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SEWAGE SLUDGE LAND DISPOSAL EFFECTS ON GROUNDWATER

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Abstract: Three year, lysimetric research on the influence of land application of sewage sludge on the ground water quality was done. Three plant species were tested as possible ways of sewage sludge application: grass – for restoration of contaminated soils; corn – for feeding staff production, and willow – for energy production from biomass. As control, plantless lysimeters were used. The following sewage sludge doses were applied: 0, 10, 50, 50, 110, 225, and 450 Mg d.m./ha. Significant ($p < 0.05$), linear correlations between the increase in the sewage sludge dose and EC, COD_{Cr} and NO_3 content in the ground waters indicate a potential risk of contaminating ground waters during the land application of sewage sludge, particularly with high doses exceeding 50 Mg d.m./ha. These correlations and risks of ground water contamination were observed during all three years of experiment for indicators such as EC and COD_{Cr}. In the case of nitrates the risk of their migration was detected only in the first year after sewage sludge application. Additionally, the very low level of heavy metals and pathogens in ground water was determined. The applied plants did not reduce the negative effect of the increasing doses of the sewage sludge on the ground waters quality.

INTRODUCTION

Landfilling and incineration are identified as potential options for the disposal of sewage sludge. Disposal of sewage sludge by landfilling is a feasible option currently practiced in many parts of the world. However, in Europe, due to the limitations imposed on biodegradable waste disposal [6], landfilling is no longer a favored option for sewage sludge disposal.

Incineration can effectively reduce the volume of waste and sterilize the end product. About 10–30% of initial weight of dry solids will remain as ash depending on the characteristic of the sludge. Incineration not only requires a high capital and operation cost but also intensive energy demands. Besides, the possibility of generation of odor and air pollutants and the disposal of toxic ash would also cause a potential environmental hazard [8]. Both these disposal strategies will cause potential environmental problems that affect the people's health as well as the environment. Land application has become another attractive option to be considered for sludge treatment and disposal. It is not only to treat the waste but also to reutilize the residual resource in the sludge for the waste authority. Sewage sludge has been utilized in agriculture for many years. It is represents a good source of nutrients such as N and P for plant growth [21]. Besides, sludge has a large amount of organic matter that can improve soil physical properties such as aeration and water holding capacity [12]. Sewage sludge is also a good fertilizer, with properties similar to manure [19]. The BIOPROS Project [3], part of 6 Framework Programme, promotes usage of sewage sludge as a fertilizer for Short Rotation Plantation (SRP) of fast growing plants (willow, poplar) and energy reuse. However, there are problems associated with land application of sludge, including odors and esthetics, potential pathogens in sludge, suitable site and soil, and sludge quality [11, 17]. The environmental and hygienic effects of land application of sewage sludge have been under extensive research. Sewage sludge contains macro- and micronutrients beneficial to plants, but also a series of hazardous compounds such as heavy metals, organic compounds, and nutrients in excess or pathogenic organisms. Duarte-Davidson and Jones [7] have provided a list of 300 organic compounds detectable in sewage sludge, whose concentrations may range from pg/kg to g/kg.

However, applying sewage sludge to agricultural areas may pose threats mainly for the environment in terms of groundwater pollution (nitrate, P, organic compounds, and pathogens) and soil pollution (heavy metals and persistent organic compounds, pharmaceuticals, etc.). Regarding the sludge applications to environment and potential leaching involved after such practices, the element that usually is under investigation for leaching is N. Research on N leaching from crops fertilized with sewage sludge has been mainly conducted in the UK, Sweden and Denmark. In order to avoid negative effects on the groundwater and drainage water quality, good monitoring of the nitrate levels is needed, as well as a test research on a small scale before the implementation on a larger scale.

In Poland the procedure for sewage sludge application in the environment is regulated by the Regulations by Polish Minister of the Environment on municipal sewage sludge [14]. According to the Regulations sewage sludge doses should not exceed 250 Mg d.m./ha for the ground surface being fixed with plants. It seems that the doses above might be frequently too high, as they may pose a threat to ground waters. The degree of water pollution depends substantially on the amount of sewage sludge doses as well as the plant lining of the surface [20].

