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CONTENTS

VARIA

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ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 11 2011

Małgorzata HAWROT-PAW[1], Beata SMOLIK
and Agnieszka KAMIENIECKA

PRELIMINARY STUDY ON THE EFFICIENCY OF BIODIESEL BIOLOGICAL DECOMPOSITION WITH AUTOCHTHONOUS SOIL MICROFLORA

WSTĘPNE BADANIA NAD EFEKTYWNOŚCIĄ BIOLOGICZNEGO ROZKŁADU BIODIESLA PRZY UDZIALE AUTOCHTONICZNEJ MIKROFLORY GLEBOWEJ

Abstract: The presented study referred to biodegradation of biodiesel with natural soil microflora and its effect on biofuel decomposing microorganisms and heterotrophic microorganisms. It was found, basing on the obtained results, that microorganisms decomposed biodiesel in 51–52 % at 1 and 5 % soil contaminations and only in 34 % at 10 % biodiesel dose in soil. The stimulating effect of biodiesel fuel on the number of microorganisms participating in biodegradation and of heterotrophs was mainly observed for 1 % contamination.

Keywords: biodiesel, biodegradation, soil, microorganisms

Biofuels that come from natural components are considered to be sources of renewable energy and the same of environmental-friendly one. It has been found after many studies that the best alternative for conventional diesel fuel is rapeseed oil methyl or ethyl ester [1, 2].

Biodiesel is obtained in the first place in the process of transesterification [3], mainly from rapeseed oil but can be also obtained from soybean, palm, cottonseed, sunflower, coconut oil as well as from waste oil and animal fat [4]. In the transesterification process, esters (biodiesel) are produced in the reaction of vegetable or animal oil with alcohol (methyl or ethyl ones), as well as glycerol as a by-product. Usually, sodium hydroxide is a catalyst [3] and the reaction proceeds according to the diagram presented below (Fig. 1).

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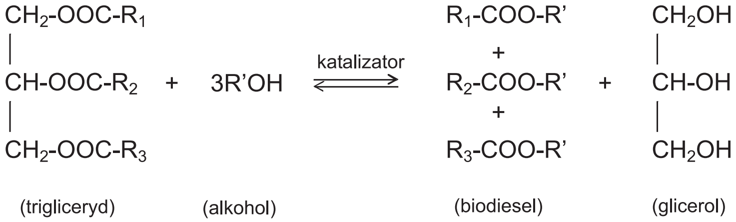

Fig. 1. The diagram of transestrification process [3]

Similar properties of both fuels as well as requirements of the fuel policy of the European Union (2003/30/EC) have led to the appearance of mixtures of diesel fuel with biodiesel on the markets of many countries, which bring new threats for environment. Biodiesel, although considered to be easily degraded in environment like conventional diesel fuel, is a foreign substance in soil. Similar properties of both fuels open possibilities of using the same methods of bioremediation to lands contaminated both with diesel fuel and biodiesel. Easy biodegradability of biodiesel is commonly pointed to, which is confirmed by the study of Peterson and Moller [5]. Some authors propose to use biodiesel as a biological solvent in the process of cleaning sand from crude diesel oil contamination [6, 7].

The present study aimed at broadening the knowledge referring to biodiesel biodegradation in natural soil environment. The aspect of autochthonous soil flora participation in this process was of particular importance. Also the effect of biofuel on the number of soil microorganisms was determined in this study.

Materials and methods

In the study, the soil was used from a plough land in the locality of Ostoja near Szczecin. Soil material was collected from a 0–15 cm horizon. It was a black earth (light loam) with the content of carbon at 19 $g \cdot kg^{-1}$ d.m. soil and of nitrogen at 1.5 $g \cdot kg^{-1}$ d.m. soil. Biodiesel used in the study was obtained directly from manufacturer, ie one of the Polish petroleum refineries. The soil under study was divided into 1 kg samples and brought to 50 % maximum water capacity, thereafter introducing biodiesel at the following concentrations: 1 % (object I), 5 % (object II) and 10 % (object III) (w/w – converted to d.m. soil). The soil sample without biodiesel was a control sample (K). The experiment was carried out at room temperature for 112 days. Analyses were made on experiment set-up day and then after 7, 14, 28, 56 and 112 incubation days.

Biodiesel content changes during incubation were analysed with the weight method according to PN-75/C-04573/10 using the Soxhlet apparatus with a 100 cm^3 extraction flask. During examinations, also the number of heterotrophic microorganisms as well as of those decomposing biodiesel was determined by soil dilution culture method. All measurements were made in three repetitions. For determination of heterotrophic microorganisms, meat peptone agar MPA (Difco) was used. Determination of the number of microorganisms decomposing biodiesel was made using Bushnell-Haas culture medium with the following composition [g · dm^{-3}]: $MgSO_4 \cdot 7H_2O$ – 0.2, K_2HPO_4 – 1.0, KH_2PO_4 – 1.0, $FeCl_3$ – 0.05, NH_4NO_3 – 1.0, $CaCl_2$ – 0.02, and NaCl – 2.0 %; a 2 % biodiesel addition was introduced into it. Culture incubation was carried out at 28 °C. The number of heterotrophic microorganisms was determined after 3 days, while that of biodiesel decomposing microorganisms after 14 days. The number of microorganisms was converted to 1 g dry matter of soil.

Results and discussion

There is relatively little information in the available literature on biodegradation of biodiesel and its effect on microflora. However, numerous studies have been performed on the behaviour of conventional diesel fuel, the results of which can be used as comparative material due to certain similar properties of both fuels and planned introduction of their mixtures onto market.

In object I (with 1 % contamination dose), biodegradation of biodiesel after 14 days reached the level of 24 %, after 56 days – 44 %, while 51 % of this biofuel was decomposed after 112 days (Fig. 2). In the object with 5 % biodiesel dose (object II), a loss of 17 % of this biofuel was observed after 14 days and 40 % after 56 days; reduction of its quantity increased gradually up to 52 %. In object III (with 10 % biodiesel addition), 18 % of biodiesel contamination was decomposed after 14 days and 30 % after 56 days. Maximum contamination reduction level after incubation was 34 %. Peterson and Moller [5] examined decomposition of 0.001 % biodiesel in the water environment using bacterial inoculum and obtained an 84 % biodegradation after 28 incubation days. They also carried out the analysis of biodegradation of that contamination in soil. After 28 days, biodiesel introduced into soil at a concentration of 1 %

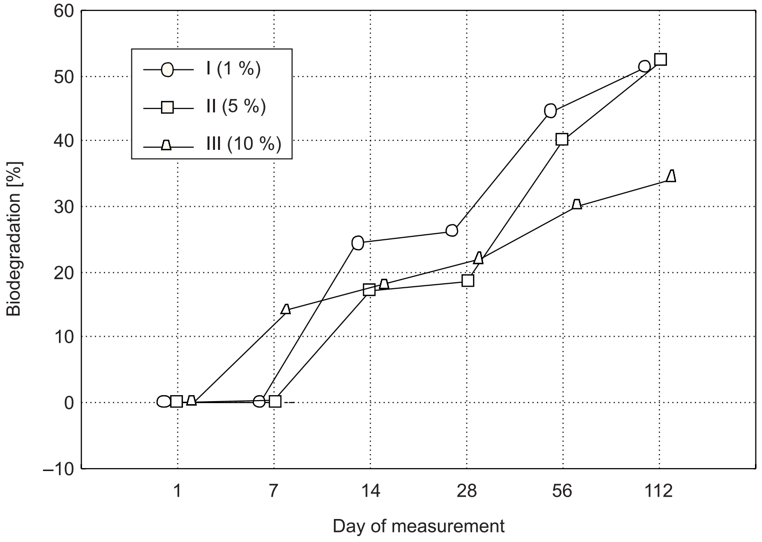

Fig. 2. Level of biodiesel biodegradation

was decomposed in 88 %. In the study of Pasqualino et al [7] referring to biofuel decomposition in water, its biodegradation reached almost 100 % at substrate initial concentration being equal to 1.5 %. Its decomposition proceeded with the use of specialised microorganism strains. Zhang et al [8] obtained a 60 % decomposition of contamination (after 14 days) in their study on decomposition of 1 % biodiesel addition in the water environment. In comparison with these results, biodiesel decomposition in the soil environment observed in the present study was considerably lower – a 26 % reduction was obtained for 1 % dose after 28 incubation days, 18 % for 5 % dose and 22 % for the highest concentration. In the study on conventional diesel fuel, Hawrot and Nowak [9] obtained a 73 % decomposition of substrate for 5 % contamination dose in non-modified soil, ie with the participation of autochthonous microflora. Their experiment was carried out for 150 days and they obtained considerably better result when compared with biodiesel decomposition observed in the present study (52 % decomposition after 112 days), despite the same dose applied. High biodegradation values were also obtained by Boszczyk-Maleszak et al [10], who reported a decomposition of 5 % contamination reaching 44 % after 21 days; biodiesel decomposition in the same time period of own examination reached 17 %. The analyses carried out by Nowak and Hawrot [11] on the biodegradation activity of bacterial strains demonstrated large efficiency of using bacterial inoculates in the processes of cleaning soils from petroleum derivative substances. Hawrot and Nowak [9] found that inoculation of soil increased diesel fuel biodegradation by 46 % when compared with the soil not modified by any treatment. The study of Bieszkiewicz et al [12] carried out on liquid culture at diesel fuel concentration of 0.1 % showed that the loss of diesel fuel fraction in single strain cultures amounted to 80–90 % after 12 days, whereas in strain mixture culture even to 98 %. The study of Nowak and Hawrot [13] on 5 % and 15 % soil contamination with diesel fuel also showed a positive effect of applying inoculation. These authors found that basic agrotechnical measures increased biodegradation only by 5 %, whereas bioaugmentation in light soil allowed reduction of 83 % of contamination at 5 % diesel fuel dose and of 39 % at substrate concentration of 15 %. In medium-heavy soil, these values were respectively 52 % at 5 % addition of diesel fuel and 17 % at a dose of 15 %.

