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CULTIVATION CONDITIONS, PELLET MANUFACTURING PARAMETERS AND PHYSICOCHEMICAL PROPERTIES OF PRAIRIE CORDGRASS (*SPARTINA PECTINATA*) AS A DEDICATED ENERGY CROP

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A b s t r a c t. The paper presents information on the cultivation of prairie cordgrass as a dedicated energy crop. The basic agro-technical treatments for this plant are also presented. Moreover, the optimum parameters of compaction to the form of pellets for prairie cordgrass, i.e. optimal chaff length and moisture content of the material, obtained as a result of the study, are indicated. The study showed that optimum moisture content of the raw material for the pelleting process should be in the range of 12-14%. It is also important to prepare prairie cordgrass in terms of particle size. For the production of pellets form prairie cordgrass, the optimum chaff length should be in the range of 3-8 mm. With the optimal parameters for raw material, the pellet obtained has the correct shape and form while maintaining stability during storage and warehousing. The study showed that for pellet made from prairie cordgrass at moisture content of 10.09% the heat of combustion was 17.02 MJ kg^{-1} and the calorific value was 15.62 MJ kg^{-1}, and at moisture level of 7.55% the heat of combustion reached the value of 18.31 MJ kg^{-1} and the calorific value was 16.93 MJ kg^{-1}. Analysis of results indicates that when moisture content increases by 2.54% the heat of combustion decreases by 7.07% and the calorific value by 7.76%. The tests showed a low level of ash content for prairie cordgrass compared to that of fossil fuels. At combustion temperature of 600ºC it amounted to 6.02% at moisture content of 10.09%, and to 4.86% when the level of moisture content was 7.55%. Statistical analysis showed that moisture content of material affects the ash content. The obtained result of the calorific value and ash content indicate that this plant is a good renewable source of energy. Moreover, easy forming of pellets with set parameters for raw material makes this plant a valuable fuel in power plants.

K e y w o r d s: prairie cordgrass, pellet, biomass, moisture content, length of chaff, calorific value, cultivation

INTRODUCTION

Prairie cordgrass, known also as freshwater cordgrass and tall marshgrass, originates from North America. It appears in areas extending from Newfoundland and Quebec (Canada) to the Americal states of Arkansas, Texas and New Mexico. East of the Rocky Mountains it constitutes one of the main component of the prairie flora (Gradziuk *et al*. 2003, Boe and Lee 2007). In Europe it is grown primarily as an ornamental plant, and at the same time it is used for strengthening sandy embankments, dams and dykes. Irrespective of the compactness of the soil, its strong and sharp-pointed roots permit its penetration. It should be noted that prairie cordgrass has a considerable anti-erosion function, and growing on the banks of streams it prevents flooding during periods of intensive rainfalls (Majtkowska and Majtkowski 2005, Konieczny 2007, Gonzales-Hernadez *et al.* 2009).

Prairie cordgrass is characterised by notable capabilities of adaptation to extreme habitat conditions. The plant can grow well both in dry and excessively wet habitats (Boe and Lee 2007). It can be grown on soil with low quality classes, i.e. classes V and VI, and also on stony, slaking and crusty soils. It should be noted that the plant is also tolerant of acidified soils with low pH (Kim et al. 2011, Boe *et al*. 2009). Prairie cordgrass is resistant to unfavourable habitat conditions and can be used for the reclamation of soils degraded by the chemical industry (Budzyński and Bielski 2004). Moreover, it is a plant with high resistance to low temperatures.

Under the conditions of Poland, prairie cordgrass produces seeds, but due to the rapid drop in the germination capacity of the seeds it is recommended to reproduce it through vegetative propagation. In spring the runners are split, and planting is made from mid-April till the end of May. Due to the weakly developing root system, the optimum spacing of the plants in inter-rows should be 0.5 m, and spacing in the rows should be 0.5 m. To facilitate the agro-technical treatments in the first year of cultivation, planting in double rows is often applied, which spacing of 0.7 m and 1.75 m, which permits minimisation of mechanical damage to the plants during harvest. The depth of planting of the runners of the plant should be within the range of 15-20 cm. It should be noted that prairie cordgrass requires particularly careful preparation of the soil, especially in terms of weed control. Due to its low nutrition requirements, no organic fertilisation or liming is necessary, and its strong root system does not require winter ploughing (Kościk 2007).

