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WORK INPUTS AND COSTS OF ERADICATION OF ENERGY WILLOW PLANTATION[1]

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ABSTRACT

The objective of the paper was to determine the work expenditures and costs of eradication of an energy willow plantation with currently applied mechanical methods and with the use of the test model of a machine for cutting willow rootstocks as a part of the scientific project no. PBS2/A8/26/2014. The scope of the paper covered research for four machine units constructed for a twelve-year willow plantation with the surface area of 3 ha. Work inputs for eradication of the plantation of the investigated aggregates were within 8.1 to 50.4 mhr·ha^{-1}. Work inputs with the new machine were 22.3 mhr·ha^{-1}. The level of work inputs was influenced by low working speeds of the tractor-machine unit and working speeds from 0.4 to 2.3 m. Costs of willow plantation eradication with current mechanical methods were from 4302 to 15536 PLN·ha^{-1}, and with the use of the new machine it was 5457 PLN·ha^{-1}.

Introduction

Harvesting and eradication of a plantation are the most problematic from among all technological processes related to production of biomass from energy willow. These processes require the use of specialist machines and devices which influences the increase of the incurred work and costs (Adamczyk et al., 2015; Kwaśniewski et al., 2010; Spinelli et al., 2008).

Each perennial agricultural crop should be eradicated and reclaimed or changed into another type of cultivation in an appropriate time. Decision on the eradication depends on many factors. The most important is a demand for a given raw material and price offered for it, obtained crops from the unit of surface area and as a result financial profit. Some-

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times, it results from the need to eradicate a plantation due to natural ageing of plants and the need to plant new, better species and varieties. Livelihood of correctly set and exploited plantations of bushy willow is assessed as 20-25 years (Szczukowski et al., 2004; Dubas, Tomczyk 2005; Larsson, 2006; Stolarski, 2009; Frąckowiak et al., 2016).

For eradication of a plantation the following is indispensable: (1) removal (uprooting) rootstocks form soil or (2) cutting roots into pieces which will not grow again. Cutting roots and leaving them in soil is a more favourable solution on account that some nutrients taken during perennial exploitation of a plantation, remain in soil (Kowalkowski, Olejarski 2013).

Eradication of perennial plantations, including bushy willow may be carried out with mechanical, chemical and biological methods. Moreover, by connection of some elements from the above mentioned methods, mixed methods are applied (Szczukowski et al., 2004; Stolarski et al., 2008). Allocation of biomass of energy willow roots plays a significant role in the process of eradication of a plantation and research results concerning distribution of willow roots constitute precious information for constructors concerning eradication machines (Juliszewski et al., 2015).

In the literature of the subject there is a small number of research results related to eradication of perennial plantations of energy plants (Frąckowiak et al., 2016; Adamczyk et al., 2015; Kwaśniewski et al., 2010; Stolarski et al., 2008). Information published in Poland is mainly in the form of theoretical analyses not supported with field tests. It results, among others, from the fact that a decisive majority of the set plantations are quite young (few years) which do not need to be eradicated.

Determination of the financial profit of a plantation from its exploitation is a priority of research on a willow plantation. On the other hand, a lot of attention is paid to issues related to eradication of a plantation. Quite often, analyses do not include expenditures of work and costs of liquidation of a plantation (Ericsson et al. 2006; McKendry 2002).

Objective, scope and methodology

The objective of the paper was to determine the work expenditures and costs of liquidation of the energy willow with current mechanical methods and with the use of the test model of a machine for cutting willow roots as a part of the scientific project.

The scope of the paper covered research of four machine units, made on the twelve-year plantation of energy willow with the surface area of 3 ha set in Kaniów (Śląskie voivodeship, Bielsko Biala province). The plantation was set on the heavy soil on the floodplain area of Vistula river. Tests were carried out in May and December 2015 and in June 2016.

Performance of operation of aggregates was determined with the simplified chronometer method including the working width (options 0.4; 0.7; 2.0 and 2.30 m) and working speed (options 0.5; 0.8; 1.2 and 1.5 $km \cdot h^{-1}$) Firstly, effective performance was determined (in effective time of operation) then exploitation performance (in exploitation time – including returns and stoppages). Work inputs for eradication of the plantation were expressed in man-hours per one hectare ($mhr \cdot ha^{-1}$).

