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EFFECTIVENESS OF THE USE OF WILLOW TREE (*SALIX VIMINALIS*) FOR WASTEWATER TREATMENT****

1. Introduction

A great number of papers concerning environmental pollution by ultra-trace elements has been published. Accumulation of ultra-trace elements in the soil is a result, apart from natural processes occurring in the soil, of industrial emissions, road transport, and, to a lesser extent, mineral fertilisation, and agricultural chemicals [1, 2].

Wastewater, sewage and sludge may pose a potential source of environmental pollution, due to contamination with high concentration of trace elements and other toxic substances, and bacteria and parasites; on the other hand, however, they make a valuable source of micro- and macro-elements, and a large amount of organic materials. They may increase crop productivity in case of green crops and some fodder crops, root plants, and industrial plants as well as cultivation of trees and bushes [3].

One of the most important criteria for the use of sludge in agriculture, is the content of heavy metals. According to literature data, the contents of trace-elements in the sludge vary greatly. For instance, the concentration of Cd is 0.5–2500 $mg \cdot kg^{-1}$, Pb 7–7627 $mg \cdot kg^{-1}$, Cu 12–8000 $mg \cdot kg^{-1}$ and Zn 180–96 000 $mg \cdot kg^{-1}$ [4–6].

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In order to use the sludge in agriculture, the content of trace elements must meet the criteria, and therefore, there is a need to develop a method to decrease the concentration of selected elements and allowing utilisation of the sludge.

One of the biological methods employed is planting willow trees (*Salix*), which are especially useful due to 1) fast biomass increase, particularly after irrigation with sewage from sewage treatment plant, 2) high tolerance to pollution with heavy metals, and 3) their ability to accumulate large amounts of heavy metals in their organs.

2. Materials and Methods

2.1. Willow and sludge residue

Willows of a species *Salix viminalis var. Rapp* were used for experiments. The material were cuttings of the mentioned species of the length of about 25 cm.

The extraction of elements of the sludge samples and plants was done by the mixture of two acids ($HClO_4$ and HNO_3), and then the content of Na, Mg, K, Ca, Cu, Zn, Sr, Cd, Pb was determined by the method of atomic absorption spectrophotometry (spectrophotometer of atomic absorption, model Hitachi 8200 with Zeeman polarisation).

The samples of sewage sludge were analysed according to standard procedures. The following was determined in the samples:

- pH in H_2O and KCl by potentiometric method;
- proper conductivity by conductometry method in the relation — ground: water, 1:5;
- the content of organic substance through calcination;
- the content of organic carbon Tiurin's method;
- the content of total nitrogen by Kjedahl's method;
- the content of total sulphur by Butters-Chenery's method;
- the content of phosphorus was determined by vanadium-mollibdenate method.

2.2. Experiments, the analysis of plant material

The cuttings were grown on a sewage settlement pond of a surface of 50 m^2. They were grown every 30 cm in rows and the distance between rows was 40 cm, (it resulted in 83 300 cuttings per 1 ha) at the beginning of April.

The experiments were made for one year (stage I.). Willows, during their vegetation period (April — September) were temporary partially flooded with the sewage sludge after biological stabilisation. In this period 100 m^3 of wet sludge was supplied in total, which gives 400 kg of the dry mass of residue, i.e. 80 $t \cdot ha^{-1}$. Estimated into pure fertiliser compound, annually (during the vegetation period) about 1260 kg nitrogen, 1240 kg phosphorus and about 320 kg potassium were provided.

The determinations of the contents of selected elements in different organs of willows were made on one-year old material (leaves, stems). The measurements of stem lengths were made at the end of vegetation period (late September). Parallelly the leafs and stems were collected from experimental fields and the growth of biomass was measured. The length of stems was measured with the accuracy of 1 cm. The weight of the dry mass of leaves and stems was established by weighing them on a laboratory balance with the accuracy up to 1 mg.

3. Results

3.1. Physical and chemical properties of the sewage sludge

The raw sludge from the settlement pond was characterised by pH values ranging from neutral (pH = 6.6) to alkaline (pH = 8.3). The contents of nitrogen, phosphorus, sulphur, carbon and organic substance is presented in Table 1, and Na, K, Ca, Mg in Table 2. The contents of nitrogen, phosphorus, carbon, K, Ca, Mg do not exceed those encountered in sewage sludge in Poland.

