energies

Article

Evaluation of the Effects of Using the Giant Miscanthus (*Miscanthus* × *Giganteus*) Biomass in Various Energy Conversion Processes

Alina Kowalczyk-Juśko [1], Andrzej Mazur [1,*], Patrycja Pochwatka [1], Damian Janczak [2] and Jacek Dach [2]

[1] Department of Environmental Engineering and Geodesy, University of Life Sciences in Lublin, Leszczyńskiego 7, 20-069 Lublin, Poland; alina.jusko@up.lublin.pl (A.K.-J.); patrycja.pochwatka@up.lublin.pl (P.P.)
[2] Department of Biosystems Engineering, Poznań University of Life Sciences, Wojska Polskiego 50, 60-624 Poznan, Poland; damian.janczak@up.poznan.pl (D.J.); jacek.dach@up.poznan.pl (J.D.)
* Correspondence: andrzej.mazur@up.lublin.pl

Abstract: The giant miscanthus (*Miscanthus* × *giganteus*) is one of the most essential energy plants. It also finds various alternative uses, including installing belts to prevent soil erosion. Biomass from such belts should be removed and rationally managed every year. The parameters of miscanthus biomass were investigated in terms of its suitability for combustion and anaerobic fermentation. Under the conditions of the experiment, miscanthus achieved a stable yield already in the second year of vegetation, mainly due to the high planting density. Energy parameters turned out to be typical for straw biomass (calorific value 18.06 MJ/kg). Relatively low ash melting temperatures (<1400 °C) and their chemical composition meant a high risk of contamination depositing on heating devices, which is often indicated as a shortcoming of biomass compared to hard coal. Miscanthus silage can be a valuable substrate for anaerobic digestion, but it requires a sufficiently early harvest, which affects the yield of biomass. The yield of energy in biomass obtained after drying plants was 163,623.6 MJ/ha. In contrast, the yield of energy from biomass collected in summer and processed into biomethane was much lower and amounted to 72,978.2 MJ/ha.

Keywords: biomass; giant miscanthus; combustion; energy value; heating boilers fouling; anaerobic digestion; energy yield

check for updates

Citation: Kowalczyk-Juśko, A.; Mazur, A.; Pochwatka, P.; Janczak, D.; Dach, J. Evaluation of the Effects of Using the Giant Miscanthus (*Miscanthus* × *Giganteus*) Biomass in Various Energy Conversion Processes. *Energies* **2022**, *15*, 3486. https://doi.org/10.3390/en15103486

Academic Editor: Dino Musmarra

Received: 22 April 2022
Accepted: 9 May 2022
Published: 10 May 2022

1. Introduction

Grasses from the *Miscanthus* family are important energy plants, mainly due to their high-yielding potential, durability, resistance to pathogens, and unfavorable environmental conditions [1]. The most outstanding prospects for disseminating energy crops are associated with the hybrid species of *Miscanthus* × *giganteus* Greef and Deuter, which was bred by crossing *M. caccharifiorus* and *M. sinensis* [2]. The plant's advantages include a high-yield potential under various agroclimatic conditions [3], high heat of combustion [4], low ash content with a slight tendency to contaminate the surface of heating devices [5], spontaneous drying out after the end of vegetation [6], the possibility of harvesting with the use of typical agricultural machines, without the need to invest in specialized agrotechnical equipment [7].

The giant miscanthus has been indicated since the beginning of the 21st century as a species of great importance for biomass production for energy purposes [8–10]. Miscanthus biomass has been studied in terms of its use in various conversion processes into usable energy: combustion [11], pyrolysis [12–14], ethanol fermentation [15], and anaerobic digestion [16,17].

The biomass of grasses from the *Miscanthus* family, collected during the growing season, has different functional characteristics than those obtained after the above-ground parts have dried [6,18]. The differences include higher humidity, different yield structures [19], lower lignification expressed by the ratio/content of lignocellulosic fraction, and at the same time, higher digestibility [20]. Due to such proportions of components building biomass, it is much more helpful for biochemical conversion processes, especially methane fermentation [18,21–23]. It also proved rational to include miscanthus cultivation in the biogas plant operation system in terms of fertilization with digestate [24].

In addition to the energetic use of miscanthus, they also find a multidirectional alternative use. These grasses are planted in wetlands in wastewater treatment plants, where they collect pollutants and support the wastewater treatment process [25–29]. These plants purify sewage and remove pollutants (e.g., heavy metals) from the soil; hence, they are used in land reclamation and phytoremediation [30,31]. The ability of the bowl to collect pollutants from soil, water, and air cause these plants to fill protective strips around industrial plants and landfills [32]. The above-ground parts of the giant miscanthus are used to produce building materials [33,34]. Miscanthus straw is characterized by good absorbency, and therefore it is used as a litter for farm animals [35]. Dried giant miscanthus was tested for use as a feed additive for various animal species, both ruminants and monogastric animals [36]. Various species of the genus *Miscanthus* are characterized by ornamental value: they reach high height, have long fluffy inflorescences, some varieties have colorful leaves, and therefore, they are used as decorative plants in parks and gardens [10]. As can be seen from the above information, miscanthus is tested for suitability in various applications. Interactions of miscanthus with various elements of the environment were also assessed: soil [37], water deficiency caused by climate change [38], mycorrhizal fungi [39], and avifauna [40].

A new concept of alternative use of miscanthus is planting it in anti-erosion belts to protect soils against water erosion and pollution [41]. Soil degradation phenomena caused by water erosion are multidirectional and complex, but they always lead to unfavorable changes in the physical and chemical properties of soils and thus, to lower yield potential [42–47]. Various methods are used to protect soils against water erosion, including installing field erosion belts planted with trees and shrubs. An alternative to anti-erosion belts made of trees and shrubs can be belts planted with miscanthus. After planting, the plants remain in the form of large clumps for several years only in the planted area. In addition, the above-ground parts of this grass dry up in late autumn, and leaves fall only in winter, which avoids crop contamination problems in crops adjacent to the belts. At the same time, the giant miscanthus, in the first year of vegetation, can produce a significant mass of underground organs: roots and short, vigorous rhizomes, which can quickly strengthen the top layer of soil, preventing erosion. Miscanthus restores the above-ground mass every year, and therefore it is advisable to collect the above-ground parts in early spring before starting the vegetation. Biomass can also be collected from plantations, including anti-erosion belts, provided that it is managed rationally during the growing season. Miscanthus is characterized by exceptionally high possibilities of regrowth after harvest [48].

The research aims to assess the suitability of giant miscanthus, obtained from plantings in anti-erosion belts, to be used for energy purposes in methane combustion and fermentation.

2. Materials and Methods

2.1. Characteristics of the Field Experiment

The study site is located in southeastern Poland in Czesławice (51°18′10′′ N, 22°15′09′′ E) in the Lublin Upland, in the central part of the mesoregion—Nałęczów Plateau. The experiment was established in an loess, eroded production field with a southeastern exposure, in the upper part of the slope with a slope of about 15%. In May of 2018, across the slope, a 30 m^2 (15 $\times$ 2 m^2) anti-erosion belt was separated, on which a perennial grass—*Miscanthus* $\times$ *giganteus*—was planted in a 25 cm $\times$ 25 cm grid. No mineral fertilizers and pesticides were used. More information about the location of the experimental object, environmental conditions and the method of setting up the anti-erosion belt planted with giant miscanthus are described in the article [41].

