Environment Protection Engineering

Vol. 37 2011 No. 3

LESZEK STYSZKO*, DIANA FIJAŁKOWSKA*, MONIKA SZTYMA-HORWAT*

INFLUENCE OF FERTILIZATION WITH COMPOST FROM MUNICIPAL SLUDGE ON THE CONTENT OF DRY MATTER AND THE YIELD OF ENERGY WILLOW PLANTED ON LIGHT SOIL

An assessment has been done of the yielding of nine clones of energy willow planted in Kościernica near Koszalin on light soil of IVb–V class, fertilized with the compost from municipal sludge in the dose of 10 $t \cdot ha^{-1}$ of dry matter and with Hydrofoska 16 fertilizer in two doses (562.5 $kg \cdot ha^{-1}$ and 1.125 $kg \cdot ha^{-1}$). The highest content of dry matter in shoots was obtained on the objects without any fertilization. Fertilization with the compost decreased the content of dry matter in the shoots and increased the yield of fresh matter in comparison with the testing object without fertilization.

1. INTRODUCTION

Sludges constitute troublesome waste in sewage treatment plants and are still difficult to recycle [1, 2]. In 2008, a total of 978 900 tons of dry matter of sludges were produced in Poland in industrial and municipal sewage treatment plants [3]. In industrial sewage treatment plants, the quantity of the sludges produced decreased annually from 700 300 tons in 2000 to 411 600 tons in 2008, while in municipal waste treatment plants it increased from 359 800 tons in 2000 to 567 300 tons in 2008. In accordance with the state ecological policy and the guidelines of the National Plan of Waste Management 2010 [4], in 2018 the following recycling from the foreseen quantity of 706.6 thousand tons of sludges from municipal sewage treatment plants 9.5% was predicted for the purposes of reclamation, for use in agriculture and in nature 9.5%, 20.6% for composting and 60.7% thermal neutralization. The guidelines included in

*Koszalin University of Technology, Faculty of Building and Environmental Engineering, Department of Environmental Biology, Unit of Energy Plants, ul. Śniadeckich 2, 75-453 Koszalin, Poland. Corresponding author L. Styszko, e-mail: lstyszko@wbiis.tu.koszalin.pl

Directive 99/31/EC concerning waste disposal [5] which are transferred to the Polish law in the Ordinance by the Minister of Economy as of 12 June 2007, prohibit starting from the day of 1 January 2013 any disposal of such sludge which contains over 5% of general organic carbon, characterised by the heat of combustion of over 6 MJ/kg of dry matter [6]. The use of sludges for the production of compost, which will then be used among others for the fertilization of the crop of energy plants, will also allows an active inclusion in the realization of the EU objectives related to the power industry. The Ordinance by the Minister of Economy as of 14 August 2008 imposes an obligation on power stations to use agricultural raw materials for energy purposes [7]. In those areas where light soils dominate, fertilization with compost from municipal sludges or also sludges may increase their productivity, the retention of rain water and may step up the soil forming process [2, 8–12].

The purpose of the present research was an assessment of the influence of the fertilization of energy willow with compost from municipal sludges and being enriched with mineral fertilizers on the content of dry matter and the yield of the shoots of nine clones in the second, third and fourth year of their crop in a place with a deep level of underground waters, weak soils yet with a relatively favourable distribution of precipitation in the vegetation period.

2. MATERIALS AND METHODS

Field experiments with nine clones of shrubby willow were conducted in Kościernica near Koszalin on a field which had been fallowed for 10 years, on light soil rated among IVb–V class, with the mechanical composition of light clayish sand with an acid reaction, and an average content of assimilable phosphorus in the soil, yet with a low content of potassium and magnesium. In the first decade of April 2005, willow cuttings were planted at the abundance of 33.2 thousand of ferns per one hectare. One year old shoot outgrowths were cut after the first vegetation of willow in the winter of 2005/2006. In spring 2006, a strict experiment was set up with the method of random split blocks in a dependent layout in three repetitions, where the first class split blocks were four fertilizer combinations, and the second class split blocks were nine clones of willow. The experimental plot had the area of 34.5 m^2 (2.3×15.0 m^2). Within the framework of fertilizer combinations, the following were randomized:

a) objects without any fertilization,

b) objects fertilized with compost (10 $t \cdot ha^{-1}$ of dry matter),

c) objects fertilized with compost (10 $t \cdot ha^{-1}$ of dry matter) and Hydrofoska 16 in the dose of 562.5 $kg \cdot ha^{-1}$ containing 90 $kg \cdot ha^{-1}$ of N, 90 $kg \cdot ha^{-1}$ of P_2O_5 and 90 $kg \cdot ha^{-1}$ of K_2O in a pure component,

d) objects fertilized with compost (10 t·ha^{-1} of dry matter) and Hydrofoska 16 in the dose of 1125.0 kg·ha^{-1} containing 180 kg·ha^{-1} of N, 180 kg·ha^{-1} of P_2O_5 and 180 kg·ha^{-1} of K_2O in a pure component.