It should be mentioned that mineral ferilisation should be started in the second year of cultivation, as it then has a favourable effect on the quality of the plant. The optimum doses of mineral fertilisation are as follows: nitrogen (N) – 60-110 kg ha^{-1}, potassium (K_2O) – 50 kg ha^{-1}, phosphorus (P_2O_5) – 100 kg ha^{-1}. P and K fertilisation should be made after prior analysis of the chemical composition of soil samples (Konieczny 2007, Majtkowska and Majtkowski 2005).

In the cultivation of prairie cordgrass properly performed plant husbandry treatments are highly important. Due to its high sensitivity to weed infestation in the first and second year of cultivation, careful weed control treatments are necessary, which unfortunately increases the costs of production.

Prairie cordgrass is a lush perennial grass growing to a height of ca. 2-3 m (Prasifka *et al.* 2011). It forms large loose tussocks thickly covered with leaves of length up to 80-90 cm, their width reaching up to 1.5 cm. In mid-summer there appear branched-bracted inflorescences with length of ca. 30 cm (Cybulska *et al.* 2010). The generative shots of the plant are hollow inside (Gradziuk *et al*. 2003, Majtkowska and Majtkowski 2005). The period of use of a plantation is 15-20 years. The time of harvest is in February or March, as the stems of prairie cordgrass get dry around the middle of November. Premature harvest means the necessity of drying of the biomass, which increases the costs of production. Dry matter yield of prairie cordgrass is estimated at around 17-29 t ha^{-1} (Budzyński and Bielski 2004, Kowalczyk-Juśko *et al.* 2004, Kościk 2007). The harvest technology of prairie cordgrass consists in cutting and either direct fragmentation into chaff or baling and storage.

In view of the problem-free conditions of prairie cordgrass cultivation presented above, an attempt was made at performing an analysis of the material in the aspect of its utilisation as a dedicated energy crop. The objective of the study was to determine parameters for prairie cordgrass for the process of pelleting in the form of the optimum chaff length and the optimum level of moisture of the input material, and to determine the heat of combustion, calorific value, and ash content for two moisture levels of the pellets produced.

MATERIAL AND METHOD

Prairie cordgrass used in the analyses was subjected to preliminary fragmentation with the use of a beater mill type Bąk with screens of mesh size of 3 mm, 8 mm and 12 mm.

Material prepared as above was subjected to the process of compaction by means of a pellet mill with an open compaction chamber (Fig. 1).

The pellet mill used in the study was equipped with a rotating flat die and bearing-supported compacting rollers mounted on a fixed shaft supported in the casing of the compaction chamber. The compacting rollers were situated directly above the die and were driven by its movement. The mill had the possibility of adjustment of the distance between the compacting rollers and the die. The slots in the die had the shape of a truncated cone with lower base length of 8.85 mm and upper base length of 8.60 mm. The thickness of the die was 24.5 mm. The die was driven by an electric motor with power rating of 3 kW, model Y10022-4.