2.2. Study of Biometric Features and Yield

During each growing season, the height of the giant miscanthus was measured, and after the end of vegetation, the thickness of the shoots, the number of shoots per seedling, and the root system's depth were determined. Biometric measurements were carried out on 20 randomly selected plants. The arithmetic mean, median, standard deviation, minimum and maximum value were calculated for the obtained results. The yield of dried-up aerial parts in working condition (fresh mass—FM) was measured annually in early spring (mid-March), sampling from 3 randomly selected plots of 1 m^2 each. In the tests, the content of dry matter (DM) was determined by the gravimetric method at 105 °C. The yield structure (share of shoots and leaves) in FM and DM was also determined. The paper presents the average values of three measurements.

Apart from the dried biomass yield, the miscanthus yield during the growing season was determined once in the third year of vegetation. For this purpose, in the third week of July, samples were taken from 3 plots, each of which had an area of 1 m^2. The biomass was weighed, and the dry matter content was determined.

2.3. Study of Energy Parameters

After the end of the third growing season and drying of the above-ground parts of giant miscanthus, samples were taken to determine the parameters necessary for thermochemical processes. The scope of the research included: humidity, ash content, volatile matter, higher and lower heating value, C, H, N, S, and Cl content (Table 1).

Table 1. Methods of studying the energy parameters.

<table>
<tr><th>Determination</th><th>Symbol</th><th>Norm</th><th>Method</th></tr>
<tr><td>Total moisture</td><td>M_{ar}</td><td>PN-EN ISO 18134-2:2017-03</td><td>gravimetric</td></tr>
<tr><td>Ash</td><td>A_d</td><td>PN-EN ISO 18122:2016-01</td><td>gravimetric</td></tr>
<tr><td>Volatile matter</td><td>V_d</td><td>PN-EN ISO 18123:2016-01</td><td>gravimetric</td></tr>
<tr><td>Higher heating value</td><td>HHV</td><td>PN-EN 14918:2010</td><td>calorimetric</td></tr>
<tr><td>Lower heating value</td><td>LHV</td><td>PN-EN 14918:2010</td><td>computational</td></tr>
<tr><td>Carbon</td><td>C</td><td rowspan="3">PN-EN ISO 16948:2015-07</td><td rowspan="2">measurement with an automatic IR analyzer</td></tr>
<tr><td>Hydrogen</td><td>H</td></tr>
<tr><td>Nitrogen</td><td>N</td><td>catharometric</td></tr>
<tr><td>Total sulfur</td><td>S</td><td rowspan="2">PN-EN ISO 16994:2016-10</td><td>measurement with an automatic IR analyzer</td></tr>
<tr><td>Chlorine</td><td>Cl</td><td>ion chromatography (IC)</td></tr>
</table>

The dry biomass was comminuted using a knife chopper into 10–30 mm particles, for which the bulk density was determined. Based on the yield and the calorific value, the energy yield contained in the biomass per area unit (MJ/ha) was calculated, and considering the bulk mass and the calorific value, the energy density of the raw material (MJ/m^3) was calculated.

2.4. Study of the Impact on Heating Devices

To assess the impact of biomass combustion on heating devices, ash melting points were determined (according to CEN/TS 15370-1:2007, microscopic—photographic method), and the chemical composition of the ash was analyzed (Table 2).

Table 2. Methods of ash composition testing.

Component	Symbol	Norm/Method
Silica	SiO_2	IB_TL_21_07 on 28.05.2013 The analysis was performed with a plasma spectrometer Thermo iCAP 6500 Duo ICP
Iron	Fe_2O_3	
Aluminum	Al_2O_3	
Manganese	Mn_3O_4	
Titanium	TiO_2	
Calcium	CaO	
Magnesium	MgO	
Sulfur	SO_3	
Phosphorus	P_2O_5	
Sodium	Na_2O	
Potassium	K_2O	
Barium	BaO	
Strontium	SrO	
Chlorides	Cl	PN-EN 196-2:2013-11 titration method
Carbonates	CO_2	PN-EN 15936:2013-02

The analyses were carried out in 3 replications (expanded uncertainty u for the coefficient k = 2 and the confidence level of 95%). The ash research results were used to evaluate the influence of miscanthus biomass combustion on heating devices. The following indicators were used [49–52]:

1. Indicator c_m:

$$c_m = \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O + P_2O_5}{SiO_2 + Al_2O_3 + Ti_2O} \tag{1}$$

c_m—the ratio of basic to acidic oxides [50].

2. Base-acid ratio B/A:

$$B/A = \frac{Fe_2O_3 + CaO + MgO + Na_2O + K_2O}{SiO_2 + Al_2O_3 + Ti_2O} \tag{2}$$

It is the ratio of base to acidic oxides. If $B/A < 0.4$ or $B/A > 0.7$, the tendency to fouling is low, if $0.7 > B/A > 0.4$—the tendency to fouling is high [49].

3. Slagging factor R_S:

$$R_S = (B/A) \cdot S^d \tag{3}$$

where: B/A—base-acid ratio, S^d—sulfur content in the fuel (% DM).

If $R_S < 0.6$—tendency to impurity formation is low, if $0.6 < R_S < 2.0$—medium, if $2.0 < R_S < 2.6$—high, if $R_S > 2.6$—very high [49,52].

4. Simplified indicator $R_{(b/a)}$:

$$R_{(b/a)} = \frac{Fe_2O_3 + CaO + MgO}{SiO_2} \tag{4}$$

The lower the $R_{(b/a)}$ index value, the higher the melting and flow point of the ash, and thus the lower the risk of slagging. At $R_{(b/a)} < 0.15$ these temperatures exceed 1600 °C [50].

5. Silica percentage S_R:

$$S_R = \frac{SiO_2 \cdot 100}{SiO_2 + Fe_2O_3 + CaO + MgO} \tag{5}$$

A high value of the S_R index means a high slag viscosity and thus a low slag tendency. If $S_R > 72$—the slag shows a low slag tendency, if $72 \geq S_R > 65$—medium, if $S_R \leq 65$—low [50]. If the S_R is 72–80, the propensity to pollute is low, if the S_R is 65–73—medium, and if it is 50–65—very high [49].

6. Indicator F_u:

$$F_u = (Na_2O + K_2O) \cdot c_m \tag{6}$$

The F_u index determines the fuel's propensity to the formation and subsequent sintering of contaminants on the heated surfaces and the tendency to form slag initiating deposits. If $F_u \leq 0.6$, the fuel does not tend to form contamination, if $0.6 < F_u \leq 40$—has a high tendency, and if $F_u > 40$—a very high tendency to form and sinter contamination [50].

7. Iron calcium ratio:

$$IC = \frac{Fe_2O_3}{CaO} \tag{7}$$

If $IC < 0.3$ or $IC > 3.0$, the propensity to pollutant formation is low, if $0.3 < IC < 3.0$—high [49].

8. Iron plus calcium:

$$I + C = Fe_2O_3 + CaO \tag{8}$$

If the sum of Fe_2O_3 + CaO oxides does not exceed 10%, the fuel has a low propensity to pollute [49].

9. Alkali index:

$$AI = \frac{(K_2O + Na_2O) \cdot A}{LHV_d} \tag{9}$$

where: A—ash content determined at 550 °C (%), LHV_d—lower heating value of dry mass (MJ/kg).

If the $AI > 0.17$, the formation of pollutants is likely; if the $AI > 0.34$, then pollutants are formed [52].

10. Sintering index:

$$SI = \frac{CaO + MgO}{Na_2O + K_2O} \tag{10}$$

If $SI > 2$, the slagging risk is low; if $SI < 2$—high [52].

11. Bed agglomeration index:

$$BAI = \frac{Fe_2O_3}{Na_2O + K_2O} \tag{11}$$

It concerns the possibility of sediment formation on fluidized beds. If $BAI < 0.15$, agglomerates are formed [52].

