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Contemporary Research Trends in Agricultural Engineering

Economic Assessment of the Technology Harvesting Maize Straw for Biogas Production

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Abstract. The aim of the study was to determine and analyse the costs of harvesting and storage of maize straw for biogas production. The investigations showed that it was the most economical to harvest maize straw with a self-loading wagon equipped with a cutting system and to store it in a field prism. The cost of this technology amounts to €12.5 per Mg d.m. The cost of maize straw harvest with a field chopper and storage in a flexible silo was the highest, amounts to €126.9 per Mg d.m. The research findings can be used for estimating the profitability of harvesting maize straw for energy production and other industrial purposes.

1 Introduction

In the last decade there has been a 40% increase in the production of maize grains. At present the volume of production amounts to 1,030 million tonnes. In 2016 the total maize grain production in the European Union was 60.3 million tonnes. In comparison with 2015 it increased by 1.8 million tonnes [1, 2]. In 2015 maize grain production in Poland amounted to 3.16 million tonnes [3]. The production of maize grains leaves crop residue, such as stalks, leaves, cob cores and cob-covering leaves. The crop residue makes 47-50% of the dry weight yield of whole maize plants [4, 5]. There is 0.15 kg of cobs , 0.22 kg of leaves, 0.14 kg of husks and 0.5 kg of stalks per one kilogram of the dry weight of maize grains [4]. Our estimates show that the annual maize straw production in Poland may amount to as much as 4 million tonnes. For this reason recently there has been increasing interest in the production of biogas from maize straw [1, 6].

There is high potential of maize residue as a substrate forbiogas production in Poland [7-9]. In Poland maize is harvested for grain in late autumn (October-November), when the air temperature drops and the humidity rises. Under these conditions the moisture of maize grains usually ranges from 30% to 35%. The moisture of maize residue ranges from 47% to 66% [10]. This causes technological problems during harvesting. Apart from that, it is impossible to dry maize straw to the moisture which guarantees lossless storage of the biomass in the field. The maize straw moisture is most influenced by random factors related with the weather conditions. Ensilage is the only reasonable solution in the storage of maize straw.

The technology of harvesting and storage of maize straw to be used as a substrate for biogas production should guarantee that the biomass is free from contamination. Apart from that, it should be characterised by low costs per raw material weight unit.

The Institute of Biosystems Engineering, Poznan University of Life Sciences, Poland, prepared four technologies of maize straw harvesting and storage as part of the project of the Ministry of Science and Higher Education N313 270938 'The Technology of Harvesting and Storage of Maize Straw as an Energy Biomass and Structural Substrate for Composting'. The aim of the study was to make an economic assessment of the technology of harvesting and storage of maize straw to be used for biogas production.

2 Material and methods

2.1 Maize straw harvesting technologies

In 2014 maize straw harvesting and storage technologies were investigated at two locations in Greater Poland Voivodeship. The main machinery used in the technologies included a field chaff-cutter, a self-loading wagon and around baler. Maize straw was stored in a field prism, in a flexible silo, in film-wrapped bales and in net-wrapped bales in a field prism (Fig. 1). The combine harvester which was used for harvesting maize grains was not taken into consideration as an element of any of the technological variants presented.

Technology A – Maize grains were harvested by a combine equipped with a harvesting head, which collected cobs but did not shred stalks. Maize straw was harvested by a field chopper equipped with a six-row unit for harvesting whole maize plants. The harvested and shredded biomass was transported by tractors with

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high volume trailers. The straw was condensed with a device for compressing silo contentin a flexible silo.

Technology B – Maize grains were harvested by a combine equipped with a harvesting head, which collected cobs and shredded stalks. Maize straw rolls were made with a rotary swat her. Then the straw was collected by a collecting trailer equipped with a cutting system. The straw was stored in a field heap covered with a silage film.