From all mentioned results it was concluded that an important issue related to sewage sludge application into the environment is the possibility of monitoring and controlling the application loads, and to monitor their environmental impact. It is important that, in the first sequence, the pollutants which are the indicators of mineral compounds – electrolytic conductance (EC), organic compounds – chemical oxygen demand (COD) and nutrients - nitrogen (N) leaching, should be monitored, especially regarding the limitation of the nitrate emission into the environment from agriculture sources [5].

The aim of this work was to determine the effect of land application of sewage sludge on ground waters quality while applying various doses of sewage sludge and within a varied plant lining of the surface. The following hypothesis was formulated: an increase in the sewage sludge dose is likely to result in ground waters contamination depending on the type of the plants applied. It was expected that the results of this work would show whether any control of water environment would be required or not during land application of sewage sludge.

RESEARCH MATERIAL AND METHODOLOGY

The experiment was conducted on the laboratory scale using a lysimeter method [1]. The lysimeter of 1 m height, with 0.6 m in diameter and with the volume of 0.28 m^3 was a model of soil profile (soil-plant system). The piezometer made of PCV tubes 5 cm in diameter was put into the lysimeter for ground water sampling, adding and level control. Piezometer was closed from the top and filtered from the bottom on the gravel layer. For temperature compensation inside the lysimeter and in the soil, the lysimeter was dug up. The lysimeter's filling was made up of a 25 cm thick, filtration layer of gravel placed at the bottom, a 35 cm thick layer of sand and a 30 cm-layer of sand and sludge at the top.

The applied sewage sludge was made up of 46.3% of moisture, 76.5% d.m. of organic matter content, 1.66% d.m. of Kjeldahl nitrogen content, 1.07% d.m. of phosphorus content and reaction in 1 N KCl on the level 6.80 pH. The concentration of heavy metals in the sewage sludge (Tab. 1) meets the most restrictive requirements of Polish Standards for sludge agricultural use [14].

Table 1. Heavy metals concentration in the sewage sludge used in the experiment

Heavy metal	Cu	Zn	Cd	Ni	Pb	Cr	Hg
Unit	mg/kg d.m.						
Measured value	199.2	1683	0.06	23	22.9	47.0	3.1
Limit value*	800	2500	10	100	500	500	5

* – according to the Polish Standards for sewage sludge agricultural use [14]

The following doses were used in the experiment: 0, 10, 50, 110, 225, and 450 Mg d.m./ha ($D_0 - D_5$), (according to [14]; the smallest dose 10 Mg d.m./ha being a maximum dose for agricultural fertilization, and the greatest dose 450 Mg s.m./ha (over) twice as great as the maximum dose for recultivation of soils.

The following 4 types of plant lining were used in the experiments:

- a control surface barren of vegetation (R)
- a surface planted with the willow *Salix amigdalina* L. (S),
- a surface planted with the corn *Zea mays* (C),
- a surface planted with the grass *Festuca rubra* (G).

The experiment configuration is shown in Table 2.

Table 2. Experiment configuration

		The sewage sludge dose [Mg d.m./ha]					
		0	10	50	110	225	450
Plant species	*Salix amigdalina* L.	SD_0	SD_1	SD_2	SD_3	SD_4	SD_5
	Zea mays	CD_0	CD_1	CD_2	CD_3	CD_4	CD_5
	Festuca rubra	GD_0	GD_1	GD_2	GD_3	GD_4	GD_5
	reference (without plants)	RD_0	RD_1	RD_2	RD_3	RD_4	RD_5

Each experimental variant was repeated three times. The lysimeters D_0 (without sludge) were used as control lysimeters and compared with the lysimeters $D_1 - D_5$ whose sewage sludge doses were gradually increased. The plantless lysimeter, with a determined sludge dose, was used as a control lysimeter (R) for all the lysimeters with the plants and the identical sewage sludge dose.

The willow cuttings were planted according to [18]. The lysimeters were sown with grass and corn seeds according to the guidelines [10]. The experiments were carried out for three years.