Such numerous findings pointing to favourable effect of bacterial inoculates on diesel fuel decomposition suggest application of similar methods in case of biodiesel. Considering the unsatisfactory effect of its biodegradation observed in the present study, research works on decomposition of this fuel should be continued using the modifications applied in remediation of soils contaminated with conventional fuels.

Changes in the number of microorganisms participating in biodiesel decomposition are presented in Fig. 3A. As reported by Kolwzan et al [14], the number of bacteria required for carrying out biodegradation process should be within a range of 10^5–10^7 cells in 1 g d.m. soil. In the own study, the number of biodiesel decomposing microorganisms at 1 and 5 % contaminations reached values of 10^5 in the whole experimental period (ie minimum values required for effective biodegradation). At 10 % biofuel addition, the number of bacteria after 14 days reached values near or equal to zero. Increase in the number of microorganisms for which this product is a source of carbon and energy was observed by Hawrot and Nowak [9] in the object contaminated with 5 % addition of diesel fuel. In the study of Boszczyk-Maleszak et al [10] on conventional fuel, the number of bacteria amounted to 10^7 cells in 1 g d.m. soil after 21 days at 1 % contamination, whereas 10^6 cells in 1 g d.m. soil at 5 % contamination. Increase in the number of microorganisms decomposing diesel fuel was also confirmed by Ruberto et al [15]. In their study on biodegradation of 1.5 % diesel fuel contamination, the number of microorganisms decomposing it in non-contaminated soil had a value of 10^4 cells in 1 g d.m. soil, whereas their number after contamination increased to 10^6 cells after 28 days.

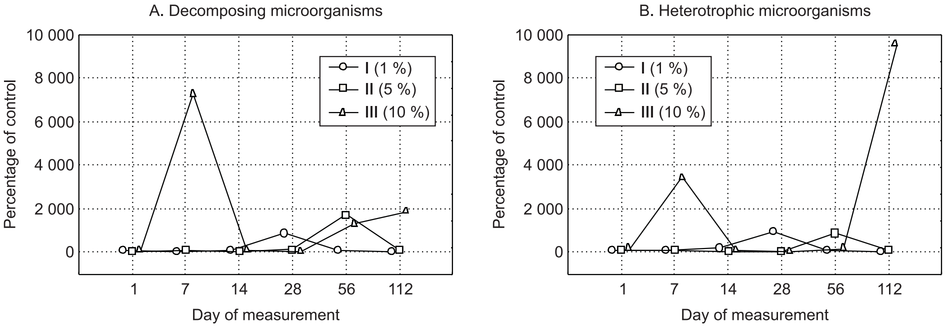

Fig. 3. Number of decomposing (A) and heterotrophic (B) microorganisms in soil as percentage in relation to control sample

Examination of the number of heterotrophic microorganisms showed a strong effect of biodiesel stimulating their growth at its 1 % contamination of soil (Fig. 3B). The largest values, amounting to 10^6 cells in 1 g d.m. soil, were recorded on experimental day 14. Similar results were obtained Ruberto et al [15]. At 1.5 % contamination of soil with diesel fuel, they observed a considerable increase in the number of microorganisms in contaminated soil (10^6–10^7 cells in 1 g d.m. soil) when compared with the control. The number of heterotrophs in object II (5 % biodiesel) was maintained at a level of 10^4–10^5 cells in 1 g d.m. soil. In the object contaminated with 10 % biodiesel addition, this number gradually decreased within a range of 10^5–10^2 cells, until it reached values approximating zero. In the study of Bento et al [16], the number of heterotrophic microorganisms and that of microorganisms decomposing contamination were found to be similar at 1 % contamination with diesel fuel. On the other hand, Margesin et al [17] found that contamination with diesel fuel at a dose of 0.5 % did not cause larger changes in the number of heterotrophs.

Conclusions

The natural origin of biofuel used in experiments suggested a possibility of its quick and effective biodegradation in soil. However, the study showed that biodiesel is relatively resistant to the activity of natural microflora and is decomposed more slowly than conventional diesel fuel. The obtained results suggest a need to continue experiments concerning biodegradation of this fuel, in particular in the context of regulations which impose the necessity of using it as a biocomponent to conventional fuels.

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WSTĘPNE BADANIA NAD EFEKTYWNOŚCIĄ BIOLOGICZNEGO ROZKŁADU BIODIESLA PRZY UDZIALE AUTOCHTONICZNEJ MIKROFLORY GLEBOWEJ

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Abstrakt: Przedstawiono badania dotyczące biodegradacji biodiesla przy udziale naturalnej mikroflory glebowej oraz jego wpływu na organizmy rozkładające biopaliwo i mikroorganizmy heterotroficzne. Na podstawie otrzymanych wyników stwierdzono, że mikroorganizmy rozkładały biodiesel na poziomie 51–52 % przy skażeniu 1 i 5 % oraz zaledwie 34 % przy 10 % dawce biopaliwa w glebie. Stymulujacy wpływ biodiesla na liczebność organizmów uczestniczących w biodegradacji oraz heterotrofów obserwowano przede wszystkim przy zanieczyszczeniu na poziomie 1 %.

Słowa kluczowe: biodiesel, biodegradacja, gleba, mikroorganizmy

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Krystyna HOFFMANN[1]* and Marta HUCULAK-MĄCZKA[1]

EVALUATION OF CONCENTRATION OF HUMIC SUBSTANCES IN SELECTED RAW MATERIALS AND WASTES

OCENA ZAWARTOŚCI SUBSTANCJI HUMUSOWYCH W WYBRANYCH SUROWCACH I ODPADACH

Abstract: Organic substances contained in the soil undergo a slow decomposition, as a result of it is the humus decrease. Various organic substances, especially lignite coal, are an abundant source of humus and nutrients. The main components of humus are high-molecular, amorphus humus acids. The calcium, magnesium, iron, micronutrients and some organic compounds like proteins, carbohydrates, enzymes, vitamins content are very important from the fertilizer point of view. Humus compounds are amorphus organic substances which have a various colouration from yellow to red and contain humic acids, fulvic acids, humins and bitumins. They are different in molecular weight, functional group amount, degree of polymerization and many other factors. The estimation of the possibility of lignites and hop wastes using as a source of humic acids was the aim of research. For this purpose organic carbon (by Tiurin and Alten method), fraction composition of humic acids and total organic substances, calcium and magnesium content were determined. The results of research showed the possibility of organic substances application as mineral – organic fertilizers components and the main component of humus preparations.

Keywords: organic substances, humus acids, fertilizing, lignite, hop wastes

The intense industrial development initiated in the mid-19th century resulted in improving the quality of living including not only industrial goods but also alterations in the way of feeding the population. The increasing number of people inhabiting the globe was impulse to create inventions enabling significant increase in the amount of the food and the improvement in their nutritional value. The main role in this scope fell for agricultural chemists who developed methods of obtaining the mineral fertilizers containing basic biogenic elements – phosphorus, potassium and nitrogen. Less significant, however considerable role should be assigned to alterations in the cropping practices. Together with mass applying fertilizers their adverse influence on the

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environment was observed. This adverse influence of fertilizer compounds on the environment can be caused by diverse factors. The most important are overdosing fertilizers ie introducing to the soil environment of large amounts of mineral fertilizers than it results from the nutrients demand of plants, the quality of the soil supporting leaching mineral elements and to a lesser degree concentration of heavy metals, resulting from applied raw materials and the method of manufacturing of mineral fertilizers. Supplying organic substance together with mineral fertilizers should be one of solutions to limit these disadvantageous processes. Among unconventional sources of organic matter a waste lignite coal of a lower energy value plays a significant role. Possibilities of using the lignite coal for fertilizer purposes result also from its peculiar physical and chemical properties as well as from big prospectivity of its applications ie possibility of supplying the horticultures with the lignite coal for years due to its huge deposits [1–3].

Properties of the lignite coal playing fundamental role in the environment and application within different fields of agriculture are [2–5]:

– the ability to absorb damp and different vapours and gasses,
– the ability of the cation exchange,
– the buffering properties,
– the concentration of organic matter.

A concentration of microelements in lignite coal, concentration of organic matter, an effect of humic acids, better availability of iron compounds which under the influence of the lignite coal are transformed into forms readily available also determine the fertilizer effect of applying organic substance [2–6].

The organic substances contained in the soil are undergoing the slow degradation because of which depletion of humus follows. Diverse organic substances, particularly lignite coal constitute the abundant source of the humus as well as nutrients. Large-molecular, amorphus humic acids are a main elements of the humus. From a fertilizer point of view a concentration of calcium, magnesium, iron, micronutrients as well as some organic compounds like proteins, carbohydrates, enzymes, vitamins is also essential. Humus compounds are amorphus organic substances of the diverse colouring, from yellow to red, containing in their composition humic and fulvic acids, humins and bitumins. They differ between themselves in the molecular weight, the number of functional groups, the degree of the polymerization, with the solubility and many different factors [4–11].