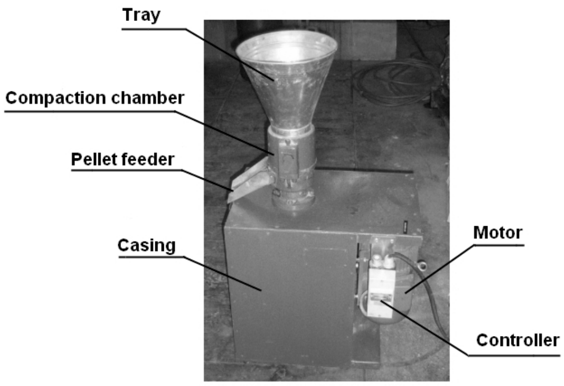

Fig. 1. Presentation of the pellet mill used in the study

The fragmented plant material was fed into the compaction chamber of the pellet mill from the top and formed a uniform layer on the die. The compaction of the material was effected as a result of the pressure of the rotating compacting rollers against the fragmented material, which caused its uniform spreading over the die and then its pressing into the slots of the die. Next, the material was pushed through the compacting slots as a result of forcing successive batches of the material into the holes of the die. The pellets were formed in the compaction slots and their consistence was stabilised. The material formed into pellets then moved from the compacting slots into the granulate chamber where, under the effect of the rotary motion of the die and the contact with the lower part of the compaction chamber it was broken off and the length of the pellets was ultimately determined. The process of compaction was conducted for four levels of moisture: 12%, 14%, 16% and 18%. The specific moisture levels of the material were achieved through drying or the addition of required amounts of water to samples with known mass and moisture that were then stored for a period of 48 hours prior to the pelleting. Chaff lengths in the process of pelleting were <3 mm, 3-8 mm, and 8-12 mm, respectively.

For the fragmented fraction of prairie cordgrass and for the pellet produced from it the total moisture content was determined with the oven-dry method. The determinations were conducted in compliance with the standards PN-93/Z-15008/02 and PN-80/G-04511. Drying of the material was performed using an electric laboratory drier, POL-ECO SLN 32 ECO, with natural air circulation and possibility of temperature adjustment with accuracy to 1ºC.

Within the scope of the study the heat of combustion was determined for two levels of moisture. The determinations were made in compliance with the technical specification PKN–CEN/TS 14588 and the standards PN-81/G-04513 and PN–ISO 1928. The heat of combustion for the biomass tested in the form of pellets was determined with the use of the calorimeter KL-12. The calorific value was calculated in accordance with the standard PN-ISO 1928.

Ash content was determined with the gravimetric method in accordance with the standard PN-80/G-04512. The determinations were made for two combustion temperatures: 600ºC and 815ºC, and for two moisture levels. The combustion of the tested biomass in the form of pellet was conducted with the use of a muffle furnace, Nabertherm L3/11/B180.

The results obtained were subjected to statistical analysis which was performed using the program SAS Enterprise Guide 4.1. Normality of distribution of the properties studied was tested by means of such tests as Shapiro-Wilk, Kolmogorov-Smirnov, Cramer-von Mises and Anderson-Darling. Verification of the results of the study was made using the graphic method in the form of qualtile-quantile graphs. Estimation of the effect of moisture on the level of the heat of combustion and the calorific value was performed using Student's t-test. The effect of moisture and combustion temperature on the amount of ash obtained was estimated by means of two-factor analysis of variance ANOVA. All statistical analyses were performed at significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

In the course of the process of compaction of the raw material, two parameters were determined through observation of the process of compaction, in the form of optimum ranges of material moisture and chaff length.

For prairie cordgrass the optimum range of moisture of the material during the process of pelleting is 12-14%. Below the lower limit of that range the material is too dry to be effectively compacted, while above the upper value it is too moist and does not retain the compacted form. The study confirmed that biomass requires suitable preparation for the process of pelleting in terms of the moisture of the material (Skonecki and Laskowski 2010, Kulig and Skonecki 2011).

