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Use of pellets from agricultural biogas plants in fertilisation of oxytrees in Podlasie, Poland

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Abstract: Agricultural biogas plants are not only a place for processing waste resulting from animal husbandry, but also for generating electricity and heat as well as organic fertiliser. In a four-year experiment, pellets were used as organic fertiliser in the establishment of an experiment with fast-growing oxytrees. The study aimed to investigate the growth and stem thickness increment, overwintering in the first and subsequent years of cultivation under the conditions of north-eastern Poland.

The dried digestate and the pellets made from it were characterised by a high content of macroelements (N – 1,95%, P_2O_5 – 1,1%, K_2O – 1,3%). The applied pellet from an agricultural biogas plant under oxytree seedlings due to its slow decomposition had a good effect on the growth of oxytrees in the second and third years. The average growth of oxytrees in the second year was 209.7 cm, and in the third year, 246.8 cm. The growth of oxytrees fertilised with pellets made from the digestate of an agricultural biogas plant was 13% higher than that of trees growing on the control strip.

Keywords: biomass, fertilisation, oxytree (*Paulownia Clon in Vitro 112*), pellet

INTRODUCTION

Oxytree (*Paulownia Clon in Vitro 112*) was bred by Castilla-La-Mancha University at the turn of the 20th and 21st centuries. The new hybrid was obtained from two species of the Paulownia family of clones (*Paulownia elongata* and *Paulownia fortunei*). The hybrid was named oxytree. The first experiments and production plantations were established in Poland in 2016.

According to the register of agricultural biogas producers of the Energy Regulatory Office, as of 21 July 2020, nine agricultural biogas plants are operating in Podlasie. The first biogas plant in Podlasie was established in 2014 in Ryboły, Zabłudów municipality and the last one in Krasowo-Częstki, Nowe Piekuty municipality [KOWR 2021]. The annual capacity of biogas installations in the nine facilities located in Podlasie is 35 278 613.8 $m^3 \cdot y^{-1}$, with a total electrical capacity of 7.674 MWe [Gramwzielone 2015].

One of the main problems for any biogas plant is the raw digestate, which contains more than 95% water [Łagocka *et al.* 2016]. Untreated digestate is abundant in nutrients essential for plants [Mata-Alvarez *et al.* 2014]. According to Białowiec *et al.* [2015] and Kowalczyk-Juśko and Szymańska [2015], the use of digestate from an agricultural biogas plant reduces the use of mineral fertilisers and improves soil properties.

The use of digestate from an agricultural biogas plant has a positive impact not only on the soil but also on the development of cultivated plants. The digestate mixed with the soil enriches it with macro- and micronutrients, which the cultivated plants then use as well as cause the development of microorganisms in the soil [Aburaker *et al.* 2013; Bauza-Kaszewska *et al.* 2017; Lošák *et al.* 2016; Sapp *et al.* 2015].

In 2015, after the start-up of the biogas plant in Wojny Wawrzyńce, the main problem was to manage the excess heat generated by burning methane in the cogeneration set. Dryers were started up, where cereal grains, mainly maize, were dried. Despite the drying of cereals, there was still excess heat. In 2016, the drying of the digestate and pellet production as an organic fertiliser was started, the chemical composition of which, according to research report No. 16N9/2 of IUNG-PIB Puławy, is presented in Table 1.

Table 1. Chemical composition of pellets produced from the digestate of the agricultural biogas plant in Wojny Wawrzyńce

Macronutrient content	Content (% w/w)
Nitrogen total	1.95
Phosphorus (P_2O_5)	1.1
Potassium (K_2O)	1.3

Source: own elaboration based on report District Chemical-Agricultural Station in Warsaw.

Based on a report made by the District Chemical and Agricultural Station in Warsaw dated 04.01.2016 [OSChR 2016], the liquid phase of the digest from the agricultural biogas plant Wojny Wawrzyńce was characterised (in % of dry matter – by a high content of nitrogen) – 1.57; phosphorus – 0.43; potassium – 1.0; magnesium – 0.30 and calcium – 2.23.

The main aim of this study was to present the growth of oxytrees in the first four years of cultivation when fertilised with pellets made from the digestate of the Wojny Wawrzyńce agricultural biogas plant. The pellets, produced from one-year-old shoots of oxytrees obtained as a result of cultivation treatments after the first year, were also investigated from an energetic point of view.