Determination of the costs of eradication of the energy willow plantation was carried out with the assumption that own aggregates with varied working width will be used without adding the service provider's profit. Costs of exploitation of machines for investigated aggregates were calculated according to the commonly used methodology of costs calcula-

tion (Michałek et al., 1998, Muzalewski, 2009). The calculations of exploitation costs of aggregates include:
– costs of maintenance (fixed costs): amortization, insurance for tractors, costs of storage,
– costs of use (variable costs): costs of fuel and oils, costs of technical service and maintenance, costs of work.

Assumptions taken to the calculations are as follows:
– average annual use of tractors – 600 h·year^{-1},
– average annual use of machines – 70 h·year^{-1},
– price of tractors and machines from the 3rd quarter of 2015,
– price of the test model of a machine is PLN 35 thousand,
– price of diesel oil 4.3 PLN·l^{-1} (consumption of fuel was determined with the method of a full tank),
– annual insurance for tractors is 300 PLN·year^{-1},
– costs of work – 13 PLN·mhr^{-1}.

The paper was written as a part of the scientific project no PBS2/A8/26/2014 "Development of a new technology and functional model of a machine for reclamation of fields after cultivation of energy willow". Project is carried out by a scientific and industrial consortium:
1. University of Agriculture in Krakow – a project leader:
– Faculty of Forestry (Department of Forest Work Mechanization, Department of Forest Ecology and Reclamation),
– Faculty of Production Engineering and Power Energy (Institute of Machinery Management, Ergonomics and Production Processes, Institute of Agricultural Engineering and Informatics),
2. Industrial Institute of Agricultural Engineering in Poznan,
– Department of Devices for Renewable Energy Acquiring and Farming and Storage Works Researches and Development,
– Testing Laboratory of Agricultural Machines,
3. Enterprise Przedsiębiorstwo Wielobranżowe PROMAR Spółka z o.o. in Poznań.

Research results

Four machine aggregates determined in the further part as Aggregate 1, Aggregate 2, Aggregate 3 and Aggregate 4. Aggregate 1 to 3 are used for eradication of the plantation of energy willow with current mechanical methods. Methods applied so far consists in the use of soil cutters with a horizontal rotation axis, working width from 2 to 2.5 m and working depth from 0.3 to 0.45 m. It requires the use of 150-200 kW tractors. On the other hand, Aggregate 4 is a test model of a machine for cutting willow roots as well as bushes and young trees carried out as a part of the scientific project.

The model of a machine (fig. 1) is construed of a frame made of plate griders, between which bodies of drive gears and the body of the main gear are located; bushings are fixed to the bottom parts of drive gear bodies.

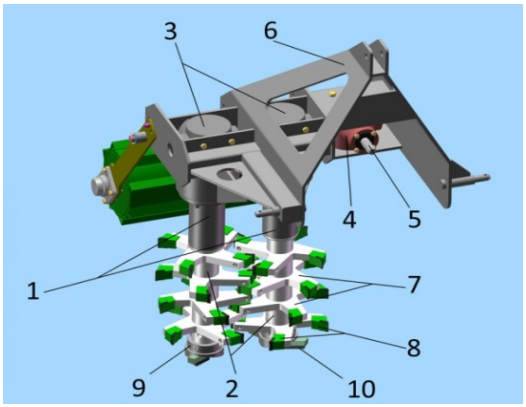

Figure 1. Virtual model of a new machine for cutting of willow rootstocks as well as bushes and young trees

The machine has a characteristic feature which consists in the fact that in bushings (1) there are fragmenting heads which are placed rotationally (2) distributed parallel towards each other and working in the vertical area, at the same time connected to the exits of drive gears (3); inputs of drive gears (3) are connected to the output of the main gear (4) and output (5) of the main gear (4) is connected with the power take-off shaft of a tractor to a frame (6); a real roller is mounted in a hinged manner. Rotating fragmenting heads (2) are equipped with rotors (7) ended with cutting knives (8) and ends of rotational fragmenting heads (2) have profiled hallowing head (9) with hallowing knives placed under a relevant approach angle (10). The working width of a machine is 0.7 m and fragmenting heads may work at the depth of 0.35 m.

