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IMPACT OF FERTILISATION WITH SEWAGE SLUDGE ON THE CONTENT OF LEAD IN *SALIX VIMINALIS* BIOMASS

Aleksandra SIECIECHOWICZ[1], Zofia SADECKA, Sylwia MYSZOGRAJ, Monika SUCHOWSKA-KISIELEWICZ
University of Zielona Gora,
Institute of Environmental Engineering, Zielona Góra, Poland

Abstract

Sewage sludge is considered to be high quality fertilizer. Therefore, in Poland, it is used to fertilize energy plants. On the one hand, it allows using large amount of sewage sludge on the other hand it contributes to the production of renewable energy.
The study was based on monitoring the plantation of energetic willow *Salix viminalis* fertilized with sewage sludge from wastewater treatment plant in Sulechow. The aim of the investigation was to study changes of the lead content in different parts collected during a year and analyze the differences in the accumulation of lead in the plants planted at different times. The results of the study showed that the amount of lead content in the biomass willow was not influenced by sewage sludge used as a fertilizer.

Keywords: lead, heavy metals, sewage sludge, *Salix viminalis*

1. INTRODUCTION

The share of renewable energy in the energy-fuel balance of Poland in the year 2020 should make 14%. The prime objectives of the Energy Policy of Poland up to the year 2030 include the protection of forests from excessive exploitation, obtaining of biomass, a balanced use of agricultural areas for these purposes, agricultural-food wastes and municipal wastes management[11,15]. It is predicted that the main source of biomass in the future will be energy plant

[1] Corresponding author: University of Zielona Gora, Institute of Environmental Engineering, Szafrana 15, 65-246 Zielona Góra, Poland; a.sieciechowicz@iis.uz.zgora.pl, tel. +48683282574

plantations [5]. The willow biomass used for energy purposes is a fuel with zero emission of CO_2 into the atmosphere, it is characterised by great mass annual growth, fairly high fuel value and significant resistance to diseases and pests, at relatively low soil requirements. The energy value of the willow ranges from 6.2 to 19.6 GJ/Mg, depending on the humidity, and the fuel value of the dry mass constitutes about 0.7 of the hard coal fuel value [19].

There are many applications for energy willow, and, in the recent years a significant increase in the demand for this type of fuel in the power industry has been noticed [1,17]. A forecast for the development of the use of renewable energy sources up to 2030 is presented in Fig. 1.

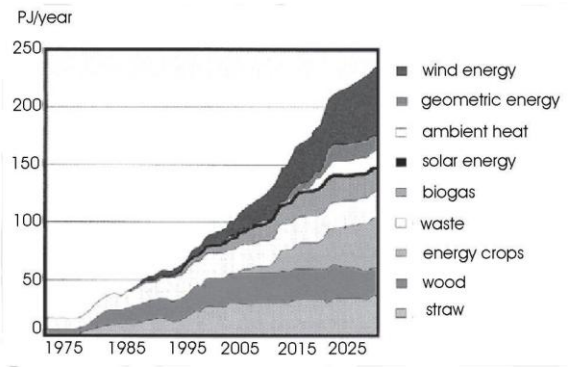

Fig. 1. Forecast of development of renewable energy sources by 2030 [19]

The data in Fig. 1 show that the percentage of energy obtained from renewable energy sources, in particular, the quantity of energy from energy plants and wind energy, will increase.

The cultivation of energy plants such as e.g. *Salix viminalis* on fields fertilized with sewage sludge is becoming more and more popular in Poland. Not only does such a solution allow great quantities of sludge to be managed (in 2010, 612 800 dry mass of municipal sewage sludge was produced), but it also contributes to the development of renewable energy [10].

The crops of common osier cultivated in Poland are estimated to be, on average, about 15 tons of dry mass/ha [18]. The soil conditions, the species and the variety of the osier as well as the relevant fertilisation are the main factors in determining the quantity of crops [4].

In order to fertilise a plantation of common osier, it is possible to use mineral and organic fertilisers as well as wastes. Taking advantage of the ability of *Salix viminalis* to collect great quantities of heavy metals, sewage sludge may be included in its fertilisation without any fear of excessive pollution of the soil by these elements [3,7,12,5]. However, bearing in mind the existing legal

regulations [16], the sewage sludge requires immediate mixing with soil, which practically limits the possibilities of using it only before the establishment of any plantation.

