	3.5	4.8	6.3
Machine performance (bales per hour):	45	62	78	41	57	74	41	57	74
Total unit costs per tractor-machine set, (€ h^{-1})	27.1	28.5	29.9	26.7	28	29.5	35.2	36.9	38.9

4 Conclusion

Harvesting, baling and transport of the straw can be considered as the initial technological operations which ensure technological process of the using of straw for energy purposes. Machinery to be used for these operations, significantly affects efficiency of using of straw as a whole. Results obtained during our research have confirmed the validity of our hypothesis - capacity and economical efficiency of the machine line consisting of different tractor-machine sets, depend upon the technical parameters and operational management.

In case that farm wants to use the straw for energy purposes in the form of straw bales and obtain high work efficiency and productivity it is very important:

- to harvest the straw with optimal moisture content with regard to baling, bales picking, bales handling and storage conditions,

- to use a proper square straw balers which are able to produce bales with high straw bulk density, what is very important from the point of transport, handling and storage of the bales,

- to use modern machines for picking, transport, handling of straw bales, which allow to reduce unit labour costs and fuel consumption and increase total productivity (an example: automatic self-picking bale stacker ARCUSIN F 54.63),

- to take into account the technical progress in the area of straw processing. It should be very effective to bale the straw by the baler mounted on the rear part of combine harvester, which allows to combine harvest of cereals with straw baling in one pass,

- to create the well balanced tractor-machine sets, where energy requirements of machine (for example, baler) are completely covered by tractor engine power. Such solution allows reducing fuel consumption up to 30 %.

ACKNOWLEDGEMENTS

The research leading to the results presented in the paper has received funding from the European Community under project no 26220220180: Building Research Centre, AgroBioTech".

The Paper was supported by the projects:

- Application of the information technologies to increase the environmental and ecological sustainability of the production agrosystem", project ITMS 26220220014, EU Operational programme RESEARCH and DEVELOPMENT

- Development of International Cooperation for the Purpose of the Transfer and Implementation of Research and Development in Educational Programs conducted by the Operational Program: Education, ITMS code: 26110230085

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