MATERIAL AND METHODS

The analyses are based on the results of an experiment conducted in 2016–2019, established on an experimental field belonging to the Agribusiness University of Łomża (53°10' N, 22°05' E). The results presented here concern a single-factor experiment, established on an area of 400 m^2, conducted for four consecutive years.

The experiment was established on lessive soil developed from boulder sands classified as good rye complex, IVa classification, with very acid reaction (pH = 4.02). The soil was characterised by a high content of phosphorus, an average content of potassium and low content of magnesium. The organic matter content was 1.51 g·kg^{-1} (Tab. 2).

Soil preparation for the oxytree seedlings consisted of digging holes 80–100 cm deep. Three rows were marked out on the plots, and in each of the six rows, oxytree seedlings were planted. In two rows, the oxytree planting holes were treated with pellets from the Wojny Wawrzyńce biogas plant at a rate of 1 kg per plant mixed with topsoil. The third row was left for control trials without treating the holes with pellets from the digestate.

Seedlings were brought and transferred to the experiment location from Oxytree Solutions in Wrocław on 18 May 2016. On the following day, they were planted at a spacing of 6 m × 4 m and watered with 3 dm^3 of water as recommended by the seedling manufacturer. During the second half of July in the first year of the experiment, manure was applied around the trees at 30 grams per tree and mixed with topsoil.

Table 2. Capacities in assimilable nutrients, organic matter and soil pH

Component		Measurement unit	Value
Nitrogen total		g·kg^{-1}	1.06
Organic carbon			1.51
Assimilable form	P	Mg·kg^{-1}	17.7
	K		8.50
	Mg		1.60
pH in KCl		–	4.02

Source: own study.

In each growing year, maintenance treatments were carried out according to the recommendations of the seedling producer. The soil surface around the trees within a 40 cm radius was shaken and kept in black fallow, and the area between the trees was mowed. In the second decade of May 2017, one-year-old stems were cut at a height of 4–6 cm from the soil surface. This treatment is recommended by the seedling producer and is intended to stimulate the development of a taproot system, which facilitates overwintering. In May 2017, of the regrown lateral shoots of the trunk, only one of the most developed shoots was left, whilst the others were removed.

In each of the following years of the experiment, when the first symptoms of oxytree growth were visible (1st–2nd weeks of May) after the disappearance of spring frosts occurring in the Podlaskie voivodeship, mineral fertilisation was applied. Around the trees, within a radius of 40 cm, 30 grams of Polifoska NPK 8–24–24 was applied as a spring dose before the start of vegetation. Additionally, in the second half of July, 20 grams of manure as a slow-release nitrogen fertiliser.

A tape measure and a 5 m measuring stick were used to measure the height of the trees. The trunk thickness was measured at a height of approximately 20 cm above the ground. In the first two years, their diameter was measured with callipers. In the third and fourth years, the stem girth and diameter were calculated.

Cut and dried for about 90 days in the open air, the trunks of one-year-old trees were chipped and sent to the Certified Chemical Research Laboratory of the Research and Fuels Laboratory of Energa Elektrownie Ostrołęka S.A. to be tested for moisture content, total sulphur, ash, hydrogen and calorific value.

Meteorological data on air temperature and precipitation were obtained from the Experimental Department of Variety Evaluation in Marianów.

Climatic conditions in individual years of the study varied (Tab. 3). In the first year of the study, they were very close to the multi-year values. The mild, long spring in 2017 (after cutting) may have had a good effect on the plants, and the abundant rainfall in summer and autumn favoured biomass formation.

The year 2018 presented an anomaly with higher air temperatures, 2°C above the multi-year average and the lowest rainfall. The very high rainfall in July significantly mitigated the

Table 3. Monthly average air temperatures and monthly precipitation totals during the research period in 2016–2019