The aim of the studies was to determine the impact of fertilisation with the use of sewage sludge on the content of lead in the respective parts of *Salix viminalis* biomass at plantations serving as the final management of municipal sewage sludge in the environment.

2. THE OBJECT OF STUDIES AND METHODOLOGY

The object of the research was sewage sludge from mechanical-biological sewage treatment plant in Sulechów - designed to receive household and industrial sewage from 26500 PE. The programme of natural use of sewage sludge at the energy willow plantation has been implemented since 2001. The dehydrated sewage sludge, after hygienisation with lime, were used for the purpose of management of those soils with low and medium quality class for energy willow plantations *(Salix viminalis).* The management of the plots, which had an area of 24 ha, was planned in sections (from A to E), resulting from testing the properties of the surface soil layer (Table 1).

Table 1. Properties of the surface layer of soil on the land before planting willow cuttings

Indicator	Unit	Section A	Section B	Section C	Section D	Section E
pH_{KCl}	-	6.70	6.50	7.00	6.70	6.90
P_2O_5	mg/100g d.m.	27.30	27.60	30.20	28.50	28.00
K_2O	mg/100g d.m.	7.90	9.00	9.00	6.90	6.80
Pb^{2+}	mg/kg d.m.	15.19	16.24	13.21	14.52	9.66
Cd^{2+}	mg/kg d.m.	0.12	0.10	0.17	0.13	0.09
Cr^{2+}	mg/kg d.m.	5.25	4.82	3.19	4.91	6.22
Cu^{+}	mg/kg d.m.	5.36	6.04	5.39	6.32	7.21
Ni^{2+}	mg/kg d.m.	3.20	5.02	4.78	3.97	4.02
Hg^{+}	mg/kg d.m.	0.04	0.05	0.06	0.05	0.07
Zn^{2+}	mg/kg d.m.	37.24	48.80	36.63	40.34	44.25

Factors that determine the preferential dose of sludge after its hygienisation with lime was its soil-forming property which ensures long-term productivity of the substrate on the area, with a high demand for nutrients and water, designated for the future plantations. The factors limiting the amount of sludge after hygienisation with lime entering the soil were the relations between heavy metals in sediment and soil formations highly alkaline sludge after hygienisation with lime. Concentrations of heavy metals in the soil and in sewage sludge and acceptable criteria of their contents in light soils showed that due to the heavy

metals the dose limits, the concentration of the zinc, also a minor amount of copper, and other metals are not limiting factors.

As a result the doses of sewage sludge were established at levels of 88 to 94 tons of dry mass/ha [2]. Sewage sludge was spread on the ground once in early spring before planting willows.

The characteristics of sewage sludge were determined on a continual basis by the Water, Sewage and Waste Laboratory of the Institute of Environment Engineering at the Zielona Góra University (Table 2). The determined indicators and the methodology of tests have been specified in Table 3.

Table 2. The characteristic of sewage sludge

Indicator	Unit	2002	2003	2004	2005	2006	2007
pH	pH	11.25	10.95	10.95	11.1	11.6	11.25
Dry matter content	%	18.69	31.25	19.60	17.42	29.50	36.42
Content of organic matter	% d.m.	34.22	39.65	28.80	26.44	34.50	39.98
Total nitrogen	% d.m.	2.79	4.82	3.03	3.83	4.55	4.54
Ammonium nitrogen	% d.m.	no data	no data	0.48	0.55	0.65	0.87
Total phosphorus	% d.m.	0.8	0.82	1.21	1.36	1.85	1.53
Ca^{2+}	% d.m.	5.23	4.98	4.56	4.82	4.95	4.64
Mg^{2+}	% d.m.	0.92	0.88	0.53	0.56	0.68	0.64
Pb^{2+}	mg/kg d.m.	102.00	102.00	90.00	101.00	106.60	98.42
Cd^{2+}	mg/kg d.m.	1.00	2.00	0.80	0.90	1.20	1.12
Hg^{+}	mg/kg d.m.	0.00	0.00	0.00	0.00	0.00	0.00
Ni^{2+}	mg/kg d.m.	29.00	18.00	24.00	20.00	32.10	28,4
Zn^{2+}	mg/kg d.m.	1050.00	908.00	750.00	864.00	884.60	792.00
Cu^{+}	mg/kg d.m.	136.00	110.00	88.00	76.00	81.50	63.24
Cr^{2+}	mg/kg d.m.	28.00	22.00	39.00	42.00	42.10	36.84
Pathogenic bacteria of the genus *Salmonella*	100 g of precipitate	not isolated	not isolated	not isolated	not isolated	not isolated	not isolated
The number of viable eggs of helminths *Ascaris sp , Trichuris sp, Toxocara sp.*	pc/kg d. m.	not detected	not detected	not detected	not detected	not detected	not detected

The results of analyses of the samples of sludge collected from the sewage treatment plant in the years 2004-2007 confirm their usefulness for natural use in agriculture for the re-cultivation of soils for agricultural and non-agricultural purposes [16].