TABLE 1

Basic physical and chemical properties of sewage sludge

pH		Proper Conductivity (mS/cm)	Organic Substance	C organic	N total	S total	P total
H_2O	KCl		[mg · kg^{-1}] (mean values)				
6,6–8,3	6,4–7,9	0,20–0,98	460 000	162 637	15 790	16 330	15 550

3.2. The content of elements in sewage sludge

Raw wet sludge from the settlement pond was characterised by the content of Pb (56.10 mg · kg^{-1}), Cd (1.94 mg · kg^{-1}), Zn (1275 mg · kg^{-1}) and Cu (55.25 mg · kg^{-1}) Table 2.

The content Pb, Zn, Cu was within lower values encountered in the sludge from the sewage treatment stations in Poland (Pb 58–2970 mg · kg^{-1}, Zn 1150–2800 mg · kg^{-1}, Cu 14–1250 mg · kg^{-1}), only the content of Cd was four times lower than the lowest values found in the sludges from municipal sewage treatment stations in Poland (8–562 mg · kg^{-1}) [13–15].

TABLE 2

The content of selected elements in the sewage sludge (average values in mg · kg^{-1})

Na	K	Mg	Ca	Cu	Zn	Sr	Cd	Pb
345,0	4016	4300	42573	55,3	1275	11,8	1,94	56,1

3.3. Biomass of leaves and stems of willows and the content of elements per mass unit of respective organs

Distinct growth of stems was noticed, the average length of which (calculated per stem) was 209 cm (minimum was 101 cm, maximum 297 cm). Dry leaf mass was 8.12 g (value calculated per one plant), and the dry mass of stems was 97.89 g (average value per plant).

The content of examined elements per mass unit of the organs of willows collected at the end of vegetation period (September) is shown in Table 3.

TABLE 3
The content of elements (mg · kg^{-1}) in the organs of willows

	Na	Mg	K	Ca	P	N
Leaves – mean	1347,5	2172,5	16513	24075	4838	22063
Standard dev.	142,21	104,04	554,34	850,00	159,2	1682,9
Minimum	1200	2090	15950	23200	4700	20440
Maximum	1530	2320	17200	24900	5060	23800
Stems – mean	393,75	855,00	3742,5	4390	1675	3953
Standard dev.	38,90	55,68	196,02	234,09	71,41	176,16
Minimum	352	800	3520	4040	1600	3750
Maximum	446	930	3940	4520	1770	4060
	Cu	**Zn**	**Cd**	**Pb**	**Sr**	
Leaves – mean	5,70	157,9	0,23	1,53	12,45	
Standard dev.	0,54	17,55	0,05	0,29	0,12	
Minimum	5,0	139,5	0,15	1,20	11,50	
Maximum	6,30	177,0	0,25	1,90	14,20	
Stems – mean	4,825	77,25	1,08	0,60	4,90	
Standard dev.	0,70	6,61	0,17	0,29	0,32	
Minimum	3,80	72,50	0,90	0,30	4,70	
Maximum	5,40	87,0	1,30	0,90	5,40	

The content of biogens (N, P, K, Ca) was usually several times higher in leaves than in stems, only the content of K in leaves was about 2.5 times lower than in stems. Assessing the usefulness of willows in the utilisation of sewage sludge on should use the bioaccumulation (phytoassimilation) index of elements in respective organs of willows. The index is expressed as the proportion of mean concentration of a given element in those organs to their concentration in w sewage sludge. Following the authors quoted above four step scale of elements accumulation was accepted (see Table 4). The degree of the bioaccumulation of Cu, Zn, Cd, Pb and Sr in leaves and stems of willows is presented in Table 5.

TABLE 4
Phytoaccumulation index of trace elements in the plants calculated as the ratio of elements in plants and their content in soils

Bioaccumulation index	The degree of accumulation
0,001—0,01	none
0,01—0,1	weak
0,1—1,0	medium
1,0—10,0	intensive

TABLE 5
Bioaccumulation indexes of trace elements in the in the organs of willow *Salix viminalis var. Rapp* (the value of the accumulation index was calculated from the content of elements in leaves and stems to their concentration in sewage sludge

	Cu	Zn	Cd	Pb	Sr
Leaves	0,10	0,12	0,12	0,03	1,06
Bioaccumulation index	medium	medium	medium	weak	intensive
Stems	0,09	0,06	0,56	0,01	0,11
Bioaccumulation index	weak	weak	medium	weak	medium

The analyses of leaves for the content of Cu, Zn, Cd showed their medium index of accumulation, weak accumulation of Pb and intensive of Sr. In the stems, the bioaccumulation index of Cu, Zn, Pb was weak, and for Cd and Sr reached medium level.