Providing the soil with organic matter is an aim of organic fertilizing and supplying plants with determined amount of nutrients, as well as counteracting adverse influences on the environment by applying mineral fertilizers. Applying organic fertilizers increase the amount of humus in the soil which is essential in proper plant nutrition. Regulating aqueous-air, sorption, red-ox and thermal relationships, as well as undervalued possibility of improving the biological activity belong to the most important functions of the organic substance performed in the soil [1, 2 ,6].

At present time of the extensive intensification of crop production utilizing potential nutrients included in organic substances is also important. Under some conditions, on account of the chemical structure, they become unavailable to plants. Natural fertilizers are an exception eg manure and litter which contain large amounts of biogenic elements like nitrogen or potassium. However a stabilization of the chemical compounds mentioned above in fertilizer constitutes a problem on due to large losses and the simultaneous environmental pollution [2–6].

Mainly peat and lignite coal belong to organic substances applied in agricultural cultivations. Sewages can also be source of organic substances under the condition of appropriate application, preparation and removing toxic and harmful for development of plants compounds. Peat and lignite coal contain nutrients from the macrogroup (calcium, phosphorus, potassium, nitrogen, magnesium, sulphur) and micronutrients (copper, zinc, iron, manganese, molybdenum, cobalt, boron), unfortunately they are unavailable to plants without preliminary chemical processing [2, 3, 12, 13].

Relationships between the crops and mineral elements were subject of examination since 19th century. In accordance with these examinations the German scientist Justus Liebig formulated a law so-called Law of the Minimum which propagates that the crop yields depend on the dose of the mineral element which in the soil appears in the smallest amount [1].

The degree of availability can be determined:

– directly – by the rate of absorption of particular compound by the root,

– indirectly – by the amount of the particular compound extracted from the soil using chemical methods.

Processes determining the availability of mineral elements by the root of the plant occur between individual phases of the soil [1].

Therefore, availability of mineral elements includes different kind of biological and chemical equilibrium processes occurring between roots and the solid, liquid and gas phase of the soil. The availability can be determined using direct method through the measurement of the amount of the compound absorbed by the root or by indirect method through the amount of the compound extracted from the soil with chemical methods applying appropriate extraction solutions. However the methods mentioned above are only an approximation describing very complicated relationships, dependent on the external factors eg climate as well as internal eg structure of the soil [1, 4, 5].

The beneficial impact on the environment is an important property of organic substances. On account of the great sorption and aqueous capacity they limit losses ensuing from the solubility of mineral elements as well as inhibit impact of the toxic substances which can pollute the soil [4, 5].

Materials and methods

The aim of conducted research was physicochemical assessment of lignite coal samples collected from Turow and Belchatow mines and so-called hop wastes, derived from hop extract production using method of the CO_2 extraction under supercritical conditions as sources of organic substance. During examinations the special attention was devoted to evaluation of concentrations of organic carbon as well as total and free humic acids.

The lignite coal is ranked among sedimentary rocks of the organic origin. It was formed at the end of the Cretaceous period. It is placed between peat and the hard bituminous coal in the rank of carbon content of primary carbonaceous material. Formation of lignite coal is a complex and complicated process, dependent on many factors ie climate, development of fauna, microorganisms, the morphology and the tectonics of given area [2–5].

A complex of amorphus humic substances is included in a lignite coal composition, where humic, hymatomelanic, fulvic acids as well as humins and bitumins can be distinguished. Considering the solubility it seems that fulvic and humic acids are of the greatest agricultural significance [10, 11].

Humic acids constitute a fraction of macromolecular compounds of the aromatic nature of the colour from dark-brown to black. It is extractable from the soil using the alkaline solvents. Their structure has not been completely identified yet. It is assumed that they are polymers, of which an aromatic core is a basic element of the structure connected with amino acids, sugars, peptides, aliphatic acids etc. The core consists of rings of the phenols type or compounds containing nitrogen in the cyclic form. Functional groups constitute the essential part of the structure of molecule. The following groups are the most important: methoxyl, carboxyl, carbonyl, phenol, quininyl, alcohol [4, 5, 10, 11].

Fulvic acids constitute a fraction of humus compounds soluble in water, NaOH solution and diluted acids. They are of yellow to yellow-brown colour. They form readily soluble salts with calcium, magnesium, sodium or potassium, however they form chelates with iron and aluminium. Their structure has not been precisely determined. It is supposed, that molecules of fulvic acid are made from benzene rings joined into the polymeric arrangement by the hydrogen bonds [2, 7, 11].

In the research on concentrations of humus substance a methodology and the laboratory analysis recommended for examinations of this type by the Soil Science Society of Poland and Polish Standards were applied [14–16].

The concentration of organic carbon in raw materials and industrial wastes can be determined using diverse methods. A Tiurin and Alten methods belong to the most investigated.

Basis of the Tiurin method [16]

The Tiurin method in the original form refers to determining concentrations of organic carbon in samples of mineral soils. However on account of resemblance of chemical composition it was applied for analyses of lignite coal samples, humus fertilizers and hop wastes. It consists in oxidizing the organic substance, using solution of potassium dichromate, contained in examined samples in the presence of the silver sulphate as catalyst. The excess of potassium dichromate is subsequently titrated using Mohr's salt in the presence of ferroine as the indicator.

Examination procedure

Sample of the mass 0.0150 g was introduced into the conical flask of volume 250 cm^3, 0.2 g of silver sulphate and 5 cm^3 of the sulphuric acid were added. The samples prepared according to the method mentioned above were left for 1 h. After this time 40 cm^3 of potassium dichromate was added, heated up and boiled for 5 min. After cooling down approximately 50 cm^3 of the distilled water was introduced and the mixture was titrated subsequently with solution hydrated ammonium iron(II) sulphate (which titre was obtained previously using the potassium permanganate) in the presence of ferroine as the indicator.

Basis of the Alten method [14]

The Alten Method is a Tiurin analogous method which allows for determining the concentration of organic carbon in samples. The difference is that oxidizing organic carbon in the Alten method is conducted during heating samples in the water bath for 3 h.

Examination procedure

Weighed portion of the sample in the amount of 0.0150 g was introduced into the 100 cm^3 calibrated flask. 10 cm^3 of solution potassium dichromate and 16 cm^3 of the concentrated sulphuric acid were added. The flasks prepared according to the method mentioned above were put in the warm water bath and heated for 3 h. After cooling, flasks were filled up with the distilled water. Then 25 cm^3 of solution was transferred into the conical flask and titrated with Mohr’s salt in the presence of phenylantranile acid to the change of the colour to dark brown.

Method for determining humus [5]

The method of determining humus in organic materials consists in analyzing the content of organic carbon in samples and subsequent multiplying the result by value of the rate equal 1.724.

$$\% \text{ humus} = \text{concentration } C_{org} \, [\%] \cdot 1.724$$

Method for determining fractional composition of organic matter using Tiurin method [14]

The method refers to determining of fractional composition of humus in soils. On account of the subject of the research it was used for analyses of tested organic materials. This method enables to extract and determine among others sodium humates, humic and fulvic acids.

Comparison of results of the organic carbon concentrations for every fraction of examined samples are demonstrated in Table 1.

Table 1

Fractional composition of samples determined by Tiurin method (C_{org} [%]) [Fraction no. 2 – 0.5 M Na_2SO_4; Fraction no. 3 – 0.1–0.02 M NaOH after decalcination; Fraction no. 4a – 0.25 M and 0.5 M H_2SO_4; Fraction no. 4b – 0.1–0.02 M NaOH alternated with acid; Fraction no. 5 – post-extraction residue; Fraction no. 6 – directly 0.25M H_2SO_4; Fraction no. 7 – directly 0.1 M NaOH]

Groups and fractions	Fractions marking	Turow lignite coal	Belchatow earthy lignite coal	Commercial humus fertilizer	Hop wastes
Substances extracted with Na_2SO_4	2	6.420	4.088	14.016	2.920
Humic acids fractions	7	2.37	4.09	2.92	1.17
	3–7	7.59	4.92	11.68	9.87
	4b	15.77	18.69	22.19	14.30
	Total	25.73	27.70	36.79	25.34
Fulvic acids fractions	6–2	2.34	5.26	4.67	4.67
	7	1.75	1.17	4.09	2.92
	3–7	4.67	2.92	8.76	5.84
	4b	2.92	1.75	5.26	2.34
	Total	11.68	11.10	22.78	15.77
Substances hydrolyzed in H_2SO_4	4a	3.21	2.57	3.80	2.45
Humates	5	53.14	47.89	61.32	42.05

The comparison of organic carbon concentrations in examined samples, applying the Tiurin or Alten method, respectively is presented in Fig. 1. Any significant differences were not stated. The results of concentrations of organic carbon for both methods were comparable.