12. Slagging index:

$$T = \frac{HT + 4 \cdot DT}{5} \tag{12}$$

where: HT—hemisphere temperature (°C), DT—deformation temperature (°C).

The slagging risk is low if T > 1340, medium when T is 1230–1340, high when T is 1150–1230, and T < 1150 is a substantial slag risk [49].

2.5. Biogas Efficiency Study

During the third year of giant miscanthus vegetation (in the third week of July), samples of the above-ground parts in the vegetative stage of development (before the formation of inflorescences) were taken and crushed to the form of 10–30 mm long chaff with a chopper. In a 3-L glass jar, the chaff was kneaded to remove the air. Then, a tightly closed jar was placed in a dark, cool room, where the biomass was ensiled. After six weeks, tests on the suitability of silage for use in a biogas plant at the Department of Biosystems Engineering at the Poznań University of Life Sciences were carried out. The tests were performed in 3 repetitions according to DIN 38414. The tests included: dry matter and organic dry matter content in silage, pH, conductivity, biogas and biomethane efficiency as a function of time, and evaluation of biomethane content in biogas.

3. Results

3.1. Biometric Parameters of a Giant Miscanthus

Miscanthus seedlings, planted at a distance of 25 × 25 cm, developed adequately. When establishing the anti-erosion belt, most seedlings produced single shoots, 30% produced two each, and 10%—3 shoots each. Plants produced only short stalks, and the average height measured from the base of the stem to the end of the longest leaf, assessed after the end of the first growing season (in October), was 98.4 cm (Table 3). The average thickness of the shoots was 4.3 mm. Plants developed root systems to a maximum depth of 23 cm, and their average length was 16.5 cm.

In the second year after planting, the plants sprouted up to 12 shoots per plant (Table 3), while in the third year, the maximum value did not change, but no single-shoot plants were found. In the second year of vegetation, the plants developed tall (202.7 cm) and thick (5.1 mm) stems, which are a characteristic feature of this species. The root systems also penetrated the soil deeper, reaching 20.1 cm. In the third year of vegetation, the plants reached the biometric parameters typical for this species: the height of some shoots exceeded 3 m, their average thickness was 8.6 mm, and the roots reached an average of 30.2 cm deep into the soil.

Table 3. Biometric parameters of a giant miscanthus.

Specification	Tested Parameter											
	Height [cm]			Number of Shoots [pcs.]			Shoot Thickness [mm]			Root Length [cm]		
	Year			Year			Year			Year		
	I	II	III	I	II	III	I	II	III	I	II	III
Mean	98.4	202.7	264.2	1.5	7.3	7.8	4.3	5.1	8.6	16.9	20.1	30.2
Minimum	75	184	187	1	1	3	2	3	6.5	12	13	15.0
Maximum	128	226	312	3	12	12	6.5	6.5	10.7	23	27	39.0
Standard deviation	17.0	11.6	48.5	0.7	2.8	2.5	1.2	0.9	1.2	3.4	4.1	6.9
Median	100.0	201.0	291.0	1.0	7.5	7.5	4.4	5.3	8.8	16.5	19.5	29.0
Variation coefficient	0.17	0.06	0.18	0.46	0.39	0.33	0.28	0.18	0.15	0.20	0.20	0.23

3.2. Biomass Yield

In the first year, the average yield of miscanthus biomass, determined as received, did not exceed 400 g/m^2, which per 1 ha gave less than 4 Mg FM. In the second and third years of growth, the harvest was similar and amounted to 11.62 and 12.01 Mg FM/ha, respectively. Miscanthus loses a significant part of water during the winter and naturally achieves a high dry matter content, which in the first, second, and third years was 69.38%, 79.30%, and 75.50%, respectively. Based on the FM yield and its moisture, the DM yield in the following years was calculated at 2.35, 9.39, and 9.06 Mg DM/ha, respectively.

The evaluation of the yield components made it possible to establish that the leaves constituted the dominant part of miscanthus in the first year of vegetation, the percentage of which in FM and DM amounted to 64.45 and 72.41%, respectively. In the second and third years, these proportions changed as the plants developed tall, thick shoots that dominated the yield structure of both FM and DM (Figure 1).

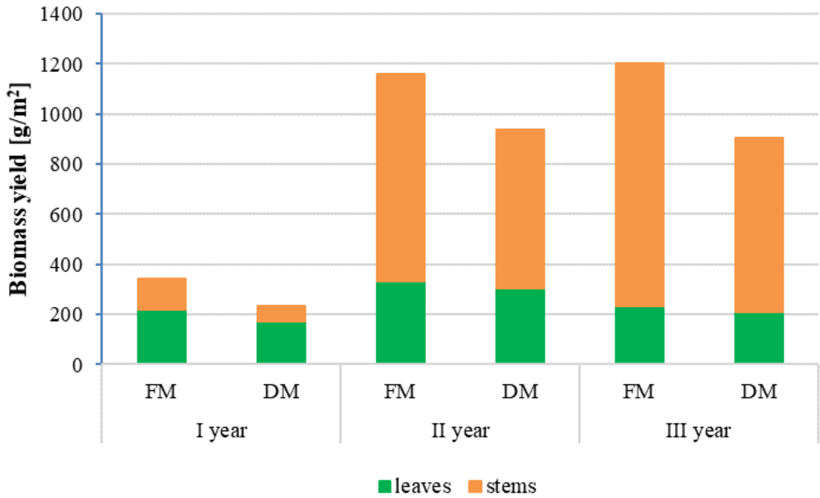


Figure 1. Share of stems and leaves in the mass of a giant miscanthus.

Miscanthus biomass yield determined during the third year of vegetation (July) was 3470 g FM/m^2, with a moisture content of 80.4%. Calculated per field unit, it yielded 34.70 Mg FM/ha and 6.80 Mg DM/ha.

The DM yield obtained in summer was almost 25% lower than that collected after the plants had dried because in the summer, the shoots were further elongated, and new leaves were formed. However, to obtain a substrate suitable for anaerobic fermentation, it is not advisable to delay harvesting, as plants become woody as they grow, and their biomass becomes less digestible for fermentation bacteria.

3.3. Energy Parameters

Elemental analysis of miscanthus biomass showed that the share of carbon was 48.96% DM, and hydrogen 5.98% DM (Table 4). These elements determine the heating value of the fuel, which was LHV 18.06 MJ/kg DM. Low carbonization of the examined biomass resulted in a high content of volatile matter (82.0% DM), which should be considered when composing mixtures for co-combustion. The content of elements unfavorable from the point of view of environmental pollution (nitrogen and sulfur) was not high and amounted to N—0.20% DM and S—0.03% DM. Miscanthus also contained a small amount of chlorine (0.045% DM), which often causes chloride corrosion in boilers used to burn biomass.

A parameter indirectly related to the energy use of biomass is its bulk mass (volumetric density), as it determines the size of rooms or tanks for storage and means of transport. The density of chaff from giant miscanthus in the working condition was 58.3 kg/m^3. Considering the bulk mass and calorific value, it was calculated that the energy density of miscanthus biomass was 947.96 MJ/m^3.

Table 4. Giant miscanthus biomass parameters important from the energetic point of view.

Parameter	Status *	Unit	Value	Extended Uncertainty u
M_{ar}	r	%	8.8	0.2
A_d	d	%	2.76	0.10
V_d	d	%	82.0	3.8
HHV	d	J/g	19,290	700
	r	J/g	17,590	830
LHV	d	J/g	18,060	700
	r	J/g	16,260	860
C	d	%	48.96	1.40
H	d	%	5.98	0.27
N	d	%	0.20	0.01
S	d	%	0.03	0.00
Cl	d	%	0.045	0.008

*—r—as received; d—dry.