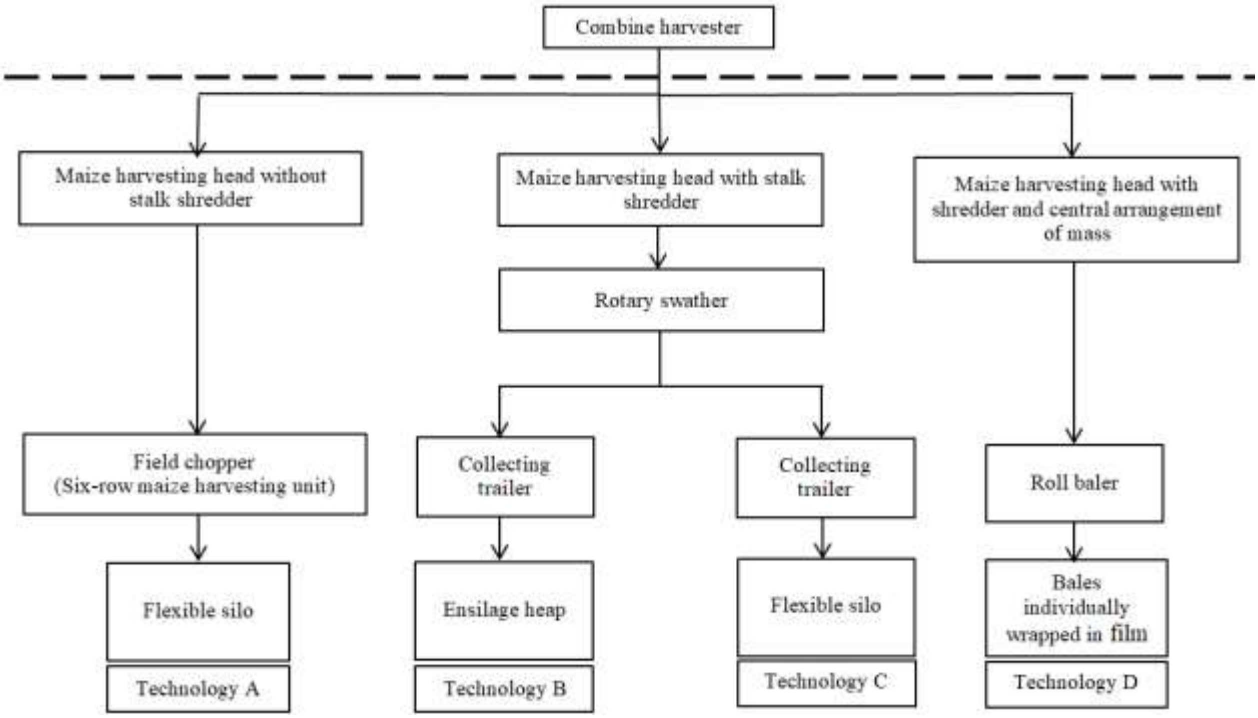

Fig. 1. A block diagram of maize straw harvesting and storage technologies.

Technology C – Maize grains were harvested by a combine equipped with a harvesting head, which collected cobs and shredded stalks. Maize straw rolls were made with a rotary swat her. Then the straw was collected by a collecting trailer equipped with a shredding system. The straw was placed in a flexible silo by means of a device for compressing silo content.

Technology D – Maize grains were harvested by a combine equipped with a harvesting head, which collected cobs, shredded stalks and made rolls of the shredded biomass. Next, net-wrapped cylindrical bales were formed. The bales were collected from the field and transported to the storage place, where they were wrapped in film.

2.2 Efficiency of machinery

The efficiency of the machinery and appliances used in the study was estimated by measuring the time and amount of work done. The time was measured to an accuracy of one second for the procedures which did not last longer than 20 minutes. The machinery uptime was measured at least during three work shifts.

The amount of fuel consumed by self-propelled machinery and tractors was measured with the ‘full tank’ method. The measurements were used to calculate the efficiency of the machinery and specific fuel consumption.

2.3 Machinery operating costs

The calculation method was used to estimate the costs of operation of technological means (machinery, tractors, appliances) and to analyse the costs of the technologies under study [11].

The costs of operation C_e of the machinery used in the maize straw harvesting and storage technologies were expressed as €/Mg d.m. and they were calculated according to the following formula:

$$C_e = \frac{C_m + C_u}{\left(\frac{W_{07}}{P_b}\right)} \quad (1)$$

where:
C_e – costs of operation of machinery, tractors, appliances [€·Mg^{-1} d.m.],
C_m – machinery maintenance costs [€·h^{-1}],
C_u– costs of use [€·h^{-1}],
W_{07}– efficiency of machinery [ha·h^{-1}],
P_b– weight of maize straw harvested [Mg d.m.·ha^{-1}].

The maintenance costs include depreciation, storage (garaging, maintenance) and insurance. The depreciation cost enables reconstruction of the value of machinery. According to the method, the cost of machinery storage amounts to 1% of the purchase price of a machine per year.The costs of maintenance of technological devices C_m were calculated according to the following equation:

$$C_m = \left(\frac{P_m}{U_y}\right) + \left(\frac{P_m S_f}{100}\right) + I_c \quad (2)$$

where:
C_m – costs of maintenance
P_m – price of machine [€],
U_y – machine uptime [h],
S_f – storage costs index [%],
I_c – insurance cost [€·year^{-1}].

Thecosts of use C_u include the costs of repairs, fuel, lubricants and accessory materials. The cost of repairs includes current repairs and overhauls:

$$C_u = \left[\frac{\left(\frac{P_m R_f}{U_y}\right)}{100}\right] + \left[1.06 F_u F_p\right] + \left[M_u M_p\right] \qquad (3)$$

where:
C_u – costs of use
R_f – repair costs index [%],
F_u – fuel consumption [l·h^{-1}],
F_p – price of fuel [€·l^{-1}],
M_u – consumption of accessory materials [kg·h^{-1}],
M_p – price of accessory materials [€·kg^{-1}].