In order to determine the effect of the applied sewage sludge on ground waters, basic pollution indicators such as electrolytic conductance (EC), chemical oxygen demand COD_{Cr}, and NO_3 were examined 5 times each year. The obtained results of ground waters pollutant indicators – EC and nitrates were compared to the values of pollutant indicators used to classify the quality of underground waters, which are binding according to the [16]. The obtained results of nitrates in the ground waters were also compared with the values of nitrates typical of contaminated waters and waters endangered with contamination - according to [15].

At the end of the 3-year-experiment the content of heavy metals such as lead, cadmium, chromium, copper, nickel, mercury and zinc was analyzed; microbiological sanitary indicators were examined such as the amount of *Salmonella sp.* bacteria in the ground waters from the lysimeters with the sewage sludge dose of 450 Mg d.m./ha. The effect of the applied sewage sludge doses on the amount/extent of the ground waters contamination was analyzed at the significance level ($p < 0.05$).

RESULTS AND DISCUSSION

Figures 1–3 show physical and chemical properties (in terms of macro components) of the ground waters from the lysimeters. Table 3 shows the results of heavy metals and bacteria *Salmonella sp.* The analysis below compares the obtained pollutant indicators with the norms for underground waters and other experimental data.

Total amount of mineral compounds (EC) in ground waters

Throughout the experiment electrolytic conductance (EC) of the ground waters in the lysimeters (irrespective of the surface lining) increased substantially ($p < 0.05$) as the sludge doses were increased (Fig. 1). The conductance values in almost all the lysimeters remained at level 1 and 3 according to the underground waters purity/quality class [16]. Only in the 2nd and 3rd year in the lysimeters with the willow, and in the 2nd year in the lysimeters with the grass the water was classified as level 4 with the applied maximum sludge dose. In the plantless lysimeters it was observed that the effect of sludge doses on the ground waters electrolytic conductance values declined over the subsequent years of the experiment, which is confirmed by the following ranges of electrolytic conductance values: from 1.05 (RD_1) to 2.88 (RD_5) mS/cm in the 1st year, from 0.70 (RD_0) to 2.26 (RD_5) mS/cm in the 2nd year and from 0.73 (RD_0) to 1.42 (RD_5) mS/cm in the 3rd year.

In the lysimeters with the plants the course of changes was different than in the control lysimeters throughout the experiment. In the 1st year electrolytic conductance values in the lysimeters with plants were smaller than in the control lysimeters and ranged between 0.83 (CD_0) and 2.43 (CD_5 and SD_4) mS/cm. In the 2nd year the effect of the increasing dose of sewage sludge on the proper electrolytic conductance value of ground waters in the lysimeters with the plants was greater than in the 1st year, and the electrolytic conductance value ranged between 0.77 (CD_0) and 3.29 (SD_5) mS/cm. Whereas in the