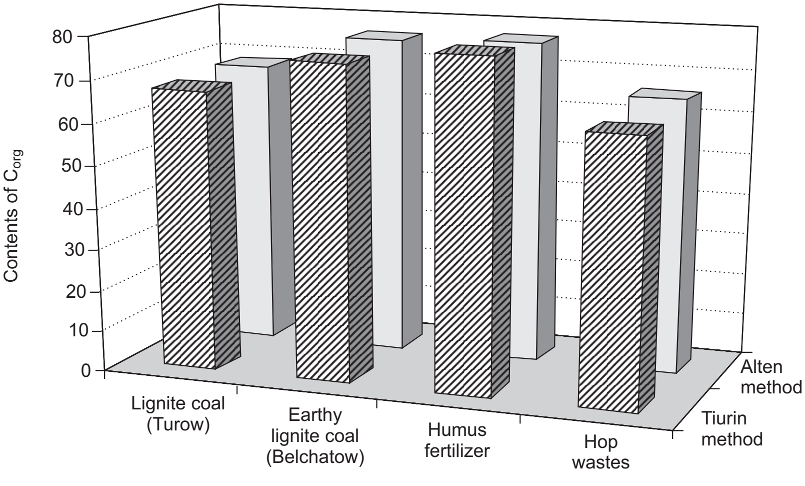

Fig. 1. Comparison of concentration of C_{org} in selected samples evaluated by Tiurin and Alten method

Total humic acids include the humic acids presented in the free form and the ones which are bound into salt forms. They are obtained by the extraction with alkaline solution of sodium pyrophosphate and secondary extraction with sodium hydroxide. Humic acids can be subsequently precipitated from the solution by treating them with mineral acids eg HCl.

Free humic acids are humic acids extracted from organic matter which appear as a result of treating the lignite coal or different organic raw material with sodium hydroxide, and then with mineral acids in order to precipitate them from the solution.

Comparison of concentrations of total and free humic acids contained in lignite coal, humus fertilizers and hop wastes is presented in Table 2.

Table 2

Concentration of total and free humic acids in examined samples

Sample / Concentration of humic acids	Lignite coal (Turow)	Earthy lignite coal (Bełchatów)	Humus fertilizer	Hop wastes
Concentration of total humic acids [% mas.]	43.16	53.35	47.17	27.16
Concentration of free humic acids [% mas.]	23.76	26.80	24.69	23.89

Concentration of total *humic acids* – $(HA)_{tB}^{daf}$ in examined samples calculated for dry and ash-less state; as well as free humic acids $(HA)_{fB}^{daf}$ of organic matter calculated for dry and ash-less state were calculated in % mas. according to the following formula:

$$(HA)_{tB}^{daf} = \frac{10000 \cdot (m_4 - m_5)}{m_6(100 - W_1^a)} \cdot \frac{V_0}{V_1},$$

where: m_4 – mass of total humic acids [g],
m_5 – mass of residue after incineration of total humic acids [g],
m_6 – mass of weighed amount of sample [g],
V_0 – total volume of the alkaline solution [cm^3],
V_1 – volume of the solution collected for examination of total humic acids [cm^3],
W_1^a – humidity content in the sample [% mas.].

$$(HA)_{fB}^{daf} = \frac{10000 \cdot (m_7 - m_8)}{m_6(100 - W_1^a)} \cdot \frac{V_0}{V_1},$$

where: m_7 – mass of free humic acids [g],
m_8 – mass of residue after incineration of humic acids [g],
m_6 – mass of weighed amount of sample [g],
V_0 – total volume of the free humic acids [cm^3],
V_1 – volume of the solution collected for examination [cm^3].

Conclusions

It results from examinations carried out that examined substances are characterized by high concentration of organic carbon and they can constitute the valuable component in mineral-organic fertilizers applicable for improving the physicochemical properties of soils and for eco-friendly purposes consisting in suppressing uptake of intoxicants. High concentrations of total and free humic acids and fractional composition characterizing concentrations of fulvic acids, completely water-soluble and of humic acids soluble in the alkaline environment indicates the possibility of inventing mineral-organic preparations for plant fertilizing purposes containing both micro as well as macronutrients.

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OCENA ZAWARTOŚCI SUBSTANCJI HUMUSOWYCH W WYBRANYCH SUROWCACH I ODPADACH

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Abstrakt: Celem prowadzonych prac badawczych była ocena możliwości wykorzystania, jako źródła kwasów huminowych, krajowych węgli brunatnych i wychmielin z przemysłu browarniczego. W ramach analiz oznaczono C_{org} metodą Tiurina i Altena, składy frakcyjne kwasów huminowych, ogólną zawartość substancji organicznej, zawartość wapnia oraz magnezu. Wyniki badań wskazują na możliwość zastosowania badanych substancji organicznych jako komponentów nawozów mineralno-organicznych i głównego składnika preparatów humusowych.

Słowa kluczowe: substancja organiczna, kwasy humusowe, nawożenie, węgiel brunatny, wychmieliny

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PROFILE DISTRIBUTION AND MOBILITY OF LEAD IN SELECTED ARABLE SOILS FROM PRADOLINA GLOGOWSKA

PROFILOWA DYSTRYBUCJA I MOBILNOŚĆ OŁOWIU W WYBRANYCH GLEBACH UPRAWNYCH Z OBSZARU PRADOLINY GŁOGOWSKIEJ

Abstract: Analysis of the total content of microelements in soils and their speciation and mobility enables to asses the quality of the environment and identify the impact of anthropogenic factors on the functioning of various natural ecosystems.

The aim of the research was to determine the mobility and profile distribution of lead and sequentially isolated fractions of lead in arable Luvisols of various texture from Pradolina Glogowska.

The total content of metals was performed using AAS method, after the digestion of soils in mixture of HF and $HClO_4$ and the content of mobile forms of Pb using sequential analysis. In the soils studied the total content of lead was in the range 17.40–45.36 $mg \cdot kg^{-1}$. These values do not exceed the geochemical background level, for this metal. The sequential analysis showed that the highest share in total lead content was fraction VII (residual) of approximately 40 % and the lowest in fractions I–III below 5 % of the total metal. The above results allow to classify the soils tested to uncontaminated. The results also indicate a relatively low mobility of lead in soils. These soils can be used for all agricultural and horticultural crops production, due to principles of rational use of agricultural production area.

Key words: soil, lead, sequential analysis

Most heavy metals, except Fe and Ti occurs in the Earth's crust in the amounts less than 0.1 %, so they are among the trace elements [1]. From the biogeochemical point of view, they are divided into two groups, namely: the elements necessary for normal metabolic processes, and toxic elements, like lead [2, 3]. One of the sources of heavy metals in soils is non-ferrous metallurgy, including metallurgy of copper. In the area of Pradolina Glogowska (Zukowice) in 1978 Copperworks Glogow II began the production, which causes emission of gaseous and solid particles that affect the surrounding soils and crop quality. The previous research undertaken on soils in the vicinity of

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copperworks, showed a dramatic increase of metal concentration in the surface layer of soils in the early years of operation of copperworks. These concentrations then decreased and stabilized at relatively low levels in agricultural areas, while in wooded areas there was a secondary increase of the content of heavy metals in the surface layers of soils. Study of soils and plant material from the vicinity of the copperworks in 2004 did not show any accumulation of metals in soils, while elevated concentrations of Pb in plant material from this area was detected. The source of lead in this case may be, the dust emissions associated with metallurgical processes, resulting in adsorption of lead oxides on the surface of leaves, which may lead to secondary contamination of soils.

The purpose of this study was to determine the mobility and profile distribution of lead in arable Luvisols in the area of Pradolina Glogowska, being under the copper industry impact.

Material and methods

The research was conducted in the agricultural area affected by the emission of gasses and dusts from the Copperworks Glogow. The research material consists of 4 soil profiles located in the distance of 3.0 to 6.8 km from the copperworks. In the soil samples from each genetic horizon the following soil analyses were made: texture using Cassagrande method with the modification by Pruszynski, pH in H_2O and in the KCl solution (1 mol/dm^3) using potentiometric method, C_{org} using Tiurin method, content of $CaCO_3$ by Scheibler volume method [4]. The total lead content was determined after mineralization of the soils in a mixture of HF and $HClO_4$ acid [5]. The mobile forms of lead was determined based on chemical sequential analysis by Miller et al [6] with modification [7]. To validate the accuracy of analysis and measurements, analysis of certified materials Till-3 and SV-M had been performed. Total and mobile forms of Pb were determined by *atomic absorption spectrometry* (AAS) using PU 9100X spectrometer. The analysis was performed in triplicates. The average values are shown in tables.

Results and discussion

The morphological characteristics of the examined soil profiles, allowed to classifiy them as typical Luvisols formed from loamy dust (Systematics of Polish Soils 1998) [8]. The bedrocks of analyzed soils show the granulation of loamy dust (Table 1), and in textural B horizon – clayey dust was determined, which is the result of lessive process. In terms of agricultural science (PTG 2008) they are classified as loamy soils (Wierzchowice – P1 and Modla – P2) and clayey soils (Kurowice – P3 and Nielubia – P4). The content of the coarse skeleton particles in the range from 5 % to 15 % is typical for low skeletal soils [9]. The pH of the investigated soils was in range of 7.33–8.55 pH_{H_2O} and pH_{KCl} of 5.81–7.75 and it was the lowest in illuvial horizon for the most of the sites (Table 1). Calcium carbonate was detected in all sites except profile P1. The richest in this component was C horizon of P3 and P4 profiles and illuvial

Table 1

Physicochemical properties of the soils

Profile genetic horizon	Depth [cm]	Percentage content of fraction [mm]				pH		$CaCO_3$ [%]	C_{org} [g · kg^{-1}]
		> 2	2–0.05	0.005–0.002	< 0.002	H_2O	KCl		
P1 Wierzchowice									
Ap	0–20	10.3	35	55	10	7.33	6.07	< 1	18.1
Eet	20–45	3.2	25	63	12	7.54	5.91	< 1	3.2
Bt	45–90	4.3	23	60	17	7.95	5.81	< 1	n.d.
C	90–100	1.2	85	9	6	8.16	6.62	< 1	n.d.
C1	> 100	9.7	34	57	9	8.14	6.58	< 1	n.d.
P2 Modla									
Ap	0–30	13.0	66	25	9	7.53	6.89	< 1	7.2
Eet	30–60	10.0	48	45	7	8.20	7.50	< 1	3.9
Bt	60–100	7.7	28	55	17	7.82	6.46	11.60	n.d.
C	> 100	5.7	23	66	11	8.48	7.65	< 1	n.d.
P3 Kurowice									
Ap	0–25	112.6	35	51	14	8.19	7.49	1.93	7.0
Eet	25–48	12.9	26	67	7	8.55	7.72	< 1	1.2
Bt	48–90	5.9	25	58	17	8.13	7.30	6.72	n.d.
C	> 90	7.1	27	63	10	8.38	7.75	8.58	n.d.
P4 Nielubia									
Ap	0–20	11.5	20	65	15	7.55	7.22	< 1	18.4
Eet	20–45	9.1	29	59	12	7.33	7.05	< 1	4.9
Bt	45–95	6.2	28	56	16	7.70	6.98	3.46	n.d.
C	> 95	8.0	27	61	12	8.10	7.30	5.82	n.d.

horizon of P2, P3 and P4 profiles. High content of $CaCO_3$ in the soils studied did not always correspond to the high value of pH.