The planting density amounted to 33 400 pieces per 1 ha. The cuttings of the common osier of Scandinavian varieties, from clones obtained in Marzęcin (Ulv and York varieties), were 40 cm long. The willow was planted in the years 2002-2007, each year during the period of early spring.

Table 3. Indicators and methodology of sludge samples

Indicator	**unit**	**Test method**
pH	pH	PN-90 C-04540/01
Dry matter content	%	PN-78 C-04541
Content of organic matter	% d. m.	PN-G-04516: 1980
Total nitrogen	% d. m.	PN-90 C-04540/01
Total phosphorus	% d. m.	PN-EN 1189: 2000
Ca^{2+}	% d. m.	PN-ISO 6058: 1999
Mg^{2+}	% d. m.	PN-ISO 6059: 1999
Pb^{2+}	mg/kg d. m.	PN-ISO 8288: 2002
Cd^{2+}	mg/kg d. m.	PN-ISO 8288: 2002
Hg^{+}	mg/kg d. m.	PN-ISO 8288: 2002
Ni^{2+}	mg/kg d. m.	PN-ISO 8288: 2002
Zn^{2+}	mg/kg d. m.	PN-ISO 8288: 2002
Cu^{+}	mg/kg d. m.	PN-ISO 8288: 2002
Cr^{2+}	mg/kg d. m.	PN-ISO 8288: 2002

The collection of plant samples took place during the years 2007 and 2008. It consisted of digging out the whole plant carefully, cleaning the root of the adjacent soil and dividing the plant into a root, a stem and foliage. The air-dried samples - the stem and the root - were processed in the form of chips, and the leaves were ground into mortar. The lead content was determined by the referential method (atomic absorption spectrometry after mineralisation in aqua regia) in accordance with the Regulation of the Minister of Environment dated August 1st, 2002 on municipal sewage sludge [16]. The plant samples were collected from those plantations established in the years 2002, 2004 and 2007. The plantation from the year 2007 was divided into three sections: a section fertilised with sewage sludge, a section that was not fertilised and the section fertilised only with N, P, K.

3. RESULTS

The highest lead content in the root of the willow was obtained in the samples coming from the oldest plantation - the one established in 2002 (21.70 mg Pb /kg d.m.) (Figure 2). This result was obtained from the spring samples, and the lead content in the roots of the willow from this plantation was the lowest in the summer and amounted to 13.40 mg Pb/kg d.m.

For the plantation established in 2004, the lead content was the lowest in the autumn samples (15.0 mg Pb/kg d.m.), and the highest value was observed in the spring samples (20.40 mg Pb/kg d.m.). In the case of the plantations established

in the year 2007, no significant differences were noticed between the fertilised and non-fertilised plantations. The lowest lead content was present in the roots of the willow fertilised with sewage sludge (13.90 mg Pb/kg d.m.), and the highest one was observed in the roots of the willow fertilised with minerals. For the non-fertilised control plantation the lead content in the roots of the plants ranged from 13.98 mg Pb/kg d.m. (summer) to 21.18 mg Pb/kg d.m.(autumn).