3.4. Ash Properties

The ash content in the giant miscanthus biomass was 2.76% of dry mass. Acid oxides predominated in the ash composition: silica (SiO_2) and aluminum oxide (Al_2O_3), while the basic oxides of calcium (CaO), potassium (K_2O), magnesium (MgO), and iron (Fe_2O_3) were in the minority (Table 5). The results of the ash composition analysis were used to assess the impact of the biomass burned on the condition of heating devices [18].

Table 5. Composition of ash from the combustion of a giant miscanthus biomass.

Component	Content [% DM]	Extended Uncertainty u
SiO_2	61.3	3.3
Fe_2O_3	0.48	0.04
Al_2O_3	1.25	0.11
Mn_3O_4	0.39	0.04
TiO_2	0.33	0.04
CaO	8.27	0.71
MgO	2.49	0.26
SO_3	2.02	0.26
P_2O_5	8.16	0.53
Na_2O	0.44	0.08
K_2O	12.50	1.36
BaO	0.04	0.01
SrO	0.04	0.01
Cl	1.22	0.28
CO_2	0.13	0.02
Sum	99.06	3.73

The melting temperatures of miscanthus biomass ash < 1500 °C (Table 6) indicate that the ash tends to settle on the heating surfaces of the boilers, and as a result, the heat exchange may be disturbed. Also the subsequent temperatures ranges of state ash change (shrinkage, deformation, hemisphere, and flow) were relatively low.

Table 6. Ash melting points (reducing/oxidizing atmosphere).

Parameter	Unit	Value
Shrinkage temperature, SST	°C	750
Deformation temperature, DT	°C	900
Hemisphere temperature, HT	°C	1300
Flow temperature, FT	°C	1370

The values of indicators confirm it for assessing ash's tendency to contaminate the surfaces of heating devices (Table 7). The high probability of sediment formation on the fluidized beds was also determined. Deposits and impurities on the heat exchange devices hinder this exchange, which reduces the efficiency of the installation. They can also cause corrosion and erosion phenomena in heating boilers.

Table 7. Indicators of the assessment of the risk of contamination of heating surfaces of boilers.

Indicator	Pattern No.	Value	Deposition Hazard
c_m	1	0.51	—
B/A	2	0.38	low
R_S	3	12.82	severe
$R_{(b/a)}$	4	0.18	severe
S_R	5	84.51	low
F_u	6	6.66	high
IC	7	0.06	low
I + C	8	8.75	low
AI	9	1.98	severe
SI	10	0.83	high
BAI	11	0.04	severe
T	12	980	severe

3.5. Biogas Efficiency

Miscanthus biomass, collected in the vegetative phase, hardened correctly and observed no mold or abnormal changes. The silage reaction was 5.12, its conductivity was 1.54, the dry matter content was 18.3%, and the dry organic matter content (ODM) was 91.5% DM.

Biogas yield from giant miscanthus silage was 547.0 m^3/Mg ODM (Table 8). The biomethane content in biogas was high (56.88%), which, combined with the high yield of biogas, resulted in a significant yield of biomethane per mass unit. Converted to a field area unit, with the yield of the fresh mass of 34.7 Mg/ha, the yield of biogas and biomethane amounted to 3177.13 and 1807.18 m^3/ha, respectively.

Table 8. Biogas yield from giant miscanthus silage.

No.	Fresh Mass—Efficiency		Dry Matter—Efficiency		Organic Dry Matter—Efficiency		Methane Content [%]
	Accumulated Methane [m^3/Mg FM]	Accumulated Biogas [m^3/Mg FM]	Accumulated Methane [m^3/Mg DM]	Accumulated Biogas [m^3/Mg DM]	Accumulated Methane [m^3/Mg ODM]	Accumulated Biogas [m^3/Mg ODM]	
1.	51.75	90.51	282.86	494.72	309.15	540.70	57.18
2.	51.54	92.61	281.71	506.30	307.89	553.23	55.65
3.	52.95	91.58	289.44	500.54	316.34	547.06	57.82
Mean	52.08	91.56	284.67	500.52	311.13	547.00	56.88

Figures 2 and 3 show the course of the fermentation process and the time when the process was most effective: HRT (Hydraulic Retention Time) was 26 days from the start of methane fermentation. Although the substrate was kept in the reactor up to 59 days from the initiation of the process, the increase in the amount of biogas from the 27th day was negligible.

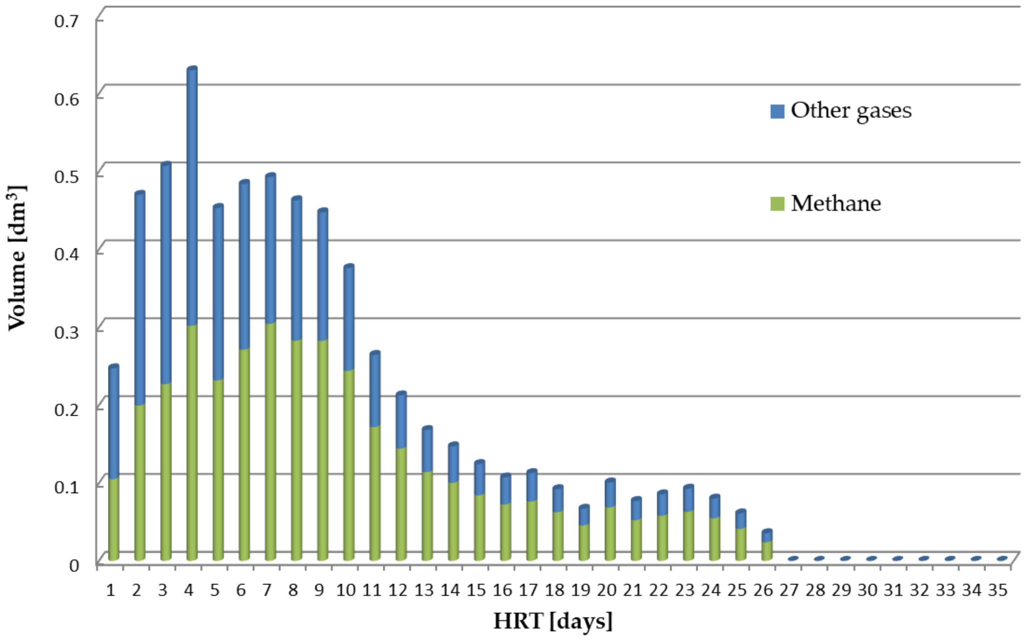
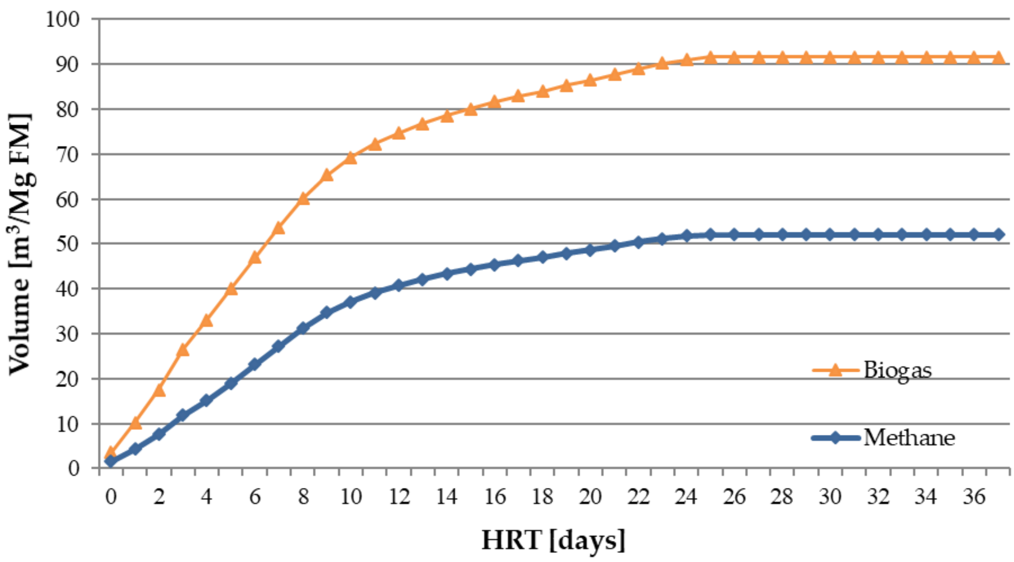
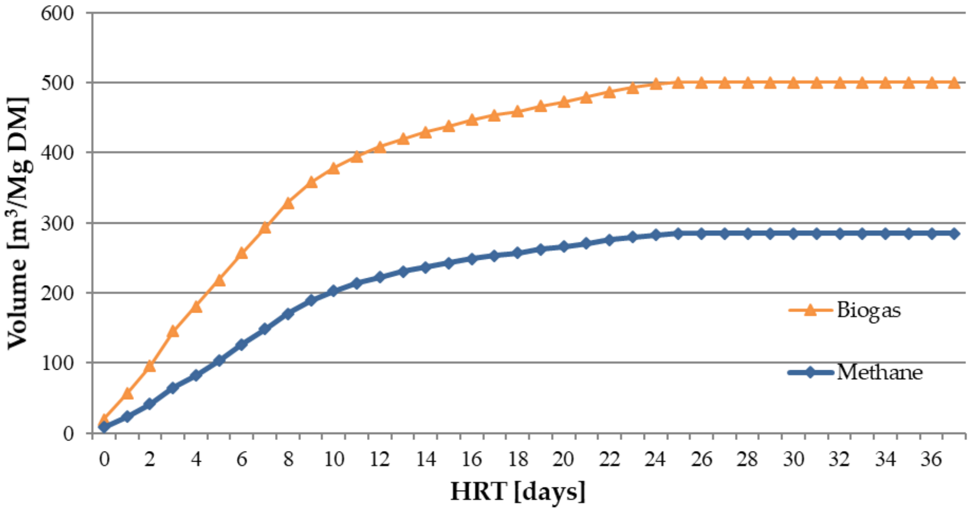


