U.P.B. Sci. Bull., Series C, Vol. 79, Iss. 2, 2017 ISSN 2286-3540

THE EFFECT OF SEWAGE SLUDGE ON ENERGY WILLOW (*SALIX VIMINALIS* "ENERGO") PRODUCTIVITY

Viorica Ruxandu SUBŢIRELU[1], Diana Mariana COCÂRŢĂ[2], Adrian BADEA[3]

The present work illustrates the main results of long-term field experiment with sewage sludge used on agricultural land, in order to assess the influence of sewage sludge on willow productivity. The productivity level was assessed considering three years after planting. The sewage sludge was from "Sfântu Gheorghe" wastewater treatment plant, Covasna County (non-fermented sewage sludge from the dewatering press). Field experiments led to positive results related to the solution of spreading sewage sludge on land used for energy willow plantation. Using a dose of 50 t/ha/month sewage sludge, it was observed an improvement in the amount of harvested energy willow: the productivity increased from 31 t/ha (for the untreated experimental filed plot), to 57 t/h (for the treated experimental filed plot with sewage sludge). In this way, it was demonstrated that a dose of 50 t/ha/month non-fermented sewage sludge used on land is ensuring an important energy willow crop productivity of about 84%.

Keywords: sewage sludge, willow, productivity, heavy metals

1. Introduction

Alternative sources of energy have gained and will gain in the next future importance in the framework of the energy systems worldwide. This is sustained by the promoted politics and the research efforts that are involved in their development, but also by the rising energy prices obtained through traditional methods.

Alternative energy sources have the advantages of the perennially and negligible impact on the environment without emitting greenhouse gases. Primary energy sources are those from the natural environment and can be divided in two main categories: non-renewable or renewable. By renewable energy means energy derived from a wide range of resources, all with the ability to renew, such as:

[1] PhD student, Faculty of Power Engineering, Department of Energy Production and Use, University POLITEHNICA of Bucharest, Romania, e-mail: subtirelu.ruxandu.viorica@gmail.com

[2] Lecturer, Faculty of Power Engineering, Department of Energy Production and Use, University POLITEHNICA of Bucharest, Romania, e-mail: dmcocarta@gmail.com

[3] Professor, Faculty of Power Engineering, Department of Energy Production and Use, University POLITEHNICA of Bucharest, Academy of Romanian Scientists, e-mail: adrian.badea@energ.pub.ro

solar, wind, hydraulic, geothermal and biomass (household waste, municipal, industrial and agriculture).

At the European Union level, the use of renewable energy is being prioritized nowadays, in order to avoid greenhouse gas emissions and to increase energy independence. Current researches have shown that the short rotation of energy forestry, i.e. the production of fast growing tree species, is a real alternative for the production of energy. With this aim, sewage sludge has been increasingly used as a fertilizer. A recent study developed in Lithuania illustrated that sewage sludge application does not pose toxicity to willows (*Salix viminalis*) growth [1]. The same results have been obtained in Hungary, but scientists there have emphasized the importance of choosing the most suitable variety of willow for the area that is fertilized [2]. Higher wood yield was reported also after the soil treatment with sludge, in Estonia, where the willow was cultivated [3]. In the US, sewage sludge fertilizer for willows has been recommended since 2005. However, the full potential of this alternative energy production has not yet been achieved due to economic restraints [4].

The present work is illustrating the main results of long-term field experiment with sewage sludge used on agricultural land in order to assess the influence of sewage sludge on productivity of energy willow.