Structural solutions applied in the machine were filed for protection in the Patent Office of the Republic of Poland as an invention, number of application P.415825 (Szczepaniak et al., 2016). The machine model with a vertical rotational axis of cutting heads was developed in the Industrial Institute of Agricultural Machines and made by the Consortium of the Project – company P.W. PROMAR Sp. z o.o. (Fig. 2).

Figure 2. Model of a new machine for cutting willow rootstocks as well as bushes and young trees

Machine aggregates covered with the scope of research and their exploitation parameters were presented in table 1. Amount of work incurred on eradication of energy willow plantation was set in table 2.

Table 1.
Machine aggregates and their exploitation parameters

Item	Machine aggregate			Parameter (m)	
	Tractor	Power (kW/KM)	Machine	Working width	Working depth
1	CRYSTAL ORION	176/240	Milling heads for strip soil preparation FAO-FAR model FV4088	0.4	0.3
2	CRYSTAL ORION	118/160	Crusher Meri Crushers MJS-2.0	2.0	0.25
3	CRYSTAL ORION	176/240	Mulcher SFM-225	2.3	0.3
4	CRYSTAL ORION	145/197	Research model of a machine for cutting willow rootstocks	0.7	0.35

Work performance and work inputs for Aggregate 1 were determined for four options W1, W2, W3 and W5 related to various working speeds from 0.5 to 1.5 km·h^{-1} and the constant working width of 0.4 m. In this case the working speed had a decisive impact on the obtained performance and work inputs. For the lowest speed of 0.5 km·h^{-1} (option W5) exploitation performance was the lowest (0.020 ha·h^{-1}) and work inputs were the highest (as much as 50.4 mhr·ha^{-1}). For the biggest speed of 1.5 km·h^{-1} (option W5) exploitation performance was (0.056 ha·h^{-1}) and work inputs were the highest (as much as 17.9 mhr·ha^{-1}). The highest performances and thus the lowest work inputs were characteristic for Aggregate 2 (option W4) and Aggregate 3 (option W6) with the highest working width (2.0 and 2.3 m). Exploitation performances are respectively 0.123 and 0.087 ha·h^{-1}and work expenditures are 8.1 and 11.4 mhr·ha^{-1}.

For the model of a new machine for cutting willow rootstocks made as a part of the research project (Aggregate 4) exploitation performance was 0.045 ha·h^{-1} and work inputs were 22.3 mhr·ha^{-1}.

Fuel consumption and unit exploitation costs for the investigated machine aggregates with a division into costs of maintenance and use were set in table 3. In order to show the impact of fuel on the fuel costs during operation of aggregates they were separated as an element in the costs of use of aggregates.

The exploitation costs for Aggregate 1 were determined, similarly as performances and work expenditures for four options W1, W2, W3 and W5. In this case, calculated unit costs of exploitation were at a similar level and were within 293.7 PLN·h^{-1} (option W3) to 308.4 PLN·h^{-1} (option W5). On the other hand, costs of fuel for those options were from 108.1 PLN·h^{-1} to122.8 PLN·h^{-1}. In the exploitation costs these costs were from 36.8% to 39.8%.

The highest costs of exploitation were calculated for Aggregate 2 (option W4) and Aggregate 3 (option W6). They were respectively 413.0 and 773.3 PLN·h^{-1}. In these costs, participation of fuel costs is respectively 18.6 and 27%. In case of exploitation of these aggregates one should pay attention that the used machines were very expensive and amortization and costs of technical service and maintenance has a considerable participation in the total costs of exploitation.