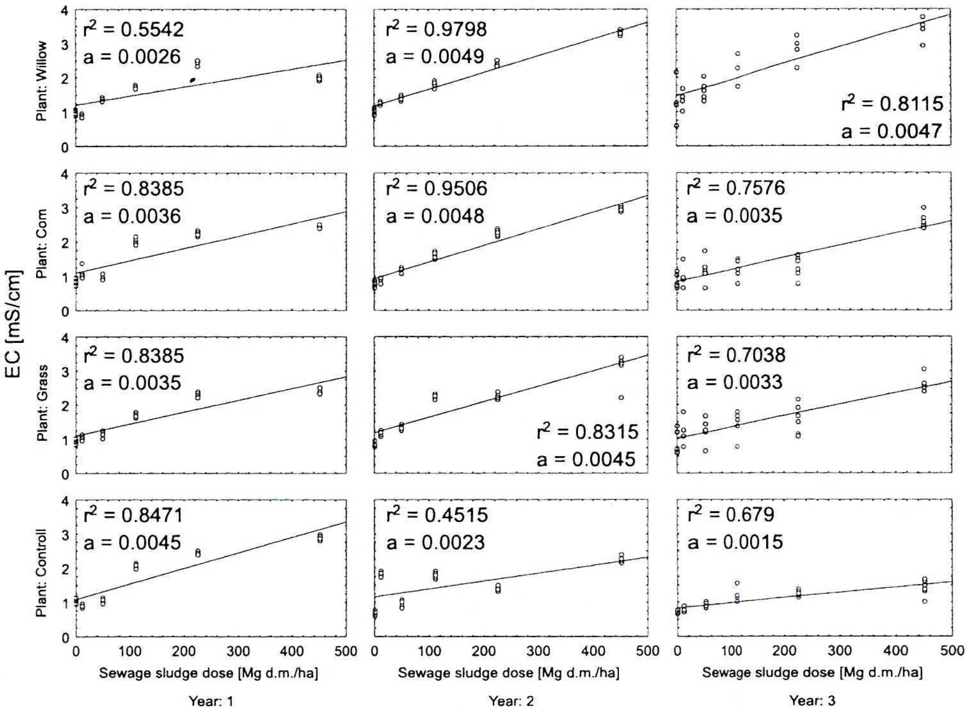

Fig. 1. The effect of the sewage sludge dose ($p < 0.05$) on the underground waters conductance as a function of the plant lining of the surface during the 3 year-experiment prior to the application of sewage sludge to the ground, and with reference to the classification for underground waters quality; according to [16] the limit values of EC concentration for each quality class are as follows: class 1 – 0.4 mS/cm, class 2 and 3 – 2 mS/cm, class 4 – 3 mS/cm, and class 5 > 3 mS/cm, the ground water quality decreases from class 1 (the highest quality) to class 5 (the worst quality), r^2 – determination coefficient, a – linear regression parameter

3rd year the ground waters EC in the lysimeters with the corn and grass slightly declined and ranged from 0.84 (CD_0) to 2.60 (CD_5) mS/cm. In the lysimeters with the willow the electrolytic conductance remained at a similar level as in the 2nd year.

The obtained results show that during the 1st year the plants reduced the release of the pollutants generating electrolytic conductance, whereas in the 2nd year in the lysimeters with the plants the pollutants were released to the ground waters. In the 3rd year the lysimeters with the willow showed no significant change, whereas in the lysimeters with the grass and corn pollutants release declined and was comparable to the results in the 1st year.

The contamination of ground waters with organic compounds

In every year of the experiment, irrespective of the type of the surface lining, the organic matter content COD_{Cr} in ground waters increased significantly ($p < 0.05$) as the sewage sludge dose was increased (Fig. 2) In the control lysimeters it was observed that the influence of the sewage sludge dose on the organic matter content in the ground waters declined subsequently in the course of the experiment, and ranged from 98.0 (RD_0) to 229.8 (RD_5) mg O_2/dm^3 in the 1st year, from 96.7 (RD_0) to 238.5 (RD_5) mg O_2/dm^3 in the