2. Experimental research

2.1. Sewage sludge characterization data

Land application of raw or treated sewage sludge can cause soil contamination with negative influence and risks on human health [5] [6] [7]. Even that are existing different approaches for assessing human health risks from contaminated soils [5] [6] and various methods for contaminated soil remediation [8] [9] [10] [11], the best measure is prevention of land pollution. For these reasons the use of sewage sludge in agriculture is covered by national and international regulation. The European Directive with concern to using the sludge from wastewater treatment plants in agriculture is the Directive 86/278/CCE [12]. This directive was transposed by Romania through the MO no. 344/08/2004 [13]. Besides other important characteristics related to soil and sludge characteristics to be taken into account when sludge is used in agriculture, the MO 344/08/2004 specifies also the maximum admissible concentrations (MAC) in sludge for different contaminants of concern when land is used for food purposes. According to the regulation in force, sludge from wastewater treatment plants may be utilized in soils whose reaction is higher than pH 6,5 and the level of heavy metals contained in the sludge does not exceed levels defined by the Romanian Ministry of Environment, Waters and Forests [13].

The content of heavy metals and nutrients in sewage sludge was analyzed in a certified laboratory (National Research and Development Institute for Industrial Ecology: INCD ECOIND Bucharest) before of being used in the experimental field (Table 1 and Table 2). Although the use of sludge in energy willow cultivation is not directly regulated by the Romanian legislation, a maximum content of pollutants in sludge similar to that available for use in agriculture was considered. Results of the analyses confirmed that the heavy metals content of sludge was substantially lower than the limits established for wastewater sludge allowed for use in agriculture. These results indicated the possibility to use the investigated sewage sludge in agriculture according to the national regulation.

Table 1

Sewage sludge characteristics

Parameters	M.U.	Value measured
N_{tot}	%	7,73
P_{tot}	$mg/kg_{s.u.}$	5401
K	$mg/kg_{s.u.}$	5143
pH	-	7,47

Table 2

Chemicals content in sewage sludge

Chemical indicators	M.U.	Concentration level	Maximum admissible concentrations according to MO 344/708/2008
Cadmium	mg/kg d.w.	0,75	10
Lead	mg/kg d.w.	37,2	300

2.2. Soil characterization data

The main physicochemical characteristics of native soil are presented in the Table 3. In the present work, the quality indicators tracked in laboratory experiments mainly focused on the content of heavy metals (lead and cadmium), first considering the Ministry Order 756/1997 [14] and after taking into accounts the Ministry Order no. 344/2004 [13]; other investigated parameters were pH, humus, phosphorus, potassium and nitrogen.

'Sensitive use' of the land is represented by their use residential and leisure areas, for agricultural purposes, as protected areas or areas with sanitary regime restrictions, and land surfaces provided for such use in the future [14].

The obtained results showed that Pb and Cd concentrations in soil not exceed the limit values according the Ministry Order no. 344/08/2004 [13] being almost six times lower than the admissible limit for Pb and about four times lower in case of Cd.

Table 3

Soil characteristics from the experimental field

Parameters	M.U.	Value measured
pH	-	6,56
Humus	%	2,72
CEC*	m^3/100g	11,7
Vah**	%	67,8
P-Alc	ppm	30,25
K-Al	ppm	212
Ammonia nitrogen	mg/100g sol	3,436

*CEC - cation exchange capacity
**Vah - degree of base saturation

Table 4

Soil chemical indicators and admissible concentrations

Chemical indicators	M.U.	Value measured	Alert thresholds Sensitive use* MO 756/1997	Intervention thresholds Sensitive use MO 756/1997	Maximum admissible concentrations according to MO 344/708/2008
Cadmium	mg/kg d.w.	0,53	3	5	3
Lead	mg/kg d.w.	7,97	50	100	50

2.3. Climate data

The length of vegetative period (VP) is approximately 6 months usually extending from late April (month) to October (month). Climate data characterizing the study area are presented in Table 5 .

Table 5

Climate data of the region under study in 2011–2013

Year	Average temperature of VP [°C]	Total Precipitation [mm]	Total Precipitation of VP [mm]
2011	7,5	444,3	325
2012	7,6	573,9	410
2013	8,5	486,2	387

The source of the data is from Regional Meteorological Centre *Sibiu Transilvania Sud*.