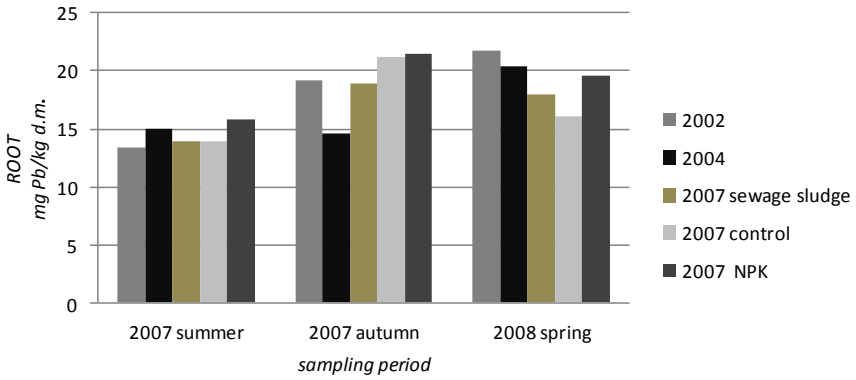

Fig. 2. Changes in the content of lead in the root of *Salix viminalis*

The greatest lead content in the stem of the willow was obtained from the samples coming from the plantation established in the year 2004 (Fig. 3). The oldest plantation was characterised by the lowest content of lead in the stem (11.10 mg Pb/kg d.m.). Similarly to the content of lead in the root for the 2004 plantation, the lowest lead content in the stem was obtained when collecting samples in autumn (14.05 mg Pb/kg d.m.).

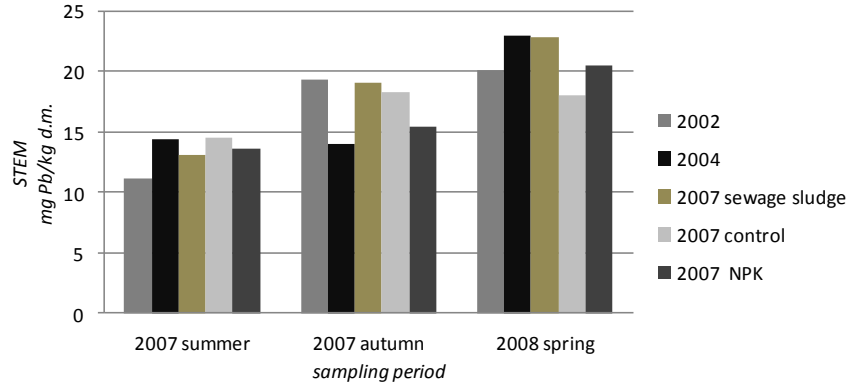

Fig. 3. Changes in the content of lead in the stem of *Salix viminalis*

Both, for the plantation fertilised with sludge and the one fertilised with minerals (2007), the lead content increases systematically over time. The lowest lead contents were obtained in the summer samples (13.06 and 13.70 mg Pb/kg d.m.), and the highest ones in the samples collected almost one year later (spring 2008). They amounted to 22.89 and 20.52 mg Pb/kg d.m. respectively. The lead content in the stem for the control plantation was the lowest in summer 2007 and amounted to 14.48 mg Pb/kg d.m. An increase in the lead content in the stem by about 4.00 mg Pb/kg d.m. was observed in autumn, and the lead content in spring fell slightly to the value of 18.07 mg Pb/kg d.m.

The leaves of the willow collected from the oldest plantation (2002) did not differ significantly from the samples collected from younger plantations (Figure 4) in terms of the lead content. However, the lead content in the samples collected in autumn was the highest of all the plantations and amounted to 18.87 mg Pb/kg d.m.

The lowest content of lead in the foliage was obtained in the samples coming from the 2004 plantation (12.67 mg Pb/kg d.m.). For most of the plantations, the lead content in the foliage reached the highest value in the samples collected in autumn, and the lowest value in the samples collected in summer. The foliage samples from the plantation, which was established in 2007 and fertilised with sewage sludge, were characterized by an increase in the content of lead in the foliage during the year. The lowest lead content was obtained by collection of samples in summer (15.08 mg Pb/kg d.m.). After several months, this value increased to the level of 17.58 mg Pb/kg d.m., and in spring 2008, it amounted to 17.96 mg Pb/kg d.m.

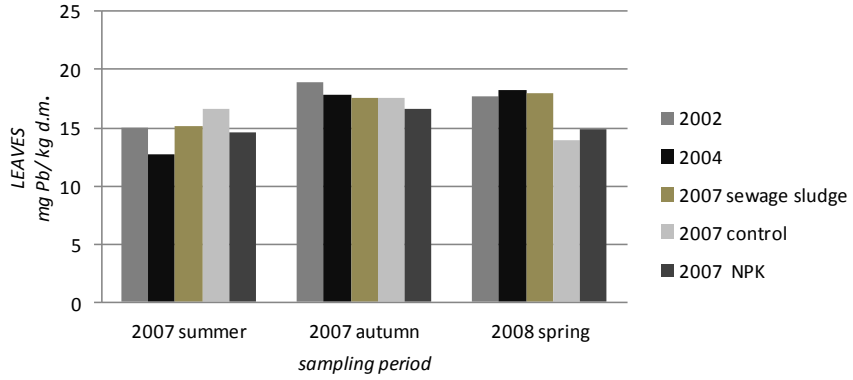

Fig. 4. Changes lead content in leaves of *Salix viminalis*

Comparing the mean contents of lead in the respective parts of the willow cultivated for the longest period of time, it is possible to notice that the roots

were characterised by the highest lead contents and the foliage had the lowest values.
For the 2004 plantation and the one from 2007 (fertilised by sewage sludge) the stems were characterized by the highest lead content and the lowest one was observed in the foliage. The samples of the willow from the non-fertilised plantation were characterised by the fact that the highest lead content was proven in stems and the lowest one in the foliage.