Compost from municipal sludges with an attestation issued by the University of Technological and Natural Sciences in Bydgoszcz was purchased from the Waste Recycling Company in Sianów. The compost contained 66.7% of dry matter as well as significant quantities of nutrients and alkali metals, while the quantities of heavy metals were in accordance with the Polish standards. In the dose of 10 Mg·ha^{-1} of compost, 3906 kg of organic matter, 174.6 kg of nitrogen in total and 160.1 kg of phosphorus and also considerable quantities of alkali metals: 20 kg of sodium, 32.5 kg of potassium, 110 kg of calcium and 17.2 kg of magnesium were all carried to the soil. In the year 2006, the compost was applied on 7 days before spreading of Hydrofoska 16, which was then mixed with the soil. The dose of Hydrofoska 16 was divided into two parts, which were applied in the interval of one month. In the years 2007, 2008 and 2009 re-fertilization with Hydrofoska 16 was applied on c and d objects with the omission of compost before the start of the vegetation of willow. Nine clones of willow: 1047, 1054, 1023, 1013, 1052, 1047D, 1056, 1018 and 1033 were investigated. The shoots were every time mowed from 1/3 of the area of the experimental plot after the second vegetation in February 2008, after the third vegetation in February 2009 and after the fourth vegetation in November 2009. On the day of mowing, the yield of fresh matter of the shoots and the content of dry matter were evaluated. The data of the yield of biomass was statistically processed with the use of Statistica programme. Analyses of variances were performed, the gravity of the effects was evaluated with the F test and the significance of the factors examined was calculated with the method of variance components.

3. RESULTS

Precipitation in all years of the experiment was above 753 mm in the period from January to December, and from 459 mm in the period from April to October in 2008 to 654 mm in 2007. The highest precipitations (1062 mm) occurred in 2007 which was considered very wet. The year 2008 with the precipitation of 855 mm was well wet and the years 2006 and 2009 with the precipitation of 753 mm and 787 mm, respectively, were wet [21].

Yields of fresh and dry matter depending on fertilization and the content of dry matter in willow shoots in the years of 2006–2009 are presented in Table 1. In the table and subsequent ones, $NIR_{0.05}$ is the smallest significant difference on the confidence level of $\alpha = 0.05$. One asterisk (*) denotes significance on the confidence level $\alpha = 0.05$, two asterisks (**) $\alpha = 0.01$, (***) – $\alpha = 0.001$. Fertilization with the com-

post (case b) and with Hydrofoska 16 (cases c and d) decreased the content of dry matter in the shoots in comparison with that in the testing object without any fertilization (case a). The composition of fertilizer significantly influenced the yields of the fresh and dry matter of the shoots. Fertilization with the compost (case b) increased the yield of fresh matter by 2.2 t·ha^{-1} in average, i.e. by 6.9% and the yield of dry matter by 1.0 t·ha^{-1}, i.e. by 6.9% in comparison with the testing object (case a). On the objects with the compost, fertilization with the Hydrofoska 16 in the dose of 562.5 kg·ha^{-1} (case c) contributed to an increase of the yield of fresh matter by 13.8 t·ha^{-1}, i.e. by 43.3% and the yield of dry matter by 5.8 t·ha^{-1}, i.e. by 40.3% in comparison with the testing combination a.

Table 1

Yield of fresh and dry matter depending on fertilization and content of dry matter in willow shoots in the years of 2006–2009 in Kościernica. The average from 9 clones and 3 harvests

Composition of mixture of fertilizers			Contents of dry matter in shoots [%]	Yield [t·ha^{-1}]	
Case	Fresh matter of compost [t·ha^{-1}]	Hydrofoska 16 [kg·ha^{-1}]		Fresh matter	Dry matter
a	0	0	44.5	31,9	14,4
b	15	0	44.1	34,1	15,4
c	15	562.5	43.4	45,7	20,2
d	15	1125.0	43.5	50,4	22,4
$NIR_{0.05}$			0.8*	2.0***	1.1***

Fertilization with the compost and Hydrofoska 16 in the dose of 1125.0 kg·ha^{-1} (case d) increased the yield of fresh matter by 18.5 t·ha^{-1}, i.e. by 58.0% and the yield of dry matter by 8.0 t·ha^{-1}, i.e. by 55.6% in comparison with those of the testing object (case a).