A neutral pH of soil may be caused by the ions washed out to this horizon, such as Fe, Al, Mn [2]. In the samples from Eet and C horizons in P2 profile, alkaline pH is not accompanied by a high content of $CaCO_3$, which shows that high value of pH may be due to other forms of metals alkalizing soil environment, occurring in the form of salts or hydroxides. The content of C-organic in humus horizons of investigated soils was in the range of 7.0–18.1 g · kg^{1} (Table 1). These are the typical values for soils of this region [3, 10–12].

The total content of lead was in range of 17.40–45.36 mg · kg^{-1}. Significantly higher total content of Pb was found in the surface horizons of the investigated profiles (Table 2), which may indicate its anthropogenic origin. Lead is an element with low mobility and significant affinity to clay minerals and hydrated oxides [1, 13]. It also easily combines with soil organic matter. Elevated concentration of Pb in surface layers was also reported by other authors [14–16].

Table 2

The total content of lead and metal fractions in soils

Profile genetic horizon	Total Pb content $[\mathrm{mg \cdot kg^{-1}}]$	F I	F II	F III	F IV	F V	F VI	F VII*
		$[\mathrm{mg \cdot kg^{-1}}]$						
P1 Wierzchowice								
Ap	44.64	p.d	p.d	1.60	5.72	12.72	11.60	13.00
Eet	31.36	p.d	p.d	1.12	4.40	8.12	5.92	11.80
Bt	30.16	p.d	p.d	1.72	4.80	7.80	5.52	10.32
C	27.16	p.d	p.d	1.32	5.00	8.32	2.80	9.72
C1	27.36	p.d	p.d	0.20	4.92	8.32	4.52	9.40
P2 Modla								
Ap	31.44	0.16	p.d	0.52	3.60	9.12	6.52	11.52
Eet	23.84	p.d	p.d	0.40	2.80	6.92	3.32	10.40
Bt	24.48	p.d	p.d	0.76	3.00	6.60	2.20	11.92
C	21.96	p.d	p.d	0.44	2.60	7.32	1.40	10.20
P3 Kurowice								
Ap	34.68	p.d.	p.d	0.80	2.12	11.52	7.92	12.32
Eet	17.56	0.28	p.d	p.d	1.80	5.76	1.00	8.72
Bt	22.44	p.d	p.d	0.08	0.80	6.12	3.92	11.52
C	17.40	0.24	p.d	p.d	0.92	5.52	1.12	9.60
P4 Nielubia								
Ap	45.36	p.d	p.d	1.52	5.12	19.00	5.52	14.20
Eet	34.80	p.d	p.d	1.00	5.08	10.52	6.00	12.20
Bt	32.44	p.d	p.d	0.44	4.00	8.40	8.40	11.20
C	28.72	p.d	p.d	0.40	4.20	7.40	4.92	11.80

F I – exchangeable and soluble in water fraction, F II – forms soluble in acids, F III – forms occluded on manganese oxides, F IV – forms associated with organic matter, F V – lead bound to amorphous iron oxides, F VI – forms associated with crystalline iron oxides, F VII – residual forms, p.d. – below detection limit.

The values of the total Pb content lead to a conclusion that the investigated Luvisols are not polluted with this metal [2]. These soils may be used for all agricultural crops in accordance with the principles of rational use of agricultural production area [17]. Sequential extraction studies were carried out, in order to investigate the mobility of lead and its possible release into the environment [18]. In the conducted sequential analysis, seven fractions were separated: exchangeable and soluble in water fraction (F I), fraction soluble in acids (F II), forms occluded on manganese oxides (F III), associated with organic matter (F IV), bound to amorphous iron oxides (F V), associated with crystalline iron oxides (F VI) and residual fraction (F VII) (Table 2). In the investigated soils lead dominated in fraction VII – residual form (Table 2), which is hardly soluble and unavailable for plants, due to association with soil matrix. The content of lead in this fraction was in range of 8.72–14.20 $\mathrm{mg \cdot kg^{-1}}$, which was from 29 to 55 % of total lead content. A significant portion of this fraction was observed by others in the soils from unpolluted areas [19–21]. The highest content of this fraction was determined in surface horizon of the investigated soils. The five fractions in the sequential extraction procedure used, include solid phase lead species, that can be mobilised under natural conditions. Fractions I and II are below the detection limit for almost all soil samples (Table 2). Gerritse and van Driel [21] found that Pb in exchangeable fraction was as low as 1–5 % the total Pb. In environmental samples these forms are usually very low, less than 5 % of the total content [23–26]. The content of Pb associated with manganese oxides (F III) is relatively low (Figs. 1–4). Lead bound to soil organic matter (F IV) is significant [25, 26]. The high partition of Pb fraction associated with organic matter may lead to temporary metal release, as a result of