Table 2.
Work inputs for liquidation of energy willow plantation

Specification	Unit	Aggregate 1			Aggregate 2	Aggregate 1	Aggregate 3	Aggregate 4 (Model of a new machine)
		Spring research (May 2015)				Autumn research (December 2015)		Research (June 2016)
		Options						
		W1	W2	W3	W4	W5	W6	W7
Working speed	(km·h^{-1})	0.8	1.2	1.5	0.8	0.5	0.5	0.8
Working width	(m)	0.4	0.4	0.4	2.0	0.4	2.3	0.7
Effective performance	(ha·h^{-1})	0.040	0.060	0.075	0.160	0.025	0.115	0.06
Work inputs (in effective time)	(man-hour·ha^{-1})	24.9	16.6	13.3	6.3	39.8	8.9	17.9
Exploitation performance	(ha·h^{-1})	0.034	0.046	0.056	0.123	0.020	0.087	0.045
Work expenditures (in exploitation time)	(mhr·ha^{-1})	29.6	21.5	17.9	8.1	50.4	11.4	22.3

For the model of a new machine for fragmentation of willow rootstocks, constructed as a part of the research project (Aggregate 4) the unit costs of exploitaiton were the lowest (among the assessed machines) and were 244.5 PLN·h^{-1}, and the participation of fuel costs is 43%. In this case, the machine was considerably cheaper (PLN 35 thousand) and amortization costs were the lowest.

Costs of eradication of the energy willow plantation with the use of the applied mechanical methods (options W1-W6) and the new machine (option W7) were placed in figure 1. The highest costs of eradication of the plantation for option W5 with the use of Aggregate 1 i.e. milling heads for strip soil preparation FAO-FAR (model FV4088) working with the working speed of 0.5 km·h^{-1} – working width 0.4 m and depth 0.3. Costs of eradication are in this case 15536 PLN·ha^{-1}, and their size raises a big question mark for the use of such a method of willow plantation eradication.

While, the lowest costs of eradication were reported for the option W4 namely with Aggregate 2, i.e. crusher Meri Crushers MJS-2.0 which works with the working speed of 0.8 km·h^{-1} – working width 2.0 m and depth 0.1 m. Costs of eradication with the use of such method are 4302 PLN·ha^{-1}.

In the remaining research options the costs of eradication of the plantation were within the range of 5265 PLN·ha^{-1} option W3) to 8903 PLN·ha^{-1} (option W1).

Table 3.
Fuel consumption and unit exploitation costs for the investigated machine aggregates

Specification	Aggregate 1	Aggregate 2	Aggregate 1	Aggregate 3	Aggregate 4 (Model of a new machine)		
	Spring research (May 2015)		Autumn research (December 2015)		Research (June 2016)		
	Options						
	W1	W2	W3	W4	W5	W6	W7
Fuel consumption ($l \cdot h^{-1}$)	26.2	25.5	24.6	17.6	28.0	48.3	24.0
Fuel consumption ($l\ ha^{-1}$)	776.4	548.9	441.0	142.6	1411.2	550.6	535.7
Costs of maintenance ($PLN \cdot h^{-1}$)	91.8	91.8	91.8	171.1	91.8	290.1	67.4
Costs of use ($PLN \cdot h^{-1}$)	208.9	205.8	201.9	241.9	216.6	483.2	177.1
including costs of fuel and oils ($PLN \cdot h^{-1}$)	115.1	111.9	108.1	77.2	122.8	211.7	105.3
Costs of exploitation ($PLN \cdot h^{-1}$)	300.6	297.6	293.7	413.0	308.4	773.3	244.5