Month	The average temperature (°C) of the month in				Average temperature 2016–2019 (°C)	Sum of precipitation (mm) in a month in				Average precipitation 2016–2019 (mm)
	2016	2017	2018	2019		2016	2017	2018	2019	
April	8.6	6.3	11.9	8.6	8.0	38.4	48.7	15.0	3.7	33.8
May	14.5	12.7	16.5	12.5	13.6	38.3	51.3	34.4	116.0	50.8
June	17.6	16.5	18.0	20.4	16.4	43.9	83.6	38.6	35.1	65.8
July	18.8	17.0	19.9	17.5	18.5	112.2	103.9	151.8	106.7	79.3
August	17.6	18.2	19.4	18.5	17.8	68.8	53.8	53.6	79.9	65.1
September	14.0	13.5	15.0	13.3	12.5	11.1	104.1	29.5	41.2	55.6
October	5.9	8.5	9.3	10.1	8.08	114.2	108.2	49.5	36.0	38.2
Average temperature of 7 months	13.8	13.2	15.7	14.4	13.60					
Sum of atmospheric precipitation of 7 months						426.9	553.6	372.4	418.6	388.6

Source: own elaboration based on data of Experimental Department of Variety Evaluation in Marianów.

effects of the spring drought and made up for deficiencies during the period of intensive plant growth. The average temperature for the seven months of 2019 was 1.2°C above the multi-year average. Precipitation from the seven months of the growing season was higher than the multi-year average. However, when the rainfall was averaged across the seven months, an increase in drought could be seen. The highest amount of precipitation was recorded in July each year and compared to the multi-year data during the study period. It rose from 31% in 2017 to 92% in 2018. Each year, the heavy rainfall in July resulted in water running off the soil rather than infiltrating deep into the soil profile.

RESULTS

Measurements were taken on average every 30 days from mid-June each year. In the first year, the average height of trees using pellets was 106.2 cm with a stem diameter of 28.0 mm (Tab. 4). In contrast, with the control trial, the height of one-year-old trees averaged 94.5 cm with an average stem diameter of 24.3 mm. The growth of the trees in the first year is not significant, as according to the recommendations of the seedling producer, after the first year the trees were pruned at a height of 5–6 cm from the ground surface. The pruning resulted in favourable development of the root system, which determines good and rapid growth in the following growing seasons.

In the second year of vegetation, the trees grew very fast, but this was due to an already well-developed root system. The average height of oxytrees in the experimental plots at the Agribusiness High School in Łomża was 209.7 cm, with an average stem diameter of 59 mm measured at 20 cm above ground level. The mean height of oxytrees in the control plot was 190.2 cm with a trunk diameter of 47.0 mm. The highest tree on 20.10.2017 was 268 cm high with a trunk diameter of 71 mm.

The third year of the experiment was characterised by a very long vegetation period, which amounted to 176 days under the climatic conditions of Łomża. The average height of trees, where fertilisation with pellets from the agricultural biogas plant digestate was applied, was 456.5 cm, with a trunk diameter of 107.0 mm and daily growth of 14.0 mm. In the control trial, the average height of oxytrees was 403.2 cm with an average stem diameter of 72.0 mm. and daily growth of 12.0 mm.

The fourth year of oxytree growth as a result of canopy expansion was quite good, despite the occurrence of drought. The average height of the trees was 557.0 cm, with an average trunk diameter of 140 mm. The daily height increment was 7.0 mm. In

Table 4. Biometric measurements of oxytrees on the experience of the Higher School of Agribusiness in Łomża

Year of experiment duration	The average height of the tree from the experiment in a given year	Average tree height from control	Largest daily increase in a given study year	Daily increment from control	The average diameter of the trunk from the experiment in a given year	Average stem diameter from the control	Length of the growing season (day)
	cm		mm				
2016 – first year	106.2	94.5	7.5	6.7	28	24.3	140
2017 – second year	209.7	190.2	14.0	13.0	59	47.0	146
2018 – third year	456.5	403.2	14.0	12.0	107	72.0	176
2019 – fourth year	557.0	486.2	7.0	5.0	140	105.3	148

Source: own study.

the control trial, the average height of the oxytree was 486.2 cm, with an average stem diameter of 105.3 mm and a daily height gain of 5.0 mm (Photo 1).

Photo 1. Experiment with oxytrees on the Agribusiness High School in Łomża experimental plots (phot. J. Lisowski)

In May 2017, one-year-old oxytree stems were felled at a height of 5–6 cm as recommended by the seedling producer. The results for the samples submitted for testing are presented in Table 5. The heat of combustion of oxytree at constant volume is 17,744 kJ·kg^{-1} at a total moisture content of 11.3%. The combustion of oxytree biomass resulted in very low ash and sulphur contents of 0.6 and 0.01%, respectively.