The second parameter analysed in the study and having an effect on the process of pelleting is chaff length of the biomass. It is important for the material to be correctly prepared for compaction in respect of the fraction size. Research has shown that the degree of fragmentation has a strong effect on pellet production from plant biomass. Prairie cordgrass is a material which undergoes optimum compaction at chaff length of 3-8 mm. Preparation of the material in the form of such a fraction ensures the production of pellet that does not lose its form and is not sintered. Too small a fraction also undergoes compaction, but the product obtained is not stable. Above the optimum chaff length a deterioration of the process of compaction in the pellet mill is observed. Trying to force the material in, the compacting rollers clog the die holes in such a way that the pressing of the next batch of material is not possible and thus the process is blocked. The consequence of that is continuation of processing of the material and its further fragmentation to the silt fraction. The study supported literature data on the importance of suitable fragmentation of plant biomass for the process of agglomeration (Mani *et al*. 2006, Bergström *et al*. 2008, Nielsen *et al*. 2009).

Compaction of the analysed biomass with the application of the optimum parameters resulted in the production of pellet of prairie cordgrass. The product was characterised by good strength and retained its form and shape during storage.

The pellet produced was characterised by the following parameters: diameter of 8 mm and length of 20 mm.

In the course of the study the heat of combustion and the calorific value were determined for pellets made of prairie cordgrass, for two levels of its moisture. In addition, ash content in pellets from the raw material studied was determined with relation to the adopted temperature of combustion and two levels of moisture. Table 1 presents the physicochemical properties of pellets produced from prairie cordgrass.

Table 1. Physicochemical properties of pellet made of prairie cordgrass for two levels of moisture content

Moisture content (%)	Heat of combustion (MJ kg^{-1})	Calorific value (MJ kg^{-1})	Ash content (%)	
			Combustion temperature (ºC)	
			600	815
10.09	17.02	15.62	5.63	6.02
7.55	18.31	16.93	5.00	4.86

Distribution tests and the graphic method were used to ascertain the normality of distribution of the parameters. and then statistical analysis of results concerning the calorific value and the heat of combustion of pellets made of prairie cordgrass was performed. Analysis of the results by means of Student's t-test permitted estimation of the effect of moisture of the material on the calorific value and the heat of combustion of pellets produced from the biomass under analysis. The results obtained are presented in Table 2 and 3.

The Student's t-test confirmed the literature data on the significant effect of material moisture on the level of calorific value and the heat of combustion of pellets produced from prairie cordgrass. Increase in the level of moisture causes a decrease of the heat of combustion and of the calorific value of the pellet. Increase of moisture level by 2.54% causes a reduction of the heat of combustion by 7.07% and of the calorific value by 7.76%.

Table 2. Estimators of mean and variance for the heat of combustion and calorific value for pellets made from prairie cordgrass

Variable	Moisture content (%)	N	Mean	Std Dev.	Confidence interval		Std. Err.
					For mean	For Std. Dev.	
Calorific value (J g^{-1})	7.55	6	16934	58.13	16872; 16995	36.29; 142.6	23.73
	10.09	6	15620	67.65	15549; 15691	42.23; 165.9	27.62
	Diff (1-2)		1314	63.07	1232.9; 1395.1	44.07; 110.7	36.41
Heat of combustion (J g^{-1})	7.55	6	18312	58.13	18251; 18373	36.29; 142.6	23.73
	10.09	6	17016	67.65	16946; 17087	42.23; 165.9	27.62
	Diff (1-2)		1295.1	63.07	1214; 1376.2	44.07; 110.7	36.41

Table 3. t-Student test for equality of means for calorific value and heat of combustion for prairie cordgrass at different moisture contents

T-Test			
Variable	DF	t Value	p-value
Calorific value (J g^{-1})	10	36.08	<.0001
Heat of combustion (J g^{-1})	10	35.57	<.0001

Statistical analysis was also performed for the results concerning the ash content in pellets produced from the studied plant biomass.

Based on the analysis of the distribution tests it was concluded that the ash content had normal distribution. Taking the above into account. two-factor analysis of variance was performed (Tab. 4 and Tab. 5).

The analysis of variance confirmed that the level of ash content of prairie cordgrass is not affected by the level of the material moisture and by the temperature of combustion of the material.