Table 2

Effect of synergism of the crop years and the fertilizer combinations on the yield of fresh matter of willow shoots. An average from 9 clones of willow

Harvest of shoots	Crop years	Yield of the fresh matter of willow for the fertilizer combinations [t·ha^{-1}]			
		a	b	c	d
February 2008	II	21.4	21.4	31.3	36.1
February 2009	III	31.7	32.9	46.7	48.2
November 2009	IV	42.5	47.9	59.2	67.0
$NIR_{0.05}$		3.4**			

In the second and third crop years, the differences in the yield of fresh as well as of dry matter between the object fertilized with the compost (b) and the testing object without any fertilization (a) were insignificant, in contrast to the fourth year, when the differences were considerable (cf. Tables 2, 3). In each crop year, an additional fertilization with Hydrofoska 16 (cases c and d) was favourable to obtain higher yields of dry matter of shoots (compare with cases a and b).

Table 3

Effect of synergism of the crop years and the fertilizer combinations on the yield of dry matter of willow shoots. An average from 9 clones of willow

Harvest of shoots	Crop years	Yield of the dry matter of willow for the fertilizer combinations [t·ha^{-1}]			
		a	b	c	d
February 2008	II	9.04	8.81	12.59	14.46
February 2009	III	13.35	13.66	19.53	20.66
November 2009	IV	20.84	23.64	28.44	32.22
$NIR_{0.05}$		1.85**			

Table 4

Effect of synergism of clones and the fertilizer combinations on the yield of dry matter of willow shoots. An average from 3 harvests

Willow clone	Yield of the dry matter of willow for the fertilizer combinations [t·ha^{-1}]			
	a	b	c	d
1047	16.3	17.1	21.1	29.3
1054	12.7	15.0	19.6	24.5
1023	15.5	16.1	27.0	22.0
1013	16.2	16.5	20.7	18.6
1052	12.1	12.2	16.3	25.3
1047D	14.3	13.8	21.8	23.2
1056	16.0	17.2	18.2	14.9
1018	13.0	14.7	19.8	23.3
1033	13.5	15.9	17.2	20.9
$NIR_{0.05}$	3.2***			

No significant increase of the yield of dry matter was observed for all the clones apart from that No. 1033 on objects fertilized with the compost (case b) in comparison with those unfertilized (Table 4). The increase of the yield of dry matter within the range from 2.2 to 11.5 t·ha^{-1}, i.e. from 13.8% to 74.2%, were obtained with all the clones on the objects fertilized with the compost and with Hydrofoska 16 in the dose of 562.5 kg·ha^{-1} (case c) in comparison with the object without any fertilization. Di-

versified reaction of the clones in the yield of dry matter was observed on the objects fertilized with the compost in the dose of 15 t·ha^{-1} and with Hydrofoska 16 in the dose of 1125 kg·ha^{-1} (case d). Yield of dry matter increased for eight clones examined (from 2.4 t·ha^{-1} to 13.2 t·ha^{-1}, i.e. from 14.8% to 109.1%) in comparison with the testing object.

4. DISCUSSION

An increase of the productivity of energy willow based on agricultural science methods has a large significance; however, there are still very few experimental studies in this area in Poland [8, 13–15]. In many countries, willow crops are situated in the vicinity of sewage treatment plants where municipal liquid wastes or sludges are used for the purpose of fertilization [11, 16, 17]. The willow is counted among plants with intense water requirements [15, 18]. On the grounds of research it was recognized that those areas where the annual precipitation exceeds 575 mm and there are soils counted included in the complexes of agricultural usefulness such as rye very good (4), rye good (5), cereal and fodder strong (8), cereal and fodder weak (9) and weak and very weak grasslands (3z), are fit for the crop of willow in Poland [19]. The experiment was located in Kościernica on the soil of a weak rye complex (IVb–V class) and the rain water was its only source for the willow.