Figure 2. Graph of accumulated biogas production as a function of time.

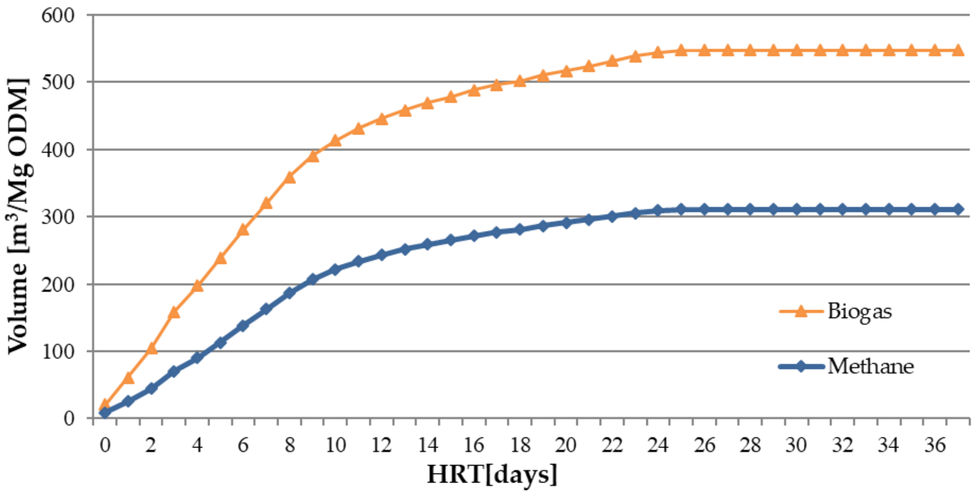


(**a**)

Figure 3. *Cont.*



(**b**)



(**c**)

Figure 3. Graph of the accumulated production of biogas and biomethane as a function of time converted into: (**a**) fresh mass of silage (FM), (**b**) dry matter (DM), and (**c**) organic dry matter (ODM).

3.6. Energy Yield

The conversion of the chemical energy contained in the giant miscanthus biomass into usable energy can be carried out thermochemically (incineration) or biochemically (anaerobic fermentation). These processes require different handling of biomass during the growing season: to obtain a substrate for biogas production, plants should be harvested in the vegetative phase, and the best combustion parameters have dried biomass harvested even a few months after the end of vegetation (in Poland, about 3–4 months after the plant development processes have ceased).

Considering the DM yield per 9.06 Mg/ha and its LHV of 18.06 MJ/kg (Table 4), it was calculated that by harvesting the biomass after drying of the plants, 163,623.6 MJ could be obtained from 1 ha of the field. On the other hand, the harvest of green biomass in the amount of 6.80 Mg DM/ha allows for the production of 1935.76 m^3 of biomethane (Table 8). Assuming the calorific value of methane at 37.7 MJ/m^3, it was calculated that the energy yield, in this case, was 72,978.2 MJ/ha. The yield of energy obtained by fermentation of miscanthus biomass turned out to be 55.4% lower than the energy contained in the dry biomass burned. It should be considered that the above calculations do not consider the efficiency of power devices, which may affect the results obtained in natural conditions.

4. Discussion

The vegetation of giant miscanthus plants was normal in the conditions of Central and Eastern Europe. The five-fold increase in the number of shoots produced by a single plant, noted between the first and second years of vegetation, in the third year was only 6.8%. The number of shoots produced by miscanthus can amount to several dozen heads/plant, and this value depends mainly on their density [53]. The planting density (25 $\times$ 25 cm) used in the present study was not typical for miscanthus plantings for energy purposes, whereas in Poland, the density of 1–8 plants/m^2 is used [48]. However, the experiment aimed to protect the soil from erosion and create a compact, turfed strip. The results of our own research confirms the ability of this species to self-regulate the number of shoots, as written by other authors [48,54,55]. Other biometric parameters: shoot height and thickness as well as root length in the third year of vegetation reached parameters similar to those reported in the literature [2,9].

Grasses from the *Miscanthus* family are perennial plants that can be used for several years [56]. In the first year after planting, the seedlings are adopted, and the yield obtained is negligible, as found in the authors' research. Yu et al. [6] also found a low yield of various *Miscanthus* genotypes in the first year of cultivation. The optimal yield is most often obtained in the third year of plantation and ranges from a dozen to over 20 Mg/ha [48,57,58]. In our research, the yield of this order (11.62 Mg/ha FM) was obtained already in the second year, which could have resulted from the plant density used. In the third year, the yield did not increase significantly.

Like that of other species intended for combustion, the high proportion of dry matter in the grass biomass is a favorable feature [1,6,11]. The plant can naturally get rid of a significant amount of water thanks to drying tissues, draining water, and transferring nutrients to the underground parts. Dry biomass does not require significant expenses for drying, which reduces the costs of its production [10,48]. Humidity of giant miscanthus biomass, collected in early spring, below 25%, allows it to be compacted or stored without additional drying. Due to the low humidity, the calorific value of the biomass in the working condition was relatively high (16.26 MJ/kg), and in the dry condition it was 18.06 MJ/kg. These values are lower compared to wood biomass, and comparable with other perennial species, such as Virginia mallow or Jerusalem artichoke [8,10,52,59].