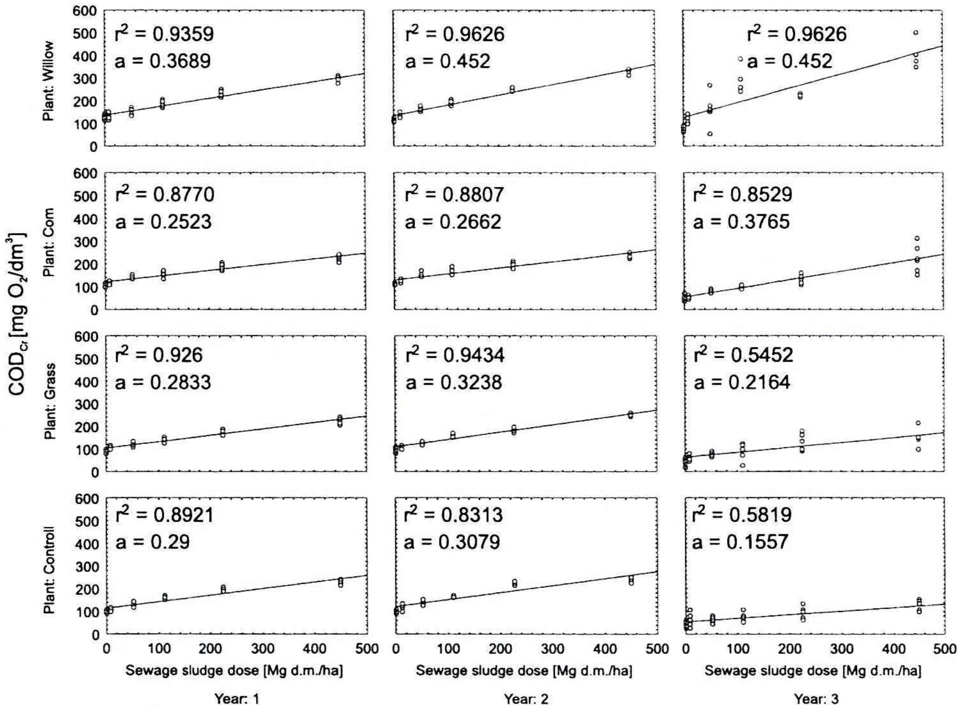

Fig. 2. The influence of the sewage sludge dose ($p < 0.05$) on the COD_{Cr} values in the underground waters as a function of the surface lining type during the 3rd year of the experiment prior to the sewage sludge application to the ground; r^2 – determination coefficient, a – linear regression parameter

2nd year and from 44.8 (RD_0) to 122.6 (RD_5) mg O_2/dm^3 in the 3rd year. A similar tendency was observed in the lysimeters with the grass and corn, in which the COD_{Cr} concentration values declined subsequently ranging from 89.0 (GD_0) to 224.6 (CD_5) mg O_2/dm^3 in the 1st year to reach a range from 43.5 (GD_0) to 224.0 (CD_5) mg O_2/dm^3 in the 3rd year. In the lysimeters with the willow a gradual increase in the organic matter release to the ground waters was observed in the subsequent years of the experiment, which is indicated by higher COD_{Cr} concentrations (exceeding even 400 mg O_2/dm^3 (SD_5) in the 3rd year) in the ground waters in comparison with other types of the lysimeters. Significant ($p < 0.05$) correlations between the increase in the sewage sludge dose and COD_{Cr} content in the ground waters indicate a potential risk of contaminating ground waters with organic matter during the land application of sewage sludge, particularly with high doses exceeding 100 Mg d.m./ha. The lysimeters with the willow as compared to the other types of the surface lining showed the greatest susceptibility to contamination with organic matter, as the contamination values increased over the subsequent years of the experiment. Therefore, it is plausible to expect that ground waters will be contaminated with organic matter while applying sewage sludge to the energetic willow cultivation , especially when the sludge doses are high and exceed 100 Mg d.m./ha. It is important to point to a very high, possible concentration of organic matter in ground water (400 mg O_2/dm^3), as high as in typical wastewater. Concluding, the land disposal of sewage sludge may pose high risk of ground water pollution by many organic compounds like AOX, pharmaceuticals, endocrine disruptors [7].