Table 4. Levels of factors for pellets made of prairie cordgrass

Factors	Levels	Values	
Combustion temperature (°C)	2	600	815
Moisture content (%)	2	7.55	10.09

Table 5. Results of analysis of variance for ash content, the combustion temperature and moisture content of the material for the pellets made of prairie cordgrass

Source	DF	Sum of Squares	Mean Square	F Value	p-value
Combustion temperature	1	0.944	0.944	83.08	<.0001
Moisture content	1	1.251	1.251	110.09	<.0001
Error	18	0.193	0.011		
Corrected Total	20	2.388			

CONCLUSIONS

1. The study showed that prairie cordgrass has good energy properties. The obtained parameters – heat of combustion of 18.31 MJ kg^{-1} and calorific value of 16.93 MJ kg^{-1} at material moisture of 7.55%. are at a fairly good level compared to hard coal whose calorific value is 25 MJ kg^{-1}.
2. The study showed that ash content of 5-6% indicates its low level compared to fossil fuels. This is undoubtedly an advantage in the utilisation of the plant as a renewable source of energy.
3. The easy cultivation of the plant and the possibility of growing it on soils of low quality classes may cause an interest among farmers in its plantation on lands that are currently fallow.
4. The problem-free process of agglomeration with the application of the presented parameters for the raw material may contribute to the popularisation of that fuel among the individual producers of pellets.

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WARUNKI UPRAWY, PARAMETRY WYTWARZANIA PELETU I WŁAŚCIWOŚCI FIZYKOCHEMICZNE SPARTINY PRERIOWEJ (*SPARTINA PECTINATA*) JAKO CELOWEJ UPRAWY ENERGETYCZNEJ

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Streszczenie. Praca zawiera informacje dotyczące uprawy spartiny preriowej, jako celowej uprawy energetycznej. Przedstawiono podstawowe zabiegi agrotechniczne. Ponadto wskazano uzyskane w wyniku badań optymalne parametry zagęszczania w formę peletu dla spartiny preriowej, tj. optymalna długość sieczki i wilgotność materiału. Badania wykazały, że do procesu peletowania optymalna wilgotność badanego surowca powinna mieścić się w zakresie 12-14%. Istotnym jest także przygotowanie spartiny preriowej pod względem wielkości frakcji. Do wytworzenia peletu z analizowanego materiału optymalna długość sieczki powinna mieścić się w zakresie 3-8 mm. Przy zastosowaniu optymalnych parametrów dla surowca otrzymuje się pelet o właściwym kształcie, formie z zachowaniem trwałości w trakcie przechowywania i magazynowania. Badania wykazały, że dla wytworzonego peletu ze spartiny preriowej ciepło spalania wyniosło 17,02 $MJ·kg^{-1}$, a wartość opałowa 15,62 $MJ·kg^{-1}$ przy wilgotności 10,09%, natomiast przy wilgotności 7,55% ciepło spalania wynosiło 18,31 $MJ·kg^{-1}$, a wartość opałowa 16,93 $MJ·kg^{-1}$. Analiza wyników wskazuje, że wzrost wilgotności o 2,54% powoduje obniżenie ciepła spalania o 7,07% i wartości opałowej o 7,76%. Analiza zawartości popiołu wykazała niską jego zawartość dla spartiny preriowej w stosunku do paliw kopalnych. Wyniosła ona odpowiednio dla temperatury spalania 600ºC i wilgotności 10,09% – 5,63%, a przy wilgotności 7,55% – 5,00%. Dla temperatury spalania 815ºC i wilgotności 10,09% – 6,02%, natomiast dla wilgotności materiału 7,55% – 4,86%. Otrzymane wyniki badań wartości opałowej i zawartości popiołu wskazują tę roślinę jako dobre, odnawialne źródło energii. Ponadto bezproblemowe formowanie w pelet dla ustalonych parametrów dla surowca czyni tę roślinę wartościowym paliwem w energetyce.

Słowa kluczowe: spartina preriowa, pelet, biomasa, wilgotność, długość sieczki, wartość opałowa, uprawa