2.4. Willow for energy

With the concern of humanity to find new energy sources the scientific research was directed towards different of unconventional energy sources, as crops that are reproducing annually and represent a safe energy source. Energy sources that have been exploited and were achieved remarkable results are diverse as solar, wind, heat pumps and biomass. In agriculture, a variety of plants were comprised the list of those known as "energetic plants" as: colza, power grass and different species as acacia, poplar and willow. The most outstanding results have been achieved with regard to the use of willow for producing energy. If the remaining forest plants need 3-5 years until they can be harvested and used for energy purposes, willow can be harvested annually, with a volume of timber 40-60 t / ha dry. The willow cultivated varieties registered for this purpose is considerable and have the following main characteristics: a huge increase in volume - up 3 – 3,5 cm / day, there are waterproof and resistant to various diseases, have a high calorific value (approx. 4900 kcal / kg) [15].

2.5. Experimental field

In order to evaluate the influence of sewage sludge on productivity of energy willow, a long-term field experiment with sewage sludge used on agricultural land was achieved. Therefore, a practice-oriented experiment design was chosen and energy willow (*Salix viminalis* “energo”) specie was arranged in a Latin rectangle with two repetitions as illustrated in Fig. 1. For the first experimental filed plot (500 m^2), 2,5 t/month of sewage sludge were used, while for the second one (500 m^2), no fertilizer was applied. The fertilizer used in the experimental field is non-fermented sewage sludge from the dewatering press with 98% water content. The fertilizer was applied on the second plot once every three days from April to October. For both experimental filed plots (1.000 m^2), a number of 2.500 seedlings were planted. The distance between the planted seedlings was equal with 1,5 m.

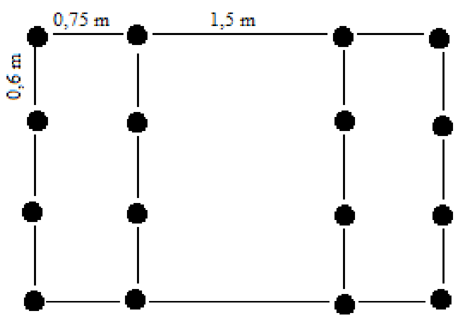

Fig. 1 Design of the experiment

For the establishment of the sewage sludge influence on soil characteristics, soil chemical characterization was completed. Specifically results are detailed in the next paragraph.

3. Results and discussion

The experimental work from the present study provides important evidence concerning the influence of sludge-fertilized treatments on energy willow productivity, but also on soil quality. Tables 6 and 7 illustrates soil characteristics and the soil chemical indicators after that the fertilizer was applied.

Table 6

Soil characteristics after that the sewage sludge was applied

Parameters	M.U.	Value measured
pH	-	5,85
Humus	%	2,71
CEC*	m^3/100g	11,7
Vah**	%	67,5
P-Alc	ppm	47,38
K-Al	ppm	287
Ammonia nitrogen	mg/100g sol	6,31

Table 7

Soil chemical indicators of soil after fertilization and admissible concentrations

Chemical indicators	M.U.	Measured concentration in soil	Alert thresholds Sensitive use MO 756/1997	Intervention thresholds Sensitive use MO 756/1997	Maximum admissible concentrations according to MO 344/708/2008
Cadmium	mg/kg d.w.	0,93	3	5	3
Lead	mg/kg d.w.	16,3	50	100	50

From the obtained results evidenced that the application of the sewage sludge as fertilizer had almost doubled the content of Cd and Pb in soil. If the initial concentrations of Cd and Pb in soil were 0,53 mg/kg$_{d.w.}$ and 7,97, respectively, (Table 4), the new concentrations of Cd and Pb after soil fertilization were 0,93 mg/kg$_{d.w.}$ and 16,3 mg/kg$_{d.w.}$, correspondingly. Even if these results did not reveale exceeding of the regulated thresholds, the new concentrations of Cd and

Pb in soil indicate that a particular attention must be paid to heavy metals concentration in soil after soil fertilization with sewage sludge because of their high degree of toxicity.