4. DISCUSSION AND CONCLUSIONS

The results of the studies show that there are no significant differences between the content of lead in the biomass samples of the willow coming from the plantation that is not fertilised by sewage sludge and from the plantations fertilised with sewage sludge. Also, the results of studies by other authors confirm that the lead content in leaf-less sprouts of willow cultivated at a control facility and facilities fertilised with sewage sludge do not differ significantly in most cases [6].
Therefore, it has not been confirmed that the fertilisation of plantations with sewage sludge exerts a significant impact on the accumulation of lead in the *Salix viminalis* biomass. Also, the plantations, which were only fertilised with minerals, did not differ in terms of lead content in the respective parts of the plants. The mean value of lead in the foliage from these plantations was the lowest of them all. It is also possible to notice that as time went by, the content of lead in biomass increased - irrespective of the type of plantation. Studies conducted, among others, by Kostecki, indicate that the lead content in all the plantations changes in a similar manner: at the beginning of the year the lead content is low; it increases in summer and autumn and becomes lower again in winter [8]. Michałowski and Gołaś claim that the lead content in the root of the willow oscillates between 7.98 mg Pb/kg d.m and 21.67 mg Pb/kg d.m. The tests performed to check the lead content of the roots of *Salix viminalis* (a mixture of *Ulv* and *York* varieties*)* prove that the lead content in the biomass approximates to the data concerning the respective individual varieties (Table 4) [13,14].
The results of the studies demonstrate that there are no significant differences between the lead content in the samples of biomass from willow coming from the plantation that was not fertilised with sewage sludge and from the plantations fertilised with sewage sludge. Therefore, the influence of fertilisation of the plantations with sewage sludge as a cause of any increase of lead in the *Salix viminalis* biomass was not ascertained.

Table 4. The lead content in the roots, stems and leaves of willow *Salix viminalis* varieties York and Ulv (Michałowski and Gołaś 2002), and *Salix viminalis* according to research their own

Unit		mg/kg d.m.		
Metal (variety of willow)		Pb (Ulv and York) (own research)	Pb (Ulv) (Michałowski and Gołas 2002)	Pb (York) (Michałowski and Gołas 2002)
Root	Minimum	13.43	10.78	7.98
	Maximum	21.73	21.67	19.34
	Average	17.23	21.54	17.50
Stem	Minimum	11.13	1.34	1.67
	Maximum	22.93	3.98	3.67
	Average	17.43	3.76	3.00
Leaf	Minimum	12.67	10.78	2.98
	Maximum	18.87	16.70	19.87
	Average	16.78	15.79	17.00

ADDITIONAL INFORMATION

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REFERENCES

1. Bień J., Bień J., Wystalska K.: *Problemy gospodarki osadowej w ochronie środowiska,*Wydawnictwo Politechniki Częstochowskiej, Częstochowa, (1998).
2. *Program utylizacji osadu oczyszczalni ścieków w Sulechowie na gruntach przyległych przeznaczonych do zagospodarowania na plantacje wierzby energetycznej*, Zakład Ochrony Środowiska i Projektowania Geosan c.c., Warszawa, 2000.
3. Greger M., Landberg T.: *Use of willow in phytoextraction,* International Journal of Phytoremediation 1, (1999) 115-123.
4. Kalembasa D., Malinowska E., Siewniak M: *Wpływ nawożenia na plonowanie wybranych gatunków wierzby krzewiastej,* Acta Agrofizyka, 8, 1 (2006), 119-136.