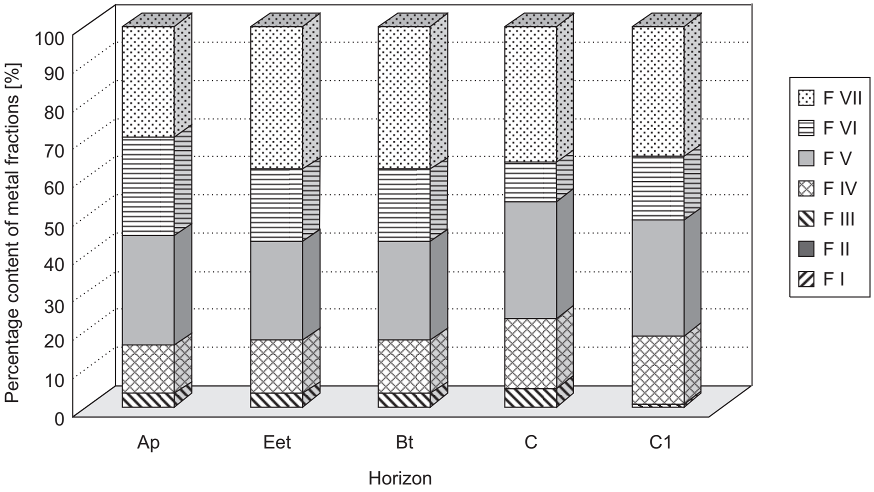

Fig. 1. Distribution of lead fractions in profile P1

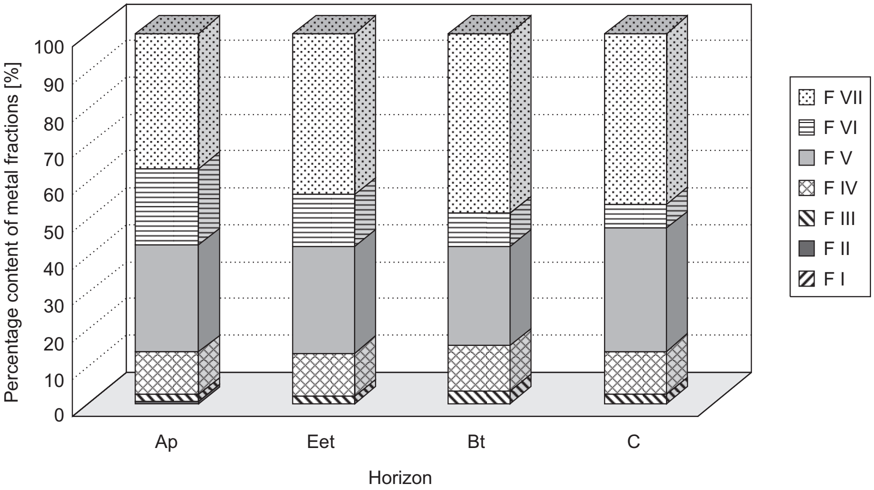

Fig. 2. Distribution of lead fractions in profile P2

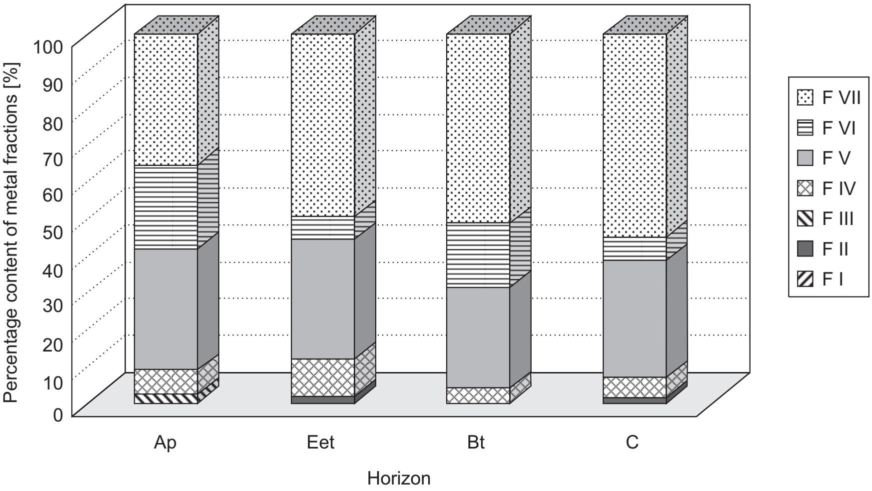

Fig. 3. Distribution of lead fractions in profile P3

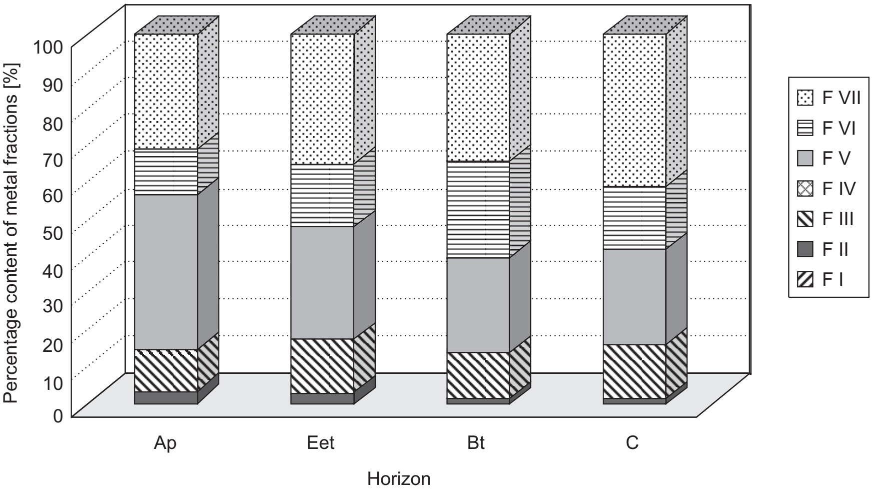

Fig. 4. Distribution of lead fractions in profile P4

naturally occurring processes of decomposition of organic material [27]. It has been shown that organic matter is the dominant constituent contributing to Pb retention in soils [27]. However, the highest contents of Pb was associated with amorphous (F V) and crystalline (F VI) iron oxides. Thus, pedogenic iron oxides are effective sink for lead. But in case of water status change in soils (water logging) iron oxides can be dissolved under the redox gradient effect and lead can be liberated from its associations.

The results of the sequential extraction shows, that lead has limited mobility in studied soils, unless changes such as mineralization of soil organic matter [26] or reduction of pH or redox potential will occur. The solubilisation of iron oxides will lead to release of Pb held by these compounds [28].

The results of the sequential extraction analysis indicate that for soils with sliglitly elevated level of Pb there is a need to monitor changes in soil pH and potential redox in order to predict lead liberation due to dissolution processes of a particular soil components.

Conclusions

Morphological and physicochemical properties allowed to classify the investigated soil profiles from Pradolina Glogowska as typical Luvisols formed from loamy dust and to category to loamy and clayey soils. Their pH was in range of pH_{KCl} 5.81–7.75 and in bedrock horizon they contained calcium carbonate (except P1 profile). The investigated soils are classify as soils with the natural total lead content, which was in range of 17.40–45.36 $mg \cdot kg^{-1}$. In the performed sequential analysis seven lead fractions were separated. In the investigated soils fraction VII – residual forms, which are hardly soluble and unavailable for plants dominated. The most mobile fractions of lead (F I and F II), readily and potentially bioavailable, were beneath the detection threshold in the investigated soils.

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PROFILOWA DYSTRYBUCJA I MOBILNOŚĆ OŁOWIU W WYBRANYCH GLEBACH UPRAWNYCH Z OBSZARU PRADOLINY GŁOGOWSKIEJ

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Abstrakt: Analiza całkowitych zawartości mikroelementów w glebach oraz ich mobilności umożliwia ocenę stanu środowiska na danym terenie oraz określenie wpływu czynników antropogennych na funkcjonowanie ekosystemów przyrodniczych.

Celem niniejszej pracy było określenie mobilności oraz profilowej dystrybucji ołowiu w uprawnych glebach płowych z obszaru Pradoliny Głogowskiej, będących pod wpływem oddziaływania Huty Miedzi Głogów.

Całkowitą zawartość ołowiu oznaczono metodą AAS po mineralizacji w mieszaninie kwasów HF i $HClO_4$, natomiast zawartość form mobilnych Pb, wg zmodyfikowanej przez Millera i in. (1986) [6] analizy sekwencyjnej.

Morfologia, uziarnienie i właściwości fizykochemiczne pozwoliły zakwalifikować badane gleby do podtypu gleb płowych typowych, wytworzonych z utworów pyłowych oraz do gleb o odczynie w zakresie od lekko kwaśnego do zasadowego. Całkowita zawartość ołowiu wynosiła 17,40–45,36 mg · kg^{-1}. Wartości te nie przekraczają poziomu tła geochemicznego, co pozwala uznać gleby tego regionu za niezanieczyszczone tym pierwiastkiem. W analizie sekwencyjnej największy udział w zawartości całkowitej ołowiu miała frakcja 7 (rezydualna) około 40 %, a najmniejszy frakcje 1–3, poniżej 5 % zawartości całkowitej badanego metalu. Uzyskane wyniki wskazują na stosunkowo małą mobilność ołowiu w badanych glebach. Gleby te mogą być przeznaczone pod wszystkie uprawy ogrodnicze i rolnicze, zgodnie z zasadami racjonalnego wykorzystania rolniczej przestrzeni produkcyjnej.

Słowa kluczowe: gleba, ołów, analiza sekwencyjna

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OCCURRENCE OF CADMIUM IN HERBS GROWING ON GRASSLAND LOCATED NEAR THE HIGHWAY

WYSTĘPOWANIE KADMU W ZIOŁACH ROSNĄCYCH NA UŻYTKACH ZIELONYCH ZLOKALIZOWANYCH W POBLIŻU DROGI SZYBKIEGO RUCHU

Abstract: The aim of this work is to determine the level of impurity by cadmium selected species of dicotyledonous plants to which belong the herbs collected from permanent grassland located near a highway. Chosen herbs were collected from the grasslands located near the international rout E-30 near Siedlce. Such herbs as common dandelion (*Taraxacum officinale* L.), greater plantain (*Plantago maior* L.) and garden sorrel (*Rumex acetosa* L.) were picked up.

The plant material was taken from the distance 2; 10; 30 and 50 m from the wayside ditch. Shoots of plants (stems and leaves) were separated from underground parts (roots and rhizome) and then they were dried them and grinded. Crumbled material in 5 g samples was put through mineralization at a temp. 450 ^{o}C. Samples prepared like that were put in to the solution with 10 cm^3 of 10 % HCl and added distilled water to the volume 50 cm^3. The content of cadmium in received solutions was determined using the AAS method.

The concentration of the cadmium content in shoots and in underground parts systematically decreased in the measure of dismissing from the source of pollution in all studied plants.

Independently from the place of the gathering of the plant material, the most cadmium was accumulated by the common dandelion in the shoots (0.24 mg $\cdot$ kg^{-1} d.m.), however the smallest concentration of cadmium in studied herbs was in the underground parts of garden sorrel (0.09 mg $\cdot$ kg^{-1} d.m.) independently from the place of gathering.

Keywords: cadmium, common dandelion, greater plantian, garden sorrel

Microelements in plants are important elements with regard to their functioning in some biological processes and because of animals nutritional needs [1]. Common feature of microelements is that after exceeding the admissible level, they affect toxically life forms [2]. Both their shortage as well as the excess cause negative results.

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Recently very big interest in elements has been focused on heavy metals. Cadmium is ranked to the most toxic and threatening the health of people and animals [3].

Cadmium is absorbed by plants extremely easily, both by their root system and by their leaves mostly proportionally to its concentration in the environment [4]. The transportation of cadmium in a plant is easy, but with increased absorption it is accumulated mainly in roots, even in the case of absorption by leaf blades. In the case of exceeding the critical point heavy metals, including cadmium, affect the crop quality becoming simultaneously a threat for animals and people's health.

Cadmium is not an indispensable component for life forms. However, even its comparatively small quantities can be already toxic for animals. Toxicity of high concentrations of cadmium manifests itself in kidneys function disorders, neoplastic diseases and in reproductive system disorders.

In a human organism cadmium accumulates first of all in a liver and kidneys, where it combines extremely hard and for quite a long time, as for about 10 years time, with a low molecular protein. Moreover cadmium blocks phosphates and some enzymes and causes anemia. The most often it causes chronic poisonings which for 1-year period can run without any symptoms. Particularly dangerous is the excess of cadmium especially in plants which are consumed both by animals and people. To these plants among others belong herbs [5].

Therefore, the aim of this work is to determine the level of impurity by cadmium selected species of dicotyledonous plants to which belong the herbs collected from permanent grassland located near a highway.