In order to present the obtained results, the used sewage sludge dose was extrapolated from initial dose applied on a surface of 500 m^2 (the first experimental field plot) to 1 ha as following: from 2,5 t/month for 500 m^2 to 50 t/ha/month. According to the scenarios taken into account, figures below are illustrating the main results gained in the framework of study. Figs. 2 - 5 are presenting the heavy metals (Cd and Pb), phosphorus (P) and potassium (K) concentration levels according to the doses of sewage sludge applied on soil.

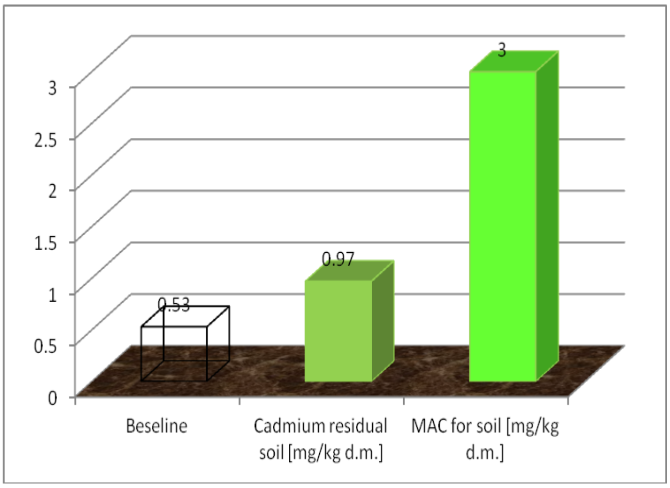

Fig. 2 Cd concentration level in soil before and after sludge-fertilized treatment

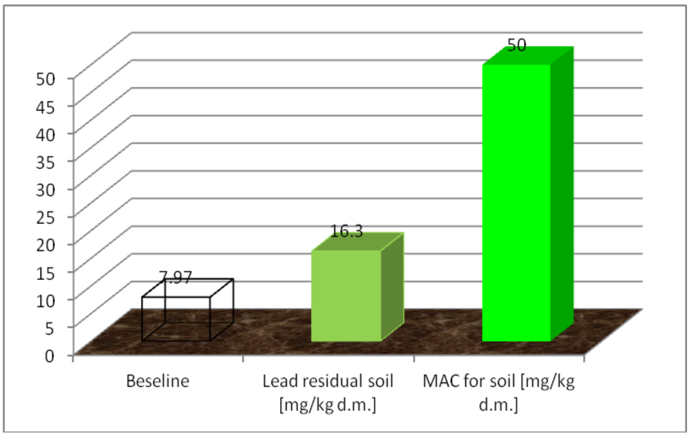

Fig. 3 Pb concentration level in soil before and after sludge-fertilized treatment

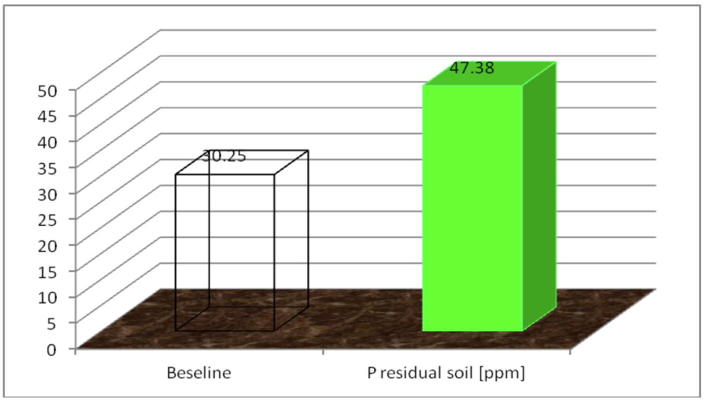

Fig. 4 P concentration level in soil before and after sludge-fertilized treatment