5. Kalembasa S., Symanowicz B., Kalembasa D., Malinowska E.: *Możliwości pozyskiwania i przeróbki biomasy z roślin szybko rosnących (energetycznych),* Nowe spojrzenie na osady ściekowe - odnawialne źródła energii, Cz.II., Wydawnictwo Politechniki Częstochowskiej, Częstochowa 2003, 358-364.
6. Kalembasa S., Wysokiński A., Cichuta R.: *Zawartość metali ciężkich w wierzbie (Salix viminalis) przy zróżnicowanym nawożeniu azotowym,* Acta Agrofizyka 13, 2 (2009), 385-392.
7. Kopeć M. Gondek K.: *The effect of long-term fertilization on sulphur content in soil and in the mountain meadow sward (Czarny Potok),* Rostlinna Vyroba 48, 12 (2002), 525-530.
8. Kostecki J., Myszograj S.: *Zawartość metali ciężkich w glebach na plantacji wierzby energetycznej nawożonej osadami ściekowymi,* Zeszyty Naukowe Uniwersytetu Zielonogórskiego 133, 13 (2007), 247-254.
9. Krajowy Plan Gospodarki Odpadami 2014, Warszawa 2010.
10. Krajowy Program Oczyszczania Ścieków Komunalnych, Ministerstwo Środowiska, Warszawa 2006.
11. Lazdina D., Lazdins A., Karis Z., Kaposts V.: *Effect of sewage sludge fertilization in short-rotation willow plantations*, Journal of Environmental Engineering and Landscape Management, 15, 2 (2007), 105-111.
12. Mathe-Gaspar G., Anton A.: *Study of phytoremediation by use of willow and rape*. Acta Biologica Szegediensis 49, 1-2 (2005), 73-74.
13. Michałowski M., Gołaś J.: *Zawartość wybranych metali ciężkich w organach wierzby jako wskaźnik wykorzystania jej w utylizacji osadów ściekowych.* Zesz. Probl. Post. Nauk Roln., 477 (2001), 411-419.
14. Michałowski M., Gołaś J.:*Próby ekologicznego zagospodarowania osadów z krakowskich oczyszczalni ścieków,* Environmental Engineering, 7, 1 (2002), 79-86.
15. Paluch J., Paruch A., Pulikowski K.: *Przyrodnicze wykorzystanie ścieków i osadów*. Wrocław, Wydawnictwo Akademii Rolniczej (2006).
16. Rozporządzenie Ministra Środowiska z dnia 01 sierpnia 2002 roku w sprawie komunalnych osadów ściekowych (Dz.U. Nr 134, poz.1140).
17. Stolarski M.: *Wszystko o wierzbie*, Czysta Energia, 10 (2003), 32-33.
18. Szczukowski S., Tworkowski J., Stolarski M., Grzelczyk M.: *Produktywność roślin wierzby (Salix spp.) i charakterystyka pozyskiwanej biomasy jako paliwa,* Zesz. Probl. Post. Nauk Roln., 507 (2005), 495-503.
19. Wielgosz G.: *Energetyczne wykorzystanie biomasy wierzbowej (Salix)* Krakowska Konferencja Mlodych Uczonych, (2008), 173-179.

WPŁYW NAWOŻENIA OSADAMI SCIEKOWYMI NA ZAWARTOŚĆ OŁOWIU W BIOMASIE SALIX VIMINALIS

S t r e s z c z e n i e

Komunalne osady ściekowe charakteryzują się dużą wartością nawozową. W związku z tym w Polsce wykorzystuje się je m.in. do nawożenia roslin energetycznych. Z jednej strony, takie rozwiązanie pozwala na unieszkodliwianie dużych ilości osadów ściekowych, a z drugiej przyczynia się do rozwoju odnawialnych źródeł energii.
Przeprowadzone badania dotyczyły monitoringu prowadzonego na plantacji wierzby energetycznej *Salix viminalis* nawożonej osadami ściekowymi z oczyszczalni ścieków w Sulechowie. Wyniki badań dotyczyły zmian zawartości ołowiu w poszczególnych częściach roślin pobieranych w okresie jednego roku analizując różnice w kumulacji ołowiu dla plantacji założonych w różnym czasie. Określono wpływ nawożenia osadami ściekowymi na zawartość ołowiu w biomasie wierzby. Wykazano, że zawartość ołowiu w biomasie wierzby nie była determinowana nawozeniem osadami ściekowymi. Stosowanie nawozów mineralnych również nie wpływa na zwiększenie zawartości ołowiu w biomasie roślin. Najwyższe średnie wartości ołowiu uzyskano w próbkach łodyg oraz korzeni, a najniższe w próbkach listowia.

Słowa kluczowe: ołów, metale ciężkie, osady ściekowe, *Salix viminalis*

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