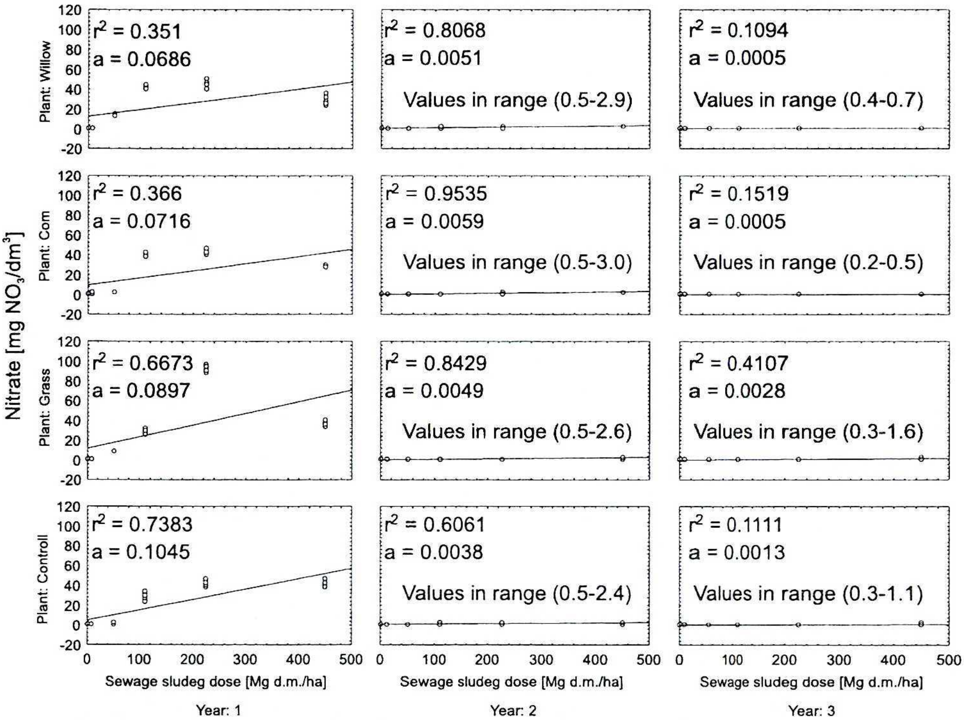

Fig. 3. The influence of the sewage sludge dose ($p < 0.05$) on the nitrates content in underground waters as a function of the surface lining type during the 3 year of the experiment prior to the sewage sludge application to the ground; according to [16] the limits values of nitrates concentration for each quality class are as follows: class 1 – 10 mg NO_3/dm^3, class 2 – 25 mg NO_3/dm^3, class 3 – 50 mg NO_3/dm^3, class 4 – 100 mg NO_3/dm^3, and class 5 > 100 mg NO_3/dm^3; the ground water quality decreases from class 1 (the highest quality) to class 5 (the worst quality), r^2 – determination coefficient, a – linear regression parameter

The contamination of ground waters with nitrates

During the 1st year in each experimental variant, a significant ($p < 0.05$) positive influence of the sewage sludge dose on nitrates concentrations in the ground waters was observed (Fig. 3) unlike in the 2nd and 3rd year. The fact that ground waters contained nitrates in the 1st year, with sewage sludge doses exceeding 50 Mg d.m./ha and their concentrations ranging between 3 and about 45 mg/dm^3 may indicate that nitrates generated as a result of nitrification were not totally absorbed by the plants, and their excess was released to the ground waters. While applying the sludge doses between 0 and 10 Mg d.m./ha, similar, very low (below 3 mg/dm^3) nitrates concentrations were observed in ground waters of the lysimeters with and without the plants. Such analogous results may indicate that the plants did not affect nitrates removal. Nitrogen leaching from the soil depends on numerous factors such as: granulometric composition of the soil, precipitation, fertilization, the plant cover of the soil, a chemical form of nitrogen, and colloid content in the soil [13]. Hemond and Fechner [9] claim that nitrates are not absorbed by the soil sorption complex, thus the migration speed of nitrogen in this form is limited only by water filtration speed. For these reasons in the present experiment it was expected to achieve high concentrations of nitrates which migrate relatively easily within the soil profile. Such results, however, were obtained only in the 1st year of the experiment, which may suggest that nitrates were released only at the initial stage of the experiment following the fertilization. Similar results were obtained by [2], who examined nitrates release to ground waters by means of fertilizing *Salix viminalis* L. cultivation. It was observed in that experiment that nitrates release gradually increased during the first weeks of the fertilization. After a month nitrates release rapidly declined, which was correlated with the increase in the plants transpiration. In the subsequent months transpiration increased whereas nitrates almost ceased to be released.

In the 1^{st} year of the experiment, while applying small doses of the sludge ranging from 0 do 50 Mg d.m./ha the ground waters remained clean and in each experimental variant showed quality class either 1 or 2. Further increase in the sludge dose up to 450 Mg d.m./ha resulted in the deterioration of the ground waters quality, which in each experimental variant showed class 3, which is considered to be satisfactory according to [16].

In the 1^{st} year of the experiment in each experimental variant the boundary value for nitrates concentration 50 mg/dm^3 [15] was not exceeded, which means that no threat of ground waters contamination was observed. In the 2^{nd} and 3^{rd} years nitrates release to the ground waters ceased to occur and in each experimental variant ground waters quality was very good and was rated as class 1 since the nitrates concentrations ranged between 0.2 (CD_0 in the 3^{rd} year) and 3.0 mg/dm^3 (CD_5 in the 2^{nd} year).

Heavy metals and bacteria Salmonella sp.