Material and methods

Chosen herbs were collected from the grasslands located near the international rout E-30 near Siedlce. Such herbs as common dandelion (*Taraxacum officinale* L.), greater plantain (*Plantago maior* L.) and garden sorrel (*Rumex acetosa* L.) were picked up. The plant material was taken from the distance 2; 10; 30 and 50 m from the wayside ditch. Shoots of plants (stems and leaves) were separated from underground parts (roots and rhizome) and then they were dried and ground. Crumbled material in 5 g samples was put through mineralization at a temp. 450 ^{o}C. Samples prepared like that were put in the solution with 10 cm^3 of 10 % HCl and added distilled water to the volume of 50 cm^3. The content of cadmium in received solutions was determined using the AAS method.

Obtained results were subjected to a statistical method of the variation one factor analysis using the Statistica programme – for Windows and module Anova/Manova. The significance of the differentiation of results was verified by the Tukey test for the level of significance $p \le 0.05$.

Results

The content of cadmium in studied herbs has changed depending on distance from the source of pollution and on plant species.

Kabata-Pendias [1] claims critical cadmium content in plants in relation to their usefulness for consumptive aims should not exceed the value of 0.15 mg · kg^{-1} d.m., but for fodder aims should come to ≤ 0.5 mg · kg^{-1} d.m. The largest concentration of this metal was in shoots of common dandelion (0.32 mg · kg^{-1} d.m.) growing nearest the highway, that is in the distance of 2 m (Table 1). According to the investigation, with the increase of the distance from the source of pollution, the content of cadmium decreased in the considered plant material in common dandelion and in the other herbs as well.

Table 1

The cadmium content in the shoots of investigated plants [mg · kg^{-1} d.m.]

Plants	Distance from the road [m]			
	2	10	30	50
Common dandelion	0.32 Aa	0.24 Ab	0.23 Ab	0.18 Ac
Greater plantian	0.18 Ba	0.13 Bb	0.10 Bc	0.07 Bd
Garden sorrel	0.20 Ca	0.17 Cb	0.16 Cb	0.10 Cc

Means in lines appointed various letters differ significantly; means in columns appointed various letters differ significantly.

The smallest quantities of this element were affirmed in the shoots of greater plantian (0.07 mg · kg^{-1} d.m.) gathered from the distance of 50 m from the source of pollution. The largest fall of the cadmium concentration with the distance from the source of pollution was in the shoots of greater plantian. This decrease was over 61 % for measurements at the distance of 2 m and 50 m. The smallest decrease of cadmium content coming to about 44 % was observed in shoots of the common dandelion for measurements on the same distances. The statistical analysis showed significant differences in the cadmium content in the shoots of greater plantian in all points of the experiment. However it was not found significant differences between the cadmium concentration in the shoots of common dandelion and garden sorrel growing at the distance of 10 and 30 m.

The comparison with literature data concerning the contamination levels of heavy metals in plants near highways is very difficult [6]. The ranges of cadmium extracted from the herbs, were lower than those observed in *Graminaceae* by many authors eg [7] and [8] who studied *Chenchrus echinatus, Sarghum halopense*, *Paspalum paniculatum* and *Stipia ichu*. Nevertheless, they are similar to the values obtained in recent studies on tobacco leaves [9] or herbs leaves and vegetables [10]. Levels of cadmium were lower than those found in earlier studies [8] although they were comparable to those recently observed [11, 12] and [9, 13]. In comparison to the values owning to subchronical toxicity for cattle through forages (0.5 Cd mg · kg^{-1} d.m., [11] the concentrations of this metal was less.

Independently from the species of the studied dicotyledonous plants the most cadmium (0.23 mg · kg^{-1} d.m.) had the plants growing in the distance of 2 m from the wayside ditch. This content systematically decreased with the distance from the source of pollution achieving the lowest average content (0.12 mg · kg^{-1} d.m.) for the distance of 50 m.

Roadside contamination was obvious by the significant negative correlations between concentrations of metals in plant samples and distance from road edge [14, 15]. Metals in roadside plant samples were within normal levels although plants from control sites were found to have slightly less metals [16]. Different parts of a plant (roots, stem & leaves) were found to accumulate metals in different concentrations.

The average cadmium contents in underground parts also decreased with the distance from the source of pollution. The largest concentration of this element had the plants gathered in the distance of 2 m (0.17 mg · kg^{-1} d.m.). Although, levels of Cd obtained in plant were lower than the EU limit and the background value given by [1], detection of the metal in plant cells for sustained monitoring. Ruminants that wander and graze along roadsides feed on these grasses while birds and domestic fowls feed on insects and earthworms [17, 18]. Transfer of metals through the food chain and accumulation are most probable the cause of health problems especially in animals that occupy the upper echelons of food chain. Thus, concerning of accumulation and toxicity ability of this metal in ruminants grazing on vegetation along these roads is very important.

The smallest quantities of cadmium had the plants gathered in the distance of 50 m (0.11 mg · kg^{-1} d.m.). The cadmium contents independently from the species of the studied plant did not show significant differences between measurements performed on the distance of 10 and 30 m. In the other cases the measurements showed significant differences between themselves.

It was reported that direct uptake of Cd into leaves can occur [5]. In particular, in the case of a high intrinsic level of Cd (usually resulting from root uptake), foliar Cd uptake increases due to increased permeability of the leaf cuticle [19]. Although Cd concentrations are usually low in plants grown in uncontaminated sites, Cd concentrations in leaves can be as high as, for example 45 μg/g, when plants are grown on contaminated sites.

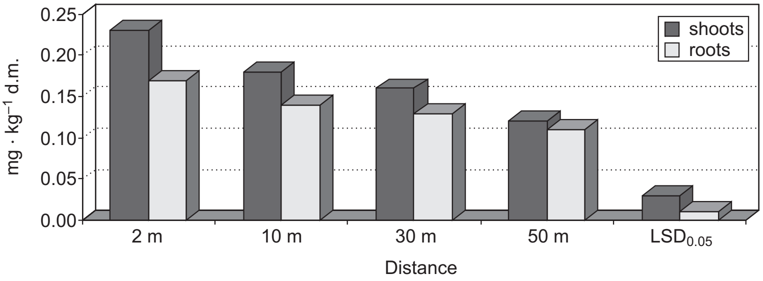

Fig. 1. The average contents of cadmium in the shoots and in underground parts of studied species of plants on the estimated distances

The accumulation of heavy metals is not only in the shoots of herbaceous plants. Their underground parts also show ability to the accumulation of heavy metals. Conducted investigations (Table 2) showed, that the largest concentration of cadmium was in underground parts of the common dandelion (0.19 mg · kg^{-1} d.m.) growing in the distance of 2 m from the wayside ditch, but the least cadmium in this distance was taken by garden sorrel (0.13 mg · kg^{-1} d.m.).

Table 2

The cadmium content in underground parts of plants [mg · kg^{-1} d.m.]

Plants	Distance from the road [m]			
	2	10	30	50
Common dandelion	0.19 Aa	0.16 Ab	0.16 Ab	0.15 Ab
Greater plantian	0.18 Ba	0.17 Bb	0.15 Bc	0.12 Bd
Garden sorrel	0.13 Ca	0.09 Cb	0.08 Cb	0.07 Cb

Means in lines appointed various letters differ significantly; means in columns appointed various letters differ significantly.

As was reported [15], average metal concentrations in scabwort leaves were clearly below the range of metal concentrations in plant leaves that are considered phytotoxic. However, concentrations of Pb, Cd, and Zn in roadside samples of scabwort leaves were higher than those reported in leaves of the same plant from the control site [20]. The ability of different plant species to accumulate metals and reflect environmental contamination has been investigated by a number of researchers [6, 15, 20, 21].

The cadmium content decreased with the distance from the source of pollution in underground parts (Table 2) of greater plantain and garden sorrel. In the case of common dandelion at the distance of 10 and 30 m the same quantities of cadmium were affirmed (0.16 mg · kg^{-1} d.m.).

The largest decrease the cadmium content with the distance from highway was in the plants of garden sorrel. The content of this metal in this plant at the distance of 50 m decreased about 46 % in the relation to the measurement performed at the distance of 2 m. The smallest decrease coming to about 21 % was observed in underground parts of the common dandelion.

The results of the conducted statistical analysis show significant differences in the content of cadmium in underground parts in the studied herbs. Significant differences cadmium content were also between all points of greater plantain. In the case of two other plants there were no significant differences in the content of this element between measurements performed at the distance of 10 m, 30 m and 50 m.

Taking into account studied plants it was showed, that the common dandelion had the most cadmium content in shoots independently to distance from the road (0.24 mg · kg^{-1} d.m.), and the least one greater plantain (0.12 mg · kg^{-1} d.m.) (Fig. 2). The similar tendency was also in underground parts of herbs, where the largest concentration of this element had the common dandelion (0.165 mg · kg^{-1} d.m.), and the smallest one, garden sorrel (0.09 mg · kg^{-1} d.m.).

Plants used in therapeutics should be picked in areas free of any contamination sources [22]. However, as can be seen from the literature [23, 24] medical raw plant materials differ significantly with respect to the content of metals.