4. Discussion

The experiments with growing *Salix viminalis var. Rapp*, in the settlement pond of the mechanical and biologicznej sewage treatment station, showed, among other aspects, significant growth of plants. It was defined by assessing the biomass growth of one year old plants (based on the dry mass of leaves and stems) and the length of their stems. It was stated (by comparing with literature data) that maximum length of stems is much greater than maximum length of stems of the same variety of willow after fertilising experimental fields with sewage containing nitrogen, phosphorus and potassium accepted (based on experiments carried out) optimal for the growth of this variety. Higher growth was noticed in case when mean lengths of the stems and the growth of their biomass of the plants from the pond were compared with those from the pot cultures, where fertilising with sewage sludge was done once then after its stabilisation to the granulation product.

The degree of the accumulation of copper, zinc, cadmium, lead and strontium in the surface organs of willow *Salix viminalis var. Rapp* was examined at the end of their vegetation period (September). The degree of the bioaccumulation in the leaves for Cu and Zn was medium, but it indicated weak accumulation in stem.

The content of Zn changes in willow organs during the vegetation period. In the first period (growth) the content of Zn is much higher in stems than in leaves and only at the end of the vegetation period these relations change.

Similar (as in case of Zn) tendencies could be noticed in the ratio of Cu accumulation in respective organs of willows. Based on the results given in this paper and the experiments with the hydroponics of *Salix viminalis* (in laboratory conditions) on water eluate from post-flotation heaps of the Mining and Metallurgy Plant of Zinc and Lead Ores. From the experience of other authors on willow *Salix viminalis*, with the use of sewage sludge, reverse relationship for Cu can be seen. They found higher content of this element in stems than leaves. The index of Cd accumulation in leaves and stems, although medium in both, was slightly higher in stems — see Table 5. From some literature data it results that Cd is accumulated in higher amounts in stems than in leaves from other that in leaves is higher.

Lead accumulation both in stems and in leaves reached low values, which complies to the numerous data from literature, showing that the main place of the accumulation of lead are roots.

Highs assimilation of biogens i.e. compounds of nitrogen and phosphorus and the accumulation of heavy metals in the organs of willows, mainly their roots was found. The accumulation of elements in roots draws to their immobilisation in the area, while the transport of these elements to surface organs can be used when the surface organs are cut just after the fall of leaves. The surface organs can be used as energy resource, and their systematic removal from the contaminated area can draw into the elimination of harmful elements from the environment. This provides new premises for the development of environmental biotechnology on national or even international scale, and yet has important meaning both from the point of view of the limitation of phytotoxic effects as well as ecotoxicological threats.

REFERENCES

[1] *Borkowska H, Jackowska I, Piotrkowski J., Styk B.*: Wstępna ocena przydatności kilku gatunków roślin wieloletnich do rekultywacji osadów pościekowych. Zesz. Probl. Post. Nauk Rol., z 434, p. 927–930, 1996.

[2] *Dickinson N.M., Punshon T., Hodkinson R.B., Lepp N.W.*: Metal tolerance and accumulation in willows, Willow vegetation filters for municipal wastewaters and sludges. A biological purification system. Proceedings of a study tour, conference and workshop in Sweden, 5–10 June 1994.

[3] *Michałowski M.*: Sludges from Mechanical and Biological Sewage Treatment Plant — Methods of Neutralization and Utilization, Polish Journal of Environmental Studies, vol. 8, p. 280–282 1999.

[4] *Perttu K.*: Biomass Production and Nutrient Removal from Municipal Wastes Using Willow Vegetation Filters. J. Sustainable Forestry, vol. 1(3) 1993.

[5] *Riddell-Black*: Heavy metal uptake by fast growing willow species, Willow vegetation filters for munucipal wastewaters and sludges. A biological purification system. Proceedings of a study tour, conference and workshop in Sweden, 5–10 June 1994.

[6] *Różanowski B.*: Influence of Laser Photostimulation on Changes of Cadmium and Lead Content in Organs of Willow *Salix viminalis*, Polish Journal of Environmental Studies, vol. 8, Supl. II, 186–188, 1999.

[7] *Różanowski B., Michałowski M., Kosturkiewicz B.*: Evaluation of the content of selected heavy metals in organs of willow tree (*Salix viminalis*}) as a measure of its potential use for biological sewage sludge utilization. W: Czysta energia, czyste środowisko 2008, ISBN 978-83-88316-83-8. p. 325–332.

[8] *Pulford I.D., Watson C.*: Phytoremediation of heavy metal-contaminated land by treesa review, Environment International 29 (2003) 529–540.