The results of our own research confirmed the risk of contamination of heating devices during biomass combustion. The giant miscanthus ash melting points were comparable with other types of biomass [51,52,60] and lower than that of hard coal. Although the ash content in the biomass was low (2.76% DM), its composition may cause deposition of pollutants, slagging and sintering in boilers, which limits heat exchange and reduces the efficiency of power equipment. This is confirmed by the results of calculations of the pollution risk indicators for the flat boilers [5,52,61]. However, ashes from miscanthus combustion can be used as biochar to improve soil properties [62].

The yield of biogas from miscanthus silage was a half lower than that obtained from the most commonly used substrate used in agricultural biogas plants—maize silage. As can be seen from various sources [63,64], the methane yield of maize ranges from 105 to 125 m^3/Mg FM, depending on the variety, harvest phase, silage quality, etc. [65–67]. An argument favoring miscanthus compared to maize is its durability: as a perennial culture, it does not require annual plantings, and after reaching the third year of vegetation, it does not require care. Literature data on miscanthus fertilization indicate that it can be cultivated with a limited supply of mineral fertilizers [24,68,69].

5. Conclusions

The giant miscanthus biomass, which is created as an added value in protecting soils against erosion, can be used for energy purposes in thermochemical and biochemical conversion processes. The specificity of the anti-erosion belt prompted the use of high plant density (16 seedlings/m^2), which contributed to the self-regulation of the number of shoots already in the third year of vegetation.

Due to the natural ability of grasses to dry out and lose moisture, a typical miscanthus harvest time in Poland is the end of winter and the beginning of spring. The evaluation of the energy parameters of the *Miscanthus giganteus* biomass confirmed the validity of such a procedure, as the plants were characterized by low humidity, maintaining a high calorific value of 18.06 MJ/Mg DM. Like other types of biomass, miscanthus tends to pollute heating devices, which was confirmed by calculating most pollution risk indicators.

An alternative way to convert the energy contained in miscanthus biomass is anaerobic digestion. It requires harvesting during the vegetation period when the plants have not reached total yield, negatively affecting biomass yield. Although the miscanthus chaff had cured correctly, it obtained a much lower biogas yield per mass unit. Comparing the energy yield obtained in thermochemical and biochemical processes speaks in favor of combustion.

In this experiment, miscanthus biomass was sourced from a belt whose primary function was to prevent erosion. Therefore, it should be considered whether the harvest of miscanthus in the vegetative phase intended for biogas production will not limit its anti-erosion function. It requires research to assess the effects of summer harvesting on plant development, durability, yield, and soil protective effect.

Author Contributions: Conceptualization, A.K.-J. and J.D.; methodology, A.K.-J., A.M. and D.J.; validation, A.K.-J., P.P. and J.D.; formal analysis, A.K.-J. and P.P.; investigation, D.J. and J.D.; data curation, A.K.-J., P.P. and D.J.; writing—original draft preparation, A.K.-J., A.M., P.P., D.J. and J.D.; writing—review and editing, J.D.; visualization, A.K.-J. and P.P.; supervision, J.D.; project administration, A.K.-J.; funding acquisition, A.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Borkowska, H.; Molas, R. Yield comparison of four lignocellulosic perennial energy crop species. *Biomass Bioenergy* **2013**, *51*, 145–153. [CrossRef]
2. Anderson, E.; Arundale, R.; Maughan, M.; Oladelnde, A.; Wycislo, A.; Volgt, T. Growth and agronomy of *Miscanthus* × *giganteus* for biomass production. *Biofuels* **2011**, *2*, 71–87. [CrossRef]
3. Fowdar, H.; Payne, E.; Schang, C.; Zhang, K.; Deletic, A.; McCarthy, D. How well do stormwater green infrastructure respond to changing climatic conditions? *J. Hydrol.* **2021**, *603*, 126887. [CrossRef]
4. Zhang, Y.; Zahid, I.; Danial, A.; Minaret, J.; Cao, Y.; Dutta, A. Hydrothermal carbonization of miscanthus: Processing, properties, and synergistic Co-combustion with lignite. *Energy* **2021**, *225*, 120200. [CrossRef]
5. Kowalczyk-Juśko, A. The influence of the ash from the biomass on the power boiler pollution. *J. Ecol. Eng.* **2017**, *18*, 200–204. [CrossRef]
6. Yu, L.; Ding, G.; Huai, Z.; Zhao, H. Natural variation of biomass yield and nutrient dynamics in *Miscanthus*. *Field Crops Res.* **2013**, *151*, 1–8. [CrossRef]
7. Witzel, C.P.; Finger, R. Economic evaluation of *Miscanthus* production—A review. *Renew. Sustain. Energy Rev.* **2016**, *53*, 681–696. [CrossRef]
8. El Bassam, N. *Energy Plant Species*; Routledge: London, UK, 1998. [CrossRef]
9. Jones, M.B.; Walsh, M. *Miscanthus for Energy and Fiber*; Routledge: London, UK, 2001. [CrossRef]
10. Lewandowski, I.; Clifton-Brown, J.; Scurlock, J.M.O.; Huisman, W. Miscanthus: European experience with a novel energy crop. *Biomass Bioenergy* **2000**, *19*, 209–227. [CrossRef]
11. Kludze, H.; Deen, B.; Dutta, A. Impact of agronomic treatments on fuel characteristics of herbaceous biomass for combustion. *Fuel Process. Technol.* **2013**, *109*, 96–102. [CrossRef]
12. Bridgwater, A.V.; Peacocke, G.V.C. Fast pyrolysis processes for biomass. *Renew. Sustain. Energy Rev.* **2000**, *4*, 1–73. [CrossRef]
13. Bok, J.P.; Choi, H.S.; Choi, J.W.; Choi, Y.S. Fast pyrolysis of *Miscanthus sinensis* in fluidized bed reactors: Characteristics of product yields and biocrude oil quality. *Energy* **2013**, *60*, 44–52. [CrossRef]