The concentration of heavy metals is one of the criteria according to which raw plants can be used for the production of medicines. Due to the importance of the

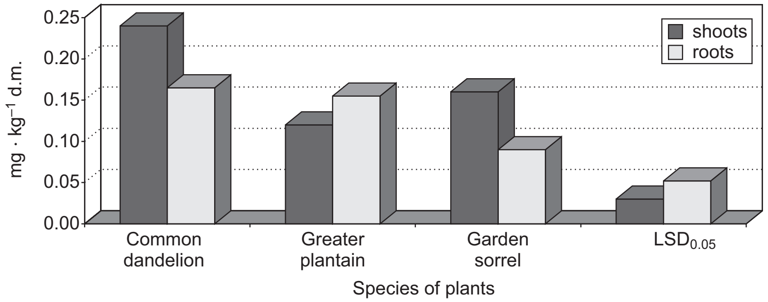

Fig. 2. The average content of cadmium in shoots and underground parts of studied species of plants

mineral and trace elements present in medicinal herbs, several studies have been carried out determine their levels [16, 18, 23, 25–27].

Elevated Cd concentrations [22] were determined in birch which is one of the most popular herbs in Poland and common dandelion (concentrations higher than the WHO permissible level of (0.3 mg · kg^{-1} d.m.).

Independently from the place of the gathering of the plant material (Fig. 2), the average content of cadmium in underground parts of the garden sorrel (0.09 mg · kg^{-1} d.m.) differed significantly from the content of this metal in common dandelion (0.165 mg · kg^{-1} d.m.) and greater plantain (0.155 mg · kg^{-1} d.m.).

Significant differences were not confirmed between common dandelion, and greater plantain independently from the distance of the gathering of the investigative material.

Medicinal plants are used for tea preparation, only the extractable component of heavy metals is available to humans [22]. Due to allow extraction efficiency from raw materials to water, only a small fraction of the total content of Ba, Cd, Cr, Ni, Pb and Zn in the raw material can be found in infusions prepared from common dandelion, birch and hawthorn in comparison with levels of these metals in raw materials themselves.

Conclusions

From among of studied herbs, the best coefficient of pollution with cadmium had common dandelion, which had the largest quantity of this metal at the distance of 2 m from highway in shoots (0.32 mg · kg^{-1} d.m.) as well as in underground parts (0.19 mg · kg^{-1} d.m.).

The concentration of the cadmium content in shoots and in underground parts systematically decreased in the measure of dismissing from the source of pollution in all studied plants.

Independently from the place of the gathering of the plant material, the most cadmium accumulates had the common dandelion in the shoots (0.24 mg · kg^{-1} d.m.), however the smallest concentration of cadmium in studied herbs was in the underground parts of garden sorrel (0.09 mg · kg^{-1} d.m.) independently from the place of gathering.

The admissible contents of cadmium for consumptive aims (0.15 mg · kg^{-1} d.m.) were exceeded in the shoots and in underground parts especially in common dandelion at all distances from the source of pollution.

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WYSTĘPOWANIE KADMU W ZIOŁACH ROSNĄCYCH NA UŻYTKACH ZIELONYCH ZLOKALIZOWANYCH W POBLIŻU DROGI SZYBKIEGO RUCHU

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Akademia Podlaska

Abstrakt: Celem pracy jest określenie stopnia zanieczyszczenia kadmem wybranych gatunków roślin dwuliściennych, do których należą m.in. zioła zbierane z trwałych użytków zielonych znajdujących się przy trasie szybkiego ruchu. Wybrane zioła zbierano z użytków zielonych przy międzynarodowej trasie E-30 w pobliżu Siedlec. Zbierano takie zioła, jak: mniszek pospolity (*Taraxacum officinale* L.), babkę zwyczajną (*Plantiago major* L.) i szczaw zwyczajny (*Rumex acetosa* L.). Materiał roślinny pobrano z odległości 2; 10; 30 i 50 m od przydrożnego rowu. Następnie oddzielono części nadziemne roślin (łodygi i liście) od części podziemnych (korzeni i kłączy), po czym wysuszono je i zmielono. Rozdrobniony materiał w 5 g próbkach poddano mineralizacji w temp. 450 °C. Tak przygotowane próbki przeprowadzono w roztwór z 10 cm^3 10 % HCl i uzupełniono wodą destylowaną do objętości 50 cm^3. W otrzymanych roztworach oznaczono zawartość kadmu za pomocą metody AAS.

Stężenie zawartości kadmu zarówno w częściach nadziemnych, jak i podziemnych systematycznie zmniejszało się w miarę oddalania od źródła zanieczyszczenia we wszystkich badanych roślinach. Niezależnie od miejsca poboru materiału roślinnego najwięcej kadmu kumuluje mniszek pospolity w częściach nadziemnych (0,24 $mg \cdot kg^{-1}$ s.m.), natomiast najmniejsze stężenie kadmu w badanych ziołach niezależnie od miejsca pobierania było w częściach podziemnych szczawiu zwyczajnego (0,09 $mg \cdot kg^{-1}$ s.m.).

Słowa kluczowe: kadm, trasa szybkiego ruchu, mniszek pospolity, szczaw zwyczajny, babka lancetowata

ECOLOGICAL CHEMISTRY AND ENGINEERING A

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Andrzej JAGUŚ[1]

ASSESSMENT OF TROPHIC STATE OF INLAND WATER (THE CASE OF THE SOLA CASCADE DAM RESERVOIRS)

OCENA STANU TROFICZNEGO WÓD ŚRÓDLĄDOWYCH (NA PRZYKŁADZIE KASKADY SOŁY)

Abstract: The objective of the study was to assess the trophic state of water in the hydrographic system of the Sola cascade, situated in the Carpathian region in southern Poland. Analyses included inflowing and retained water in dam reservoirs: Tresna, Porabka and Czaniec. The level of eutrophication of water was estimated basing on its physicochemical parameters. Out of all methods used in determining the trophic state, the selected methods included the norms determined in the Polish regulations, the Neverova-Dziopak index (ITS – *Index of Trophical State*) and the Carlson index (TSI – *Trophic State Index*). Analyses of data from years 2007–2009 showed that water quality reflected characteristic parameters for mesotrophy and eutrophy. Unfavorable trophic state concerned almost all waters that were studied, including waters of the lowest reservoir of the cascade – Czaniec reservoir, which is part of the municipal water supply system. That emphasizes the need for protection of the catchment of the cascade with regards to reduction of contamination load discharged to surface waters.

Keywords: inland water, Sola cascade dam reservoirs, water quality, eutrophication, trophic index

One of the major factors that set limitations on the use of disposable water resources is the process of eutrophication, related to excessive supply of nutrients in water. It diminishes the quality of water and causes sanitary threat resulting from anaerobic decomposition of organic matter and toxicity of metabolism products of phytoplankton organisms [1, 2]. It is therefore reasonable to establish monitoring of water trophic state in order to determine the need for protection of water from eutrophication. The most important in Poland is monitoring of water quality in the mountains, as these waters play a strategic role in nationwide water supply [3, 4]. Water reserves that occur there (about 30 % of national reserve) should be retained and transferred to lower areas without loss of quality. Geosystems of dam water reservoirs need particular care in terms of control and measurements, as their self-purification capabilities are lower than

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those of running watercourses, and at the same time they serve as water reservoirs for municipal and economic needs. Due to the fact that mountainous catchments include head-springs of rivers, water retained in those reservoirs should be of high quality, reflecting the oligotrophic (low fertility) or, possibly, mesotrophic state (moderate fertility). The eutrophic state (high fertility) should be considered as unfavorable.

The trophic state of inland water is determined using various methods, which usually consist in analysis of specific physicochemical or biological parameters. Measured values of parameters are compared – directly or after processing – with threshold values of trophic states. The most commonly used parameters include total phosphorus, phosphates, total nitrogen, nitrates(V), ammonia, oxygen, chlorophyll α, transparency of water (*Secchi disk visibility*), reaction, conductivity, etc. Of importance are also biological parameters, namely characteristics of macroinvertebrates, ichthyofauna, macrophytes and phytoplankton. The worldwide classification system for the trophic state of water was suggested by the *Organisation for Economic Co-operation and Development* (OECD) [5] and the *European Environment Agency* (EEA) [6], among others. A range of index-based methods and national norms have also been established for assessment of the trophic state of water [4, 7, 8]. The choice of the method for evaluation of the trophic state of water depends on the scope, period and frequency of quality analyses of water.

The objective of the paper was to assess the trophic state of water in the hydrographic system of the Sola cascade, composed of three dam reservoirs: Tresna, Porabka, Czaniec (Fig. 1). The dams cross the valley of the Sola river in its southern section across the Beskid Maly mountain range in the Carpathian region of southern Poland [9]. The reservoirs serve multiple functions, and the lowest one (Czaniec) is a municipal water system reservoir for Bielsko-Biala and cities of the Silesian conurbation. The reservoirs can store about 122 Mm^3 of water (Tresna – 94.6 Mm^3, Porabka – 26.6 Mm^3, Czaniec – 1.3 Mm^3) drained from the area of 1,119 km^2 [10, 11]. The cascade is mainly fed with waters from the Sola, although the reservoirs also have direct tributaries. Field observations of the catchment area show that main sources of possible contamination of water include: wastewater from regions without sewage systems, fertilizers used in agriculture, unmanaged animal waste and erosion runoff.

Methods

The research made it possible to determine the trophic state of both running waters feeding the reservoirs and standing waters in the reservoirs. The author used the values of physicochemical parameters of waters from the database of the state monitoring of the environment from years 2007–2009.

With regards to running waters, the research included the following sites (Fig. 1):

- the estuary of the Sola to Tresna reservoir;
- the estuary of the Zylica to Tresna reservoir;
- the estuary of the Lekawka to Tresna reservoir;
- the estuary of the Ponikwia to Porabka reservoir;
- the estuary of the Wielka Puszcza to the Sola.