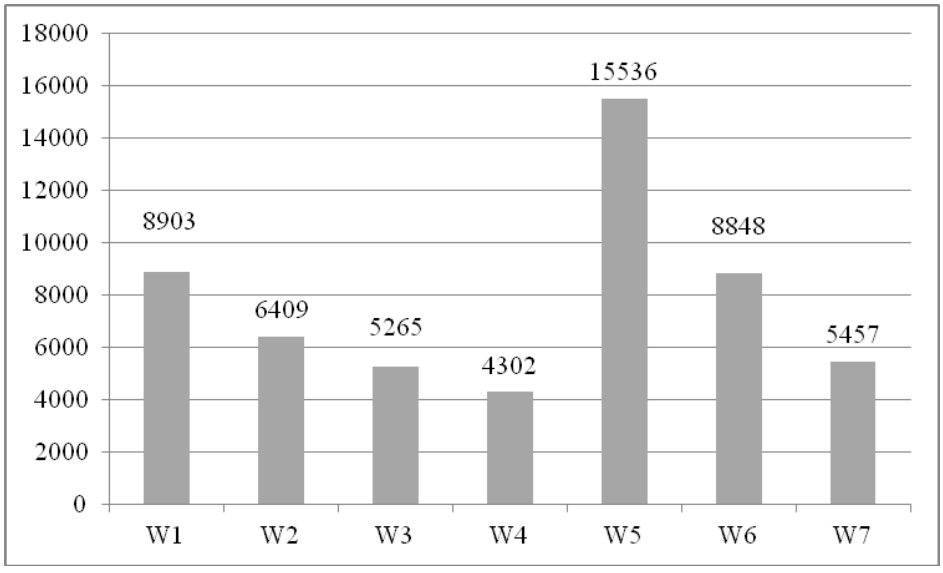

Figure 3. Costs of eradication of energy willow plantation ($PLN \cdot ha^{-1}$)

Both options are related to the use of Aggregate 1 namely milling heads for strip soil preparation FAO-FAR working with the working speed of respectively 1.5 and 0.8 km·h^{-1} – working width 0.4 m and depth of 0.3 m.

The costs of eradication of the willow plantation with the use of the new machine (Aggregate 4) constructed as a part of the scientific project, working with the speed of 0.8 km·h^{-1} (working width 0.7 m, depth of operation 0.35 m) are 5457 PLN·ha^{-1}.

Conclusions

1. Work incurred for eradication of the plantation with the use of investigated aggregates is within 8.1 to as much as 50.4 mhr·ha^{-1}. With the use of the new machine model constructed as a part of the scientific project no PBS2/A8/26/2014 these expenditures are 22.3 mhr·ha^{-1}. The level of work inputs was affected by low working speeds of the tractor-machine unit and working widths from 0.4 to 2.3 m.
2. Exploitation costs of the investigated aggregates were within 293.7 PLN·h^{-1} to 773.3 PLN·h^{-1}. Participation of fuel costs is respectively 36.8% to 27.0%. While the costs of exploitation for the new machine for cutting willow rootstocks were the lowest (from among the assessed machine aggregates) and were 244.5 PLN·h^{-1}, and participation of fuel costs were 43%.
3. The highest costs of eradication of the plantation (as much as 15536 PLN·ha^{-1}) were calculated for option W5 with the use of Aggregate 1 namely a milling head for strip soil preparation FAO-FAR (model FV4088) working with the working speed of 0.5 km·h^{-1}. Very high costs of this method seriously limit its practical use.
4. The costs of eradication of the willow plantation with the use of the new machine working with the speed of 0.8 km·h^{-1} (working width 0.7 m, depth of operation 0.35 m) are 5457^{-1}.

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NAKŁADY PRACY I KOSZTY LIKWIDACJI PLANTACJI WIERZBY ENERGETYCZNEJ

Streszczenie. Celem pracy było określenie nakładów pracy i kosztów likwidacji plantacji wierzby energetycznej dotychczasowymi metodami mechanicznymi oraz z wykorzystaniem modelu badawczego maszyny do rozdrabniania karp korzeniowych wierzby wykonanej w ramach projektu badawczego nr PBS2/A8/26/2014. Zakresem pracy objęto badania dla czterech agregatów maszynowych, wykonane na dwunastoletniej plantacji wierzby o powierzchni 3 ha. Nakłady pracy na likwidację plantacji z wykorzystaniem badanych agregatów mieściły się w przedziale od 8,1 do aż 50,4 rbh·ha^{-1}. Nakłady pracy z wykorzystaniem nowej maszyny wynosiły 22,3 rbh·ha^{-1}. Na poziom nakładów pracy miały wpływ małe prędkości robocze zestawu ciągnik-maszyna oraz szerokości robocze od 0,4 do 2,3 m. Koszty likwidacji plantacji wierzby dotychczasowymi metodami mechanicznymi wynosiły od 4302 do 15536 PLN·ha^{-1}, a z wykorzystaniem nowej maszyny było to 5457 PLN·ha^{-1}.

Słowa kluczowe: wierzba energetyczna, nakłady pracy, koszty likwidacji plantacji