The content of dry matter increased annually from the level of 41.0% after the second year of the crop to 48.6% after the fourth year of the crop, which was similar to what was observed in the research by Stolarski and Szczukowski [13, 15]. In the author's research, with the passage of the crop years, the yield of the fresh and dry matter of willow shoots grew from 27.5 t·ha^{-1} and 11.2 t·ha^{-1} after the second year to 54.1 t·ha^{-1} and 26.3 t·ha^{-1} after the fourth year, respectively. In the research by Stolarski et al. [13], the yield of dry matter of willow wood, which was acquired very year, was higher than in the author's research and was 16.89 t·ha^{-1}·year^{-1} and in the four year cycle: 24.99 t·ha^{-1}·year^{-1}. The difference in the yield of dry matter of willow between the research by Stolarski and that presented here resulted from the quality of soil and its abundance in water. In Obory near Kwidzyń, the experiment with willow was conducted on heavy fen soil produced from heavy flour clay, in a strong cereal and fodder complex of IIIb class.

In the present research, a favourable influence of fertilization with the compost on the yields of willow shoots increased with the passage of crop years; it achieved significant rises in the fourth year only by 5.4 t·ha^{-1}, i.e. by 12.7% in the yield of fresh matter and by 2.8 t·ha^{-1}, i.e. by 14.4% in the yield of dry matter in comparison with those of the objects without any fertilization. It is seems that the yield generating effect of the compost could emerge as a consequence of the improvement of the soil

fertility as a result of the fertilizing activity of the compost [9] and its stimulating influence on the abundance and activeness of oligotrophic and macrotrophic bacteria as well as total fungi and cellulotic fungi [20].

No data concerning the reaction of the clones of energy willow to fertilization with the compost from municipal sludges and with Hydrofoska 16 compound fertilizer is to be found in the literature. In the present research, the differences between those clones which on the average obtained the largest and lowest contents of dry matter in shoots were 3.9%, i.e. 8.9% of the average content in the experiment, and with the yield of dry matter: 4.4 $t \cdot ha^{-1}$, i.e. 24.3% of the average yield of dry matter in the experiment. On the objects fertilized with the compost from municipal sludges, only clone No. 1033 reacted with a significant increase of the yield of fresh matter by 6.2 $t \cdot ha^{-1}$, i.e. by 20.6% in comparison with that of the object without any fertilization. In the previous research, it was similarly confirmed that the recommendations concerning fertilization with compost with reference to species cannot be generalized in relation to the willow, yet its effects should be examined on the level of a clone [14]. A beneficial effect of the combined fertilization with the compost and Hydrofoska 16 similarly as in the case of fertilization with the compost only on the yields of fresh and dry matter increased with the passage of the crop years; it annually achieved higher average increases of the yield, but the differences in these yields between high and low doses of Hydrofoska 16 were significant only in two per three harvests. According to the literature data, the yields of willow depend on the course of weather, the quality of soil, fertilization applied and the length of the harvest rotation [13–15]. In foreign experiments, the productivity of willow was also different, depending on the location of the field, fertilization and watering. For example, in Sweden in three year rotations, the yield fluctuated from 7 to 20 $t \cdot ha^{-1} \cdot year^{-1}$ of dry matter, and in Germany it ranged from 6 to 14 $t \cdot ha^{-1} \cdot year^{-1}$ [21], in the United States in four year rotations in the range from 15 to 20 $t \cdot ha^{-1} \cdot year^{-1}$, and in Wales in the range from 6 to 12 $t \cdot ha^{-1} \cdot year^{-1}$ [22].

5. CONCLUSIONS

No access of willow roots to the underground water caused a periodic reaction of the plants to the stress of drought even though hydrothermal conditions for the crop of willow in the years of 2006–2009 in Kościernica were favourable: from January to December the precipitation was from 753 mm to 1062 mm and in the periods from April to October, it was from 459 mm in the year 2008 to 654 mm in the year 2007.

Fertilization with the compost in the dose of 10 $t \cdot ha^{-1}$ of dry matter reduced the content of dry matter in shoots by 0.4% and increased the yield of fresh matter by 2.2 $t \cdot ha^{-1}$, i.e. by 6.9% and dry matter by 1.0 $t \cdot ha^{-1}$, i.e. by 6.9% in comparison with the testing object without any fertilization.

The favourable influence of fertilization with the compost on the yields of fresh and dry matter increased with the passage of the crop years achieving significant rises only in the fourth year with the yield of fresh matter by 5.4 t·ha^{-1}, i.e. by 12.7% and with the yield of dry matter by 2.8 t·ha^{-1}, i.e. by 14.4% in comparison with the objects without any fertilization.