14. Kim, J.-Y.; Oh, S.; Hwang, H.; Moon, Y.-H.; Choi, J.W. Assessment of miscanthus biomass (*Miscanthus sacchariflorus*) for conversion and utilization of bio-oil by fluidized bed type fast pyrolysis. *Energy* **2014**, *76*, 284–291. [CrossRef]
15. Sørensen, A.; Teller, P.J.; Hilstrøm, T.; Ahring, B.K. Hydrolysis of *Miscanthus* for bioethanol production using dilute acid presoaking combined with wet explosion pre-treatment and enzymatic treatment. *Biores. Technol.* **2008**, *99*, 6602–6607. [CrossRef] [PubMed]
16. Whittaker, C.; Hunt, J.; Misselbrook, T.; Shield, I. How well does *Miscanthus* ensile for use in an anaerobic digestion plant? *Biomass Bioenergy* **2016**, *88*, 24–34. [CrossRef]
17. Zhou, X.; Li, Q.; Zhang, Y.; Gu, Y. Effect of hydrothermal pretreatment on *Miscanthus* anaerobic digestion. *Bioresour. Technol.* **2017**, *224*, 721–726. [CrossRef] [PubMed]
18. Kowalczyk-Juśko, A. Chemical composition and energetic characteristic of *Miscanthus sacchariflorus* biomass as used for generation of energy. *Przem. Chem.* **2016**, *95*, 2326–2329. [CrossRef]
19. Cerazy-Waliszewska, J.; Jeżowski, S.; Łysakowski, P.; Waliszewska, B.; Zborowska, M.; Sobańska, K.; Ślusarkiewicz-Jarzina, A.; Białas, W.; Pniewski, T. Potential of bioethanol production from biomass of various Miscanthus genotypes cultivated in three-year plantations in west-central Poland. *Ind. Crops Prod.* **2019**, *141*, 111790. [CrossRef]
20. Le Ngoc Huyen, T.; Queneudec T'Kint, M.; Remond, C.; Chabbert, B.; Dheilly, R.M. Saccharification of *Miscanthus* × *giganteus*, incorporation of lignocellulosic by-product in cementitious matrix. *Comptes Rendus. Biol.* **2011**, *334*, 837.e1–837.e11. [CrossRef]
21. Klimiuk, E.; Pokój, T.; Budzyński, W.; Dubis, B. Theoretical and observed biogas production from plant biomass of different fibre contents. *Bioresour. Technol.* **2010**, *101*, 9527–9535. [CrossRef]
22. Kowalczyk-Juśko, A.; Pochwatka, P.; Zaborowicz, M.; Czekała, W.; Mazurkiewicz, J.; Mazur, A.; Janczak, D.; Marczuk, A. Energy value estimation of silages for substrate in biogas plants using an artificial neural network. *Energy* **2020**, *202*, 117729. [CrossRef]
23. Winkler, B.; Mangold, A.; von Cossel, M.; Clifton-Brown, J.; Pogrzeba, M.; Lewandowski, I.; Iqbal, Y.; Kiesel, A. Implementing miscanthus into farming systems: A review of agronomic practices, capital and labour demand. *Renew. Sustain. Energy Rev.* **2020**, *132*, 110053. [CrossRef]
24. Stolarski, M.J.; Krzyżaniak, M.; Warmiński, K.; Tworkowski, J.; Szczukowski, S. Perennial herbaceous crops as a feedstock for energy and industrial purposes: Organic and mineral fertilizers versus biomass yield and efficient nitrogen utilization. *Ind. Crops Prod.* **2017**, *107*, 244–259. [CrossRef]
25. Barbagallo, S.; Barbera, A.C.; Cirelli, G.L.; Milani, M.; Toscano, A. Reuse of constructed wetland effluents for irrigation of energy crops. *Water Sci. Technol.* **2014**, *70*, 1465–1472. [CrossRef] [PubMed]
26. Gizińska-Górna, M.; Czekała, W.; Jóźwiakowski, K.; Lewicki, A.; Dach, J.; Marzec, M.; Pytka, A.; Janczak, D.; Kowalczyk-Juśko, A.; Listosz, A. The possibility of using plants from hybrid constructed wetland wastewater treatment plants for energy purposes. *Ecol. Eng.* **2016**, *95*, 534–541. [CrossRef]
27. Gizińska-Górna, M.; Janczak, D.; Kowalczyk-Juśko, A.; Jóźwiakowski, K.; Lewicki, A.; Marzec, M.; Pytka, A.; Czekała, W.; Listosz, A. The parameters of energy biomass plants from hybrid constructed wetland wastewater treatment plants. In Proceedings of the 3rd International Conference on Energy and Environment, Porto, Portugal, 29–30 June 2017; School of Economics and Management of the University of Porto: Porto, Portugal, 2017; pp. 97–102, ISBN 9789729539695.
28. Marzec, M.; Gizińska-Górna, M.; Jóźwiakowski, K.; Pytka-Woszczyło, A.; Kowalczyk-Juśko, A.; Gajewska, M. The efficiency and reliability of pollutant removal in a hybrid constructed wetland with giant miscanthus and Jerusalem artichoke in Poland. *Ecol. Eng.* **2019**, *127*, 23–35. [CrossRef]
29. Toscano, A.; Marzo, A.; Milani, M.; Cirelli, G.L.; Barbagallo, S. Comparison of removal efficiencies in Mediterranean pilot constructed wetlands vegetated with different plant species. *Ecol. Eng.* **2015**, *75*, 155–160. [CrossRef]
30. Praveen, A.; Pandey, V.C. *Miscanthus*–A perennial energy grass in phytoremediation. *Phytoremed. Potential Perenn. Grasses* **2020**, 79–95. [CrossRef]
31. Bilandžija, N.; Zgorelec, Ž.; Pezo, L.; Grubor, M.; Gudelj Velaga, A.; Kričká, T. Solid biofuels properties of *Miscanthus* × *giganteus* cultivated on contaminated soil after phytoremediation process. *J. Energy Inst.* **2022**, *101*, 131–139. [CrossRef]
32. Pivato, A.; Garbo, F.; Moretto, M.; Lavagnolo, M.C. Energy crops on landfills: Functional, environmental, and costs analysis of different landfill configurations. *Environ. Sci. Pollut. Res.* **2018**, *25*, 35936–35948. [CrossRef]
33. Ntimugura, F.; Vinai, R.; Harper, A.B.; Walker, P. Environmental performance of miscanthus-lime lightweight concrete using life cycle assessment: Application in external wall assemblies. *Sustain. Mater. Technol.* **2021**, *28*, e00253. [CrossRef]
34. Park, H.J.; Oh, S.W.; Wen, M.Y. Manufacture and properties of *Miscanthus*–wood particle composite boards. *J. Wood Sci.* **2012**, *58*, 459–464. [CrossRef]
35. Wolfzorn, J.; Harding, D.; Davis, A.; Santiago, M.; Porr, C. Miscanthus and hemp as alternative bedding material for horses. *J. Equine Vet. Sci.* **2019**, *76*, 97–98. [CrossRef]
36. Donadelli, R.; Aldrich, G. Miscanthus Grass as a Nutritional Fiber Source for Monogastric Animals. In *Grasses and Grassland—New Perspectives*; Iqbal, M.A., Ed.; IntechOpen: London, UK, 2021. [CrossRef]
37. Gioacchini, P.; Cattaneo, F.; Barbanti, L.; Montecchio, D.; Ciavatta, C.; Marzadori, C. Carbon sequestration and distribution in soil aggregate fractions under *Miscanthus* and giant reed in the Mediterranean area. *Soil Tillage Res.* **2016**, *163*, 235–242. [CrossRef]
38. Rolbiecki, S.; Biniak-Pieróg, M.; Żyromski, A.; Kasperska-Wołowicz, W.; Jagosz, B.; Stachowski, P.; Liberacki, D.; Kanecka-Geszke, E.; Sadan, H.A.; Rolbiecki, R.; et al. Effect of Forecast Climate Changes on Water Needs of Giant Miscanthus Cultivated in the Kuyavia Region in Poland. *Energies* **2021**, *14*, 6628. [CrossRef]