Table 5. Energy results for oxytree biomass

Tested characteristic	Test method	Unit of measurement	Content in delivered biomass
Total moisture content	PN-NE ISO 18 134-2:2015-11	%	11.3
Ash content	PN-NE ISO 18 122:2016-01	%	0.6
Total sulphur content	PN-NE ISO 16994:2015-06	%	0.01
Total carbon content	PN-NE ISO 16948:2015-07	%	43.5
Hydrogen content	PN-NE ISO 16948:2015-07	%	5.34
The heat of com-bustion at constant volume	EN 14918:2010	kJ·kg^{-1}	17 744
Calorific value at constant volume	EN 14918:2010	kJ·kg^{-1}	16 384
Calorific value at constant pressure	EN 14918:2010	kJ·kg^{-1}	16 303

Source: own study.

DISCUSSION

The use of the digestate from agricultural biogas plants is increasingly applicable. According to Białowiec *et al.* [2015], agricultural biogas plants allow not only the processing of waste arising from agricultural production and the agri-food industry to produce biogas and use it for energy production but also the use of the processed waste as organic fertiliser in wider agriculture. The main problem of large biogas plants is the supply of the raw material needed for biogas production, and further to this, there is the problem of the storage of digestate. Another problem is the management of waste heat from the combustion of the resulting biogas for electricity production using combined heat and power (CHP) technology. A large amount of unused waste heat is released into the atmosphere. The possibility of utilising waste heat in the production of pellets for fertiliser will improve the financial viability of any agricultural biogas plant.

In one year, a 1 MW biogas plant produces about 20,000 m^3 of digestate [Jadczyszyn, Winiarski 2017]. The new nitrate programme is in force from 15 February 2020 [MRiRW 2020; Rozporządzenie 2020] and does not allow the use of the digestate from an agricultural biogas plant as organic fertiliser from 16 October to the end of February. Therefore, agricultural biogas plants are increasingly performing liquid digest separation.

The development of agricultural biogas plants in Podlasie will enable the development of non-agricultural activities in rural areas and will also start to increase the production of dispersed energy.

Biomass from annual shoots of oxytrees has suitable energy parameters, containing only 0.6% ash with a calorific value of 16.384 kJ·kg^{-1} [Lisowski, Porwisiak 2018]. The energy performance of oxytree biomass has similar parameters when burning Pennsylvanian giant hogweed (*H*eracleum mantegazzianum) [Lisowski, Borusiewicz 2019].

The fertilising value of pellets was visible in the second and third years of the growth of the oxytrees. In the second year, the trees obtained an average growth of 209.7 cm and in the third year, as much as 246.8 cm. Compared to the oxytrees growing on the control strip, the growth of the trees with the application of the pellet produced from the biogas plant digest was higher in the second year of vegetation by 10% and in the third year by 12%.

The calorific value of oxytree by combustion was 16,384 kJ·kg^{-1} and is very close to the values obtained in the laboratory of the Renewable Energy Research Institute of the Science and Technology Park of Albacete [López Serrano 2015].

In their publication, Knauf and Frühwald [2015] show that there will be limited availability of high-quality wood in the near future. At this current time, there are no Polish studies of oxytree wood grown in Poland. In the year after felling the oxytree, the wood will be sent to the Institute of Wood Technology in Poznan to study the basic characteristics of the wood.

CONCLUSIONS

1. Oxytrees planted in 2016 in an experiment at the School of Agribusiness in Lomza achieved high growth. With the application of pellets from agricultural biogas plant digestate before planting, the average height of the trees after the fourth year of vegetation was 557 cm, with a trunk circumference of 20 cm from the ground surface of 140 mm.
2. The height of oxytrees growing on the control site was lower by 70.8 cm or 13%, while stem thickness at 20 cm from the ground surface was 25% lower.

3. A very high growth rate of oxytrees growing in the strips where fertilisation with pellets made from biogas plant digestate was applied occurred in the second and third years of vegetation. The average daily increment of these trees was 14 mm, while in the control strips, the daily increment of oxytrees was lower by 1–2 mm.
4. The energy value of oxytree wood after the first year of vegetation to the average value of hard coal burnt in the power plant in Ostrołęka is lower by about 30%, while the ash content as a result of oxytree combustion in relation to coal is 35 times lower and the sulphur content as much as 80 times lower.

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