The application of the combined fertilization with the compost and with Hydrofoska 16 in both doses examined (562.5 kg·ha^{-1} and 1,125.0 kg·ha^{-1}) on the average decreased the content of dry matter in the shoots by 1.1% and 1.0%, respectively and increased the yield of fresh matter on the average by 13.8 t·ha^{-1}, i.e. by 43.3% and by 18.5 t·ha^{-1}, i.e. by 58.0%, respectively and the yield of dry matter on the average 5.8 t·ha^{-1}, i.e. by 40.3% and by 8.0 t·ha^{-1}, i.e. by 55.6% in comparison with the testing object without any fertilization.

ACKNOWLEDGEMENTS

The present research has been financed by the Ministry of Science and Higher Education as the research project from the funds allocated for science in the years of 2008–2011.

REFERENCES

[1] MARCINKOWSKI T., Ochr. Środ., 2003, 25 (2), 49.
[2] ROSIK-DULEWSKA CZ., KARWACZYŃSKA U., CIESIELCZUK T., GŁOWALA K., Rocznik Ochr. Środ., 2009, 11 (2), 863.
[3] *Statistical Yearbook*, Central Statistical Office, Warsaw, 2009, www.stat.gov.pl
[4] *National Waste Management Plan 2010*, Resolution of the Council of Ministers No. 233 29.12.2006 (Polish Monitor 29.12.2006) (in Polish).
[5] *Commission of European Communities*. Council Directive 99/31/EC of 26 April 1999 on the landfill of waste.
[6] Decree of the Minister of Economy of 12 June 2007 amending the Decree on criteria and procedures for allowing waste for landfilling in landfills of given waste type (Official Journal of 6 July 2007) (in Polish).
[7] Decree of the Minister of Economy of 14 August 2008 on detailed scope of obligations in obtaining and presenting for redemption of certificates of origin, Official Journal 2008. No. 156 pos. 969 (in Polish).
[8] KRZYWY E., IŻEWSKA A., *Wastewater and Sewage Sludge Management*, Publishing House of Agricultural University of Szczecin, Szczecin, 2004 (in Polish).
[9] KRZYWY E., IŻEWSKA A., JEŻOWSKI S., Zesz. Probl. Post. Nauk Roln., 2003, 494, 215.
[10] LABRECQUE M., TEODORESCU T.I., DAIGLE S., Plant and Soil, 1995, 171, 301.
[11] LAZDI□A D., LAZDI□Š A., KARI□Š Z., KĀPOSTS V., J. Environ. Eng. Landscape Man., 2007, 15 (2), 105.
[12] RAHMONOV O., MALIK I., ORCZEWSKA A. Polish J. Soil Sci., 2004, 37 (1), 77.
[13] STOLARSKI M., SZCZUKOWSKI S., TWORKOWSKI J., Fragm. Agron., 2002, 2, 39.
[14] STYSZKO L., FIJAŁKOWSKA D., SZTYMA M., Rocznik Ochr. Środ., 2010, 12, 339.
[15] SZCZUKOWSKI S., TWORKOWSKI J., STOLARSKI M., *Energetic Willow*, Plantpress, Cracow, 2004 (in Polish).

[16] ADEGBIDI F.G., BRINGGS R.D., Biomass Bioenergy, 2003, 25, 665.
[17] MELIN G., ARONSSON P., HASSELGREN K., *Recycling of wastewater and sludge in Salix plantations*, [In:] *The Development of Renewable Energy in West Pomerania*, P. Lewandowski, W. Nowak, (Eds.), Hogben, Szczecin, 2004, p. 263 (in Polish).
[18] KUZOVKINA Y.A., QUIGLEY M. F., Water, Air, Soil Poll., 2005, 162, 183.
[19] JADCZYSZYN J., *The spatial location of plantation*s [In:] *Fuels and Energy of 21st Century*, W. Ciechanowicz, S. Szczukowski (Eds.) Higher School of Applied Informatics and Management. Printing House WIT, Warsaw, 2006, p. 218 (in Polish).
[20] JONIEC J., FURCZAK J., Ann. Univ. Mariae Curie Skłodowska, Sectio E. Agricultura, 2007, 62 (1), 105.
[21] HOFFMANN D., WEIH M., Biomass Bioenergy, 2005, 28, 267.
[22] RANDERSON P.F., HEATON R.J., SLATER F.M., *Economic prospects for short rotation coppice in Wales: The need for subsidy in a new agricultural industry*, [In:] Proc. 7th Polish-Danish Workshop Biomass for Energy, Starbienino, 2000, p. 135.