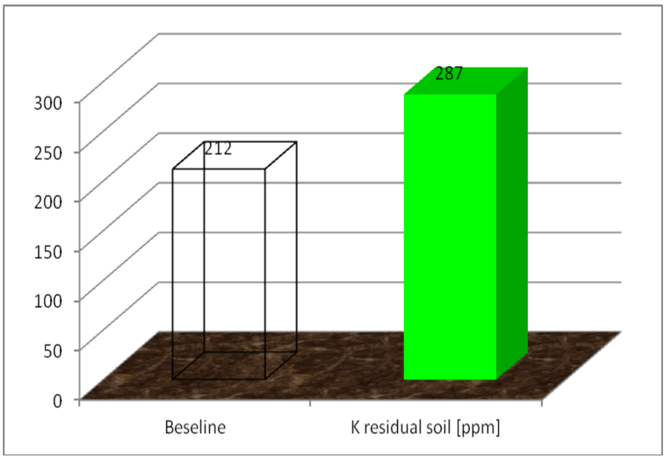

Fig. 5 K concentration level in soil before and after sludge-fertilized treatment

Another important issue in the present research study was to assess the influence of sewage sludge on productivity of energy willow. The study provides important evidence concerning the influence of sludge-fertilized treatments on energy willow productivity. From the results presented in Fig. 6 it can be observed that dose of 50 t/ha/month sewage sludge used is ensuring important energy willow productivity.

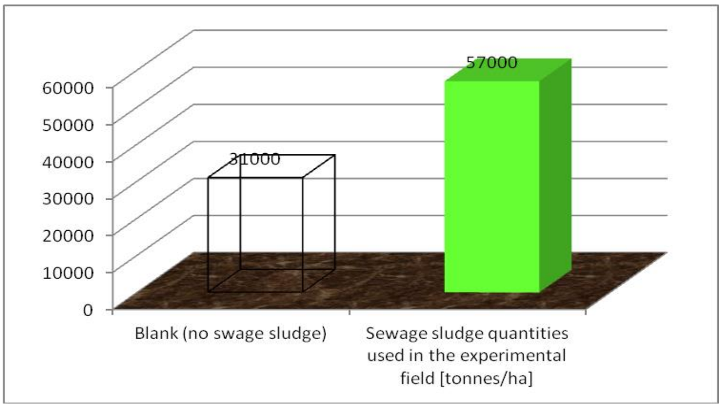

Fig. 6 The influence of sludge-fertilized treatments on energy willow productivity

4. Conclusions

Results from the present research study demonstrate how the sludge application to the soil is effective in improving crop productivity as it happened in case of energy willow. It was showed how for a certain amount of sewage sludge on land (50 t/ha/month), the energy willow production significantly increased in sludge-fertilized treatments as compared to the case in which no fertilizer was used. In the same time, it was showed that the concentration level of Pb in soil (after that the sewage sludge was applied on land) did not overcome the maximum values stipulated by the national regulation even that concentration of Pb in soil increased according to the quantity of sewage sludge applied. These results indicated the possibility to use the investigated sewage sludge in energy willow cultivation according to the national regulation.

The obtained results could be used in order to define criteria for a proper management of sewage sludge and to enlarge recycling of composted residuals on land. Not least, by preventing contamination, the soil quality is protected and, by default, the population health.

Acknowledgements

This work was partially supported under the PNII-RU-TE2014-4-2348/REMPET project, ctr. no 354/01.10.2015, SOP IEC POSCCE-A2-O2.1.2.-2009-2, RECOLAND ID519, SMIS-CSNR: 11982, ctr. 182/18.06.2010 and by the Erasmus+ Programme, EnvyJobs project, contract no 2015-1-RO01-KA203-015089.

R E F E R E N C E S

[1] *J. Zaltauskaite, S. Judeikyte, G. Sujetoviene, R. Dagiliute,* Sewage sludge application effects to first year willows (*Salix viminalis* L.) growth and heavy metal bioaccumulation, Proceedings of the 14th International Conference on Environmental Science and Technology Rhodes, Greece, 3-5 September 2015.