The analysis of a heavy metals content in ground waters (Tab. 3) shows that almost all concentrations, irrespective of the sewage sludge dose in the lysimeter, were rated as class 1 for all types of the surface plant lining. Only the lysimeters with the willow showed a higher concentration of nickel and lead, which was rated as class 2. This may indicate that no leaching of heavy metals occurs towards the inside of the soil profile during the natural application of the sewage sludge.

Leaching of heavy metals is not thought to pose threats to the environment, since after sludge application most of heavy metals are bound to the organic matter of sludge or to the soil particles and become highly immobile and unavailable even to plants [4]. Similarly, no *Salmonella* bacteria was found in none of the lysimeters, irrespective of the sewage sludge dose and the surface lining (Tab. 3)

Table 3. The content of heavy metals and *Salmonella* bacteria in ground waters from the lysimeters while applying the sewage sludge dose of 450 Mg d.m./ha, with a various surface plant lining at the end of the 3^{rd} year of the experiment

Pollution indicator	The surface lining				
	Unit	Lysimeters without plants	Lysimeters with the willow	Lysimeters with the corn	Lysimeters with the grass
Cd	[mg/dm^3]	< 0.0002	0.0013	< 0.0002	< 0.0002
Cr	[mg/dm^3]	0.0015	0.0049	0.0044	0.0047
Cu	[mg/dm^3]	0.036	0.133	0.032	0.042
Ni	[mg/dm^3]	0.0275	0.0597	0.0352	0.0503
Pb	[mg/dm^3]	0.0188	0.0214	0.0064	0.0264
Zn	[mg/dm^3]	0.84	0.161	0.41	0.65
Hg	[mg/dm^3]	0.00007	0.00004	0.00005	0.00007
Salmonella	[cell/cm^3]	No	No	No	No

CONCLUSIONS

The experiments have showed the relation between the amount of the applied sewage sludge dose and the degree of underground waters contamination, with reference to the examined pollutant indicators.

It was observed that in all years of the experiment pollutants indicators such as EC and COD_{Cr} increased significantly ($p < 0.05$) as the sewage sludge dose was increased. Whereas no significant influence ($p < 0.05$) of the sewage dose on the concentration of nitrates in ground waters was observed in the 1st and 2nd years of the experiment. The ground waters taken form the lysimeters were not classified as contaminated, since the concentration of nitrates did not exceed 50 mg/dm^3.

It was observed that the applied plants did not reduce the negative effect of the increasing doses of the sewage sludge on the underground waters quality.

Any leaching of heavy metals or other pathogenic elements into the ground waters is low.

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WPŁYW PRZYRODNICZEGO WYKORZYSTANIA OSADÓW ŚCIEKOWYCH NA JAKOŚĆ WÓD PODZIEMNYCH

Wykonano trzyletnie, lizymetryczne badania wpływu przyrodniczego wykorzystania osadów ściekowych na jakość wód podziemnych. W badaniach zastosowano trzy gatunki roślin, jako możliwe kierunki stosowania osadów ściekowych: trawa – rekultywacja gleb zdegradowanych, kukurydza – produkcja pasz, wierzba – wykorzystanie energetyczne biomasy. Jako kontrolę zastosowano lizymetry pozbawione roślinności. Przyjęto następujące dawki osadów ściekowych: 0, 10, 50, 110, 225 i 450 Mg s.m./ha. Statystycznie istotna, liniowa zależność pomiędzy dawką osadów a wielkością przewodności elektrolitycznej właściwej (EC), ChZT oraz azotanów wskazuje na potencjalne zagrożenie zanieczyszczenia wód podziemnych przy przyrodniczym wykorzystaniu osadów ściekowych, szczególnie w przypadku wysokich dawek osadów przekraczających 50 Mg s.m./ha. Zależności te oraz ryzyko zanieczyszczenia wód podziemnych obserwowano przez trzy lata doświadczenia dla wskaźników zanieczyszczenia EC i ChZT. W przypadku azotanów, zagrożenie ich migracji stwierdzono jedynie w pierwszym roku badań. Dodatkowo stężenia metali ciężkich oraz obecność patogenów w wodach gruntowych była na niskim poziomie. Stwierdzono, że zastosowane rośliny nie zmniejszyły negatywnego wpływu osadów ściekowych na jakość wód podziemnych.