39. Sarkar, A.; Asaeda, T.; Wang, Q.; Rashid, M.H. Arbuscular mycorrhizal influences on growth, nutrient uptake, and use efficiency of Miscanthus sacchariflorus growing on nutrient-deficient river bank soil. *Flora-Morphol. Distrib. Funct. Ecol. Plants* **2015**, *212*, 46–54. [CrossRef]
40. Bellamy, P.E.; Croxtona, P.J.; Hearda, M.S.; Hinsleya, S.A.; Hulmesa, L.; Hulmesa, S.; Nuttalla, P.; Pywella, R.F.; Rotherya, P. The impact of growing miscanthus for biomass on farmland bird populations. *Biomass Bioenergy* **2009**, *33*, 191–199. [CrossRef]
41. Mazur, A.; Kowalczyk-Juśko, A. The assessment of the usefulness of *Miscanthus* × *giganteus* to water and soil protection against erosive degradation. *Resources* **2021**, *10*, 66. [CrossRef]
42. Young, F.J.; Hammer, R.D. Soil-landform relationship on a loess-mantled landscape in Missouri. *Soil Sci. Soc. Am. J.* **2000**, *61*, 1443–1454. [CrossRef]
43. Mazur, A. Quantity and quality of surface and subsurface runoff from an eroded loess slope used for agricultural purposes. *Water* **2018**, *10*, 1132. [CrossRef]
44. Hladký, J.; Novotná, J.; Elbl, J.; Kynický, J.; Juřička, D.; Novotná, J.; Brtnický, M. Impacts of water erosion on soil physical properties. *Acta Univ. Agric. Silvic. Mendel. Brun.* **2016**, *64*, 1523–1527. [CrossRef]
45. Duan, X.; Xie, Y.; Ou, T.; Lu, H. Effects of soil erosion on long-term soil productivity in the black soil region of northeastern China. *Catena* **2011**, *87*, 268–275. [CrossRef]
46. Arriaga, F.J.; Lowery, B. Corn production on an eroded soil: Effects of total rainfall and soil water storage. *Soil Tillage Res.* **2003**, *71*, 87–93. [CrossRef]
47. Asiedu, J.K. Assessing the threat of erosion to nature-based interventions for stormwater management and flood control in the Greater Accra Metropolitan Area, Ghana. *J. Ecol. Eng.* **2018**, *19*, 1–13. [CrossRef]
48. Kotecki, A. Growing giant miscant. In *Energy and Non-Energy Possibilities of Using Straw*; University of Life Sciences in Wrocław: Wrocław, Poland, 2010. Available online: https://www.dbc.wroc.pl/Content/18846/download/ (accessed on 21 April 2022). (In Polish)
49. CoalTech. *Consultancy in Coal Utilisation Technology. Slagging and Fouling Indices*; CoalTech: Johannesburg, South Africa, 2007. Available online: http://www.coaltech.com.au/LinkedDocuments/Slagging%20&%20Fouling.pdf (accessed on 21 April 2022).
50. Ściążko, M.; Zuwała, J.; Pronobis, M. *Co-Combustion of Biomass and Alternative Fuels in the Energy Sector*; Institute for Chemical Processing of Coal, Silesian University of Technology: Zabrze, Poland, 2007. Available online: http://www.ichpw.pl/wspolspalanie-biomasy-i-paliw-alternatywnych-w-energetyce/ (accessed on 21 April 2022). (In Polish)
51. Vassilev, S.V.; Baxter, D.; Vassileva, C.G. An overview of the behaviour of biomass during combustion: Part II. Ash fusion and ash formation mechanisms of biomass types. *Fuel* **2014**, *117*, 152–183. [CrossRef]
52. Viana, H.; Vega-Nieva, D.J.; Ortiz Torres, L.; Lousada, J.; Aranha, J. Fuel characterization and biomass combustion properties of selected native woody shrub species from central Portugal and NW Spain. *Fuel* **2012**, *102*, 737–745. [CrossRef]
53. Olave, R.J.; Forbes, E.G.A.; Munoz, F.; Laidlaw, A.S.; Easson, D.L.; Watson, S. Performance of *Miscanthus* × *giganteus* (Greef et Deu.) established with plastic mulch and grown from a range of rhizomes sizes and densities in a cool temperate climate. *Field Crop. Res.* **2017**, *210*, 81–90. [CrossRef]
54. Humentyk, M.; Kwak, V.; Zamoyski, O.; Radejko, B. Biomass productivity of miscanthus depending on the quality of planting material and growing conditions in the western forest-steppe region of Ukraine. *Motrol. Comm. Mot. Energ. Agric.* **2013**, *15*, 84–89.
55. Kobayashi, K.; Yokoi, Y. Shoot density of *Miscanthus sinensis* populations in different habitats and their maintenance mechanisms in relation to shoot growth. *J. Plant Res.* **2017**, *130*, 143–156. [CrossRef]
56. Malinská, H.A.; Vaněk, M.; Nebeská, D.; Šubrt, D.; Brestič, M.; Trögl, J. Plant priming changes physiological properties and lignin content in *Miscanthus* × *giganteus*. *Ind. Crops Prod.* **2021**, *174*, 114185. [CrossRef]
57. Iqbal, Y.; Gauder, M.; Claupein, W.; Graeff-Hönninger, S.; Lewandowski, I. Yield and quality development comparison between miscanthus and switchgrass over a period of 10 years. *Energy* **2015**, *89*, 268–276. [CrossRef]
58. Szulczewski, W.; Żyromski, A.; Jakubowski, W.; Biniak-Pieróg, M. A new method for the estimation of biomass yield of giant miscanthus (*Miscanthus giganteus*) in the course of vegetation. *Renew. Sustain. Energy Rev.* **2018**, *82*, 1787–1795. [CrossRef]
59. Daraban Oros, A.E.; Jurcoane, Ș.; Voicea, I. Miscanthus giganteus—An overview about sustainable energy resource for household and small farms heating systems. *Rom. Biotechnol. Lett.* **2015**, *20*, 10369–10380. Available online: https://www.rombio.eu/rbl3vol20/1.pdf (accessed on 21 April 2022).
60. Bryers, R.W. Fireside slagging, fouling, and high-temperature corrosion of heat-transfer surface due to impurities in steam-raising fuels. *Prog. Energy Combust. Sci.* **1996**, *22*, 29–120. [CrossRef]
61. Rizvi, T.; Xing, P.; Pourkashanian, M.; Darvell, L.I.; Jones, J.M.; Nimmo, W. Prediction of biomass ash fusion behaviour by the use of detailed characterisation methods coupled with thermodynamic analysis. *Fuel* **2015**, *141*, 275–284. [CrossRef]
62. Pidlisnyuk, V.; Newton, R.A.; Mamirova, A. Miscanthus biochar value chain—A review. *J. Environ. Manag.* **2021**, *290*, 112611. [CrossRef] [PubMed]
63. Mazurkiewicz, J.; Marczuk, A.; Pochwatka, P.; Kujawa, S. Maize straw as a valuable energetic material for biogas plant feeding. *Materials* **2019**, *12*, 3848. [CrossRef] [PubMed]
64. Pochwatka, P.; Kowalczyk-Juśko, A.; Mazur, A.; Janczak, D.; Pulka, J.; Dach, J.; Mazurkiewicz, J. Energetic and economic aspects of biogas plants feed with agriculture biomass. In Proceedings of the 2020 4th International Conference on Green Energy and Applications, ICGEA 2020, Singapore, 7–9 March 2020; Institute of Electrical and Electronics Engineers Inc.: Piscataway, NJ, USA, 2020; pp. 130–133.

65. Mayer, F.; Gerin, P.A.; Noo, A.; Foucart, G.; Flammang, J.; Lemaigre, S.; Sinnaeve, G.; Dardenne, P.; Delfosse, P. Assessment of factors influencing the biomethane yield of maize silages. *Bioresour. Technol.* **2014**, *153*, 260–268. [CrossRef]
66. Benito Martin, P.C.; Schlienz, M.; Greger, M. Production of bio-hydrogen and methane during semi-continuous digestion of maize silage in a two-stage system. *Int. J. Hydrogen Energy* **2017**, *42*, 5768–5779. [CrossRef]
67. Steinbrenner, J.; Nägele, H.J.; Buschmann, A.; Hülsemann, B.; Oechsner, H. Testing different ensiling parameters to increase butyric acid concentration for maize silage, followed by silage separation and methane yield potential of separated solids residues. *Bioresour. Technol. Rep.* **2019**, *7*, 100193. [CrossRef]
68. Monti, A.; Zegada-Lizarazu, W.; Zanetti, F.; Casler, M. Nitrogen fertilization management of switchgrass, miscanthus and giant reed: A review. *Adv. Agron.* **2019**, *153*, 87–119. [CrossRef]
69. Dubis, B.; Jankowski, K.J.; Załuski, D.; Sokólski, M. The effect of sewage sludge fertilization on the biomass yield of giant miscanthus and the energy balance of the production process. *Energy* **2020**, *206*, 118189. [CrossRef]