[2] *G. P. Kovács, L. Alexa, I. Balla, P. Póti, C.S. Gyuricza,* Biomass production of energy willow under unfavourable field conditions, Applied Ecology and Environmental Research 12(1): 1-11., ISSN 1589 1623 (Print), ISSN 1785 0037 (Online) © 2014, ALÖKI Kft., Budapest, Hungary.
[3] *B. Holm, H. Katrin*, Influence of composted sewage sludge on the wood yield of willow short rotation coppice. An Estonian case study, Environment Protection Engineering Vol. 39 2013 No. 1 DOI: 10.5277/EPE130102.
[4] *G. A. Keoleian, T. A. Volk*, Renewable Energy from Willow Biomass Crops: Life Cycle Energy, Environmental and Economic Performance, Critical Reviews in Plant Sciences, 24:385–406, 2005 Copyright c Taylor & Francis Inc. ISSN: 0735-2689 print / 1549-7836 online DOI: 10.1080/07352680500316334.
[5] *D. M. Cocârţă, S. Neamţu, A. M. Reşetar Deac*, Carcinogenic risk evaluation for human health risk assessment from soils contaminated with heavy metals, International Journal of Environmental Science and Technology, Springer, ISSN: 1735-1472 (print version), ISSN: 1735-2630 (electronic version), DOI 10.1007/s13762-016-1031-2, 03 June 2016.
[6] *M. A. Stoian, D. M. Cocârţă, A. Badea*, Assessment of carcinogenic risk from soil pollution based on policyclyc aromatic hydrocarbons, 16th International Multidisciplinary Scientific GeoConference SGEM 2016, November 2nd–5th, 2016, SGEM Vienna GREEN 2016, Austria.
[7] *R. I. Moraru, G. B.Babut, L. I. Cioca*, Rationale and criteria development for risk assessment tool selection in work environments, Environmental Engineering And Management Journal, Vol. 13, Issue: 6, 2014, pp 1371-1376.
[8] *C. Bulmău, S. Neamțu, D. M. Cocârţă, I. Istrate, A. Badea*, Efficiency of PAHs removal from soils contaminated with petroleum products using ex-situ thermal treatments, Rev. Chim. (Bucharest), 64, pp. 1430 - 1435, no. 12, decembrie 2013 (6 pagini), ISSN 0034-7752.
[9] *I. Istrate, D. M. Cocârţă, S. Neamţu, T. Cîrlioru*, The assessment of an alternative treatment for PCB polluted soils in the romanian context - bench scale tests, Water air and soil pollution, vol 224 (4), DOI: 10.1007/s11270-013-1516-2, ISSN: 0049-6979 (print version), ISSN: 1573-2932 (electronic version), Aprilie 2013, (14 pagini).
[10] *A. Lăcătuşu, D. M. Cocârţă, R. Lăcătuşu*, Ex-situ bioremediation efficiency in removing organic and inorganic compounds from artificially and anthropogenic contaminated soil, Carpathian Journal of Earth and Environmental Sciences, Volume 8, 2013, No. 1, Feb. 2013, p. 59-70, (13 pagini), ISSN Printed: 1842 – 4090, ISSN Online: 1844 - 489X.
[11] *D. M. Cocârţă, D. M. Dumitru, A. R. Lăcătuşu, A. Badea*, Evaluation of bioremediation efficiency in crude-oil contaminated soils, 16th International Multidisciplinary Scientific GeoConference SGEM 2016, 2 - 5 November 2016, SGEM Vienna GREEN 2016, Austria.
[12] *Directive 86/278/CCE*. (Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture).
[13] *Ordin Nr. 344/708* - din 16 august 2004 pentru aprobarea Normelor tehnice privind protecţia mediului şi în special a solurilor, cand se utilizează nămolurile de epurare în agricultură. (Act issued by the Ministry of Environment and Water).
[14] *Ordin Nr. 756 din 3 noiembrie 1997 pentru aprobarea Reglementării privind evaluarea poluării mediului* (Ministry Order No. 756 from November 3, 1997 for approval of Regulation concerning environmental pollution assessment, published in Official Monitor No. 303/6 November 1997).
[15] *O. M. Murg, S. C. Martin, I. Abraham, T. Mateoc*, The energetic willow solution for agriculture, energy and environment, Lucrări Ştiinţifice, Seria I, Vol. XIV (1), Facultatea de Management Agricol.