The costs of operation of machinery and tractors were calculated according to the current price lists provided by dealers. The prices of the models of machinery and tractors which are no longer manufactured were estimated according to the prices of their brand-new equivalents. The cost of compulsory liability insurance for tractors (€32.5 per year) and the price of diesel (€1.3 per litre) were included in the calculations. Table 1 lists the costs of repairs, uptime, specific fuel consumption and efficiency of machinery, which are necessary to calculate the costs of operation of technological devices.

Table 1. Data for the calculation of machinery operating costs.

Machinery	Power [kW]	Price [€]	Operating time [years]	Annual use [h]	Repair costs index [%]	Fuel consumption [l·h^{-1}]	W_{07} [ha·h^{-1}]
Technology A							
Field chopper	297	239.2		300	70	30.0	1.0
High-volume trailer	-	17.6		400	90	-	0.3
Tractor 1	114	51.7	25	600	90		-
Device for compressing silo content	-	95.7	15	300	100	-	1.0
Tractor 2	70	42.3		600	90	10.0	-
Technology B							
Rotary swather	-	33.2	20	460	80	-	2.5
Tractor 1	114	51.7	25	600	90	8.7	-
Collecting trailer	-	120.8	20	450	100	-	1.3
Tractor 2	188	196.6	25	1600	90	16.4	-
Telescopic loader	74	84.4	20	1200	70	8.0	3.0
Tractor 3	188	196.6	25	1600	90	16.4	-
Technology C							
Rotary swather	-	33.2	20	460	80	-	2.5
Tractor 1	114	51.7	25	600	90	8.7	-
Collecting trailer	-	120.8	20	450	100	-	2.3
Tractor 2	188	196.6	25	1.600	90	16.4	-
Device for compressing silo content	-	94.3	15	300	100	-	1.1
Tractor 3	93	76.5	30	1.350	600	10.0	-
Technology D							
Roll baler	-	29.4	20	300	80	-	0.8
Tractor 1	70	42.2	25	600	90	12.0	-
Trailer	-	12.9	25	200	90	-	3.0
Tractor 2	81	36.8	25	600	90	6.0	-
Front loader	-	4.2	20	320	100	-	3.0
Tractor 3	53	28.2	25	800	90	5.5	-
Bale wrapper	-	2.5	15	200	80	-	0.6
Tractor 4	37	19.6	25	800	90	4.5	-

3 Results

The maize straw harvesting and storage technology A, which involved the use of a field chopper, proved to be the most expensive. The total cost of this technology was €126.9 per Mg d.m. (Table 2).The transport of chaff from the field to the silo had the highest share in the cost structure of this technological solution. It amounted to 58% (€74.2 per Mg d.m.). Maize straw preservation in a flexible silo cost €34.9 per Mg d.m.(28%).The share of the cost of straw harvesting by a field chopper was the smallest as it amounted to 14% of the total cost of this technology (€17.7 per Mg d.m.).

The total cost of technology D was €25.6 per Mg d.m. Wrapping bales in film was the most expensive element in the cost structure of this technological solution as it amounted to 55% (€14.2 per Mg d.m.). It is possible to reduce the costs of this variant by using an inline wrapper, which needs about half of the amount of film that is necessary for an individual bale wrapper.

Table 2. Maize straw harvesting and storage – the cost structure.

Technological variant	**Costs**			
	Harvesting [€·Mg^{-1} d.m.]	**Transport [€·Mg^{-1} d.m.]**	**Storage [€·Mg^{-1} d.m.]**	**Total [€·Mg^{-1} d.m.]**
A	17.7	74.2	34.9	126.9
B	8.3		4.2	12.5
C	9.1		12.5	21.6
D	9.2	2.3	14.2	25.6

The costs of maize straw harvesting by a collecting trailer are very economical in comparison with the costs of the harvesting technology using a field chopper and a baler. The total cost of straw storage in a field prism was €12.5 per Mg d.m. When straw was ensilaged in a flexible silo, the cost was more expensive by €9.1 per Mg d.m. and it amounted to €21.6 per Mg d.m. A film-wrapped field prism was the most economical form of maize straw storage as it cost €4.2 per Mg d.m.

4 Conclusions

1. Maize straw can be effectively harvested with standard machinery for roughage and green forage harvesting.
2. It is the most economical to harvest maize straw with a collecting trailer equipped with a shredding system. The cost of this technology amounts to €12.5 per Mg d.m.
3. A film-wrapped field prism is the least expensive form of maize straw storage. The cost of storage in a film-wrapped prism amounts to €4.2 per Mg d.m.
4. It is possible to eliminate raking and thus reduce the costs of maize straw harvesting by using harvesting heads arranging the biomass into windrow centrally, between the wheels of a combine harvester.
5. The research findings can be used for estimating the profitability of harvesting maize straw for energy production and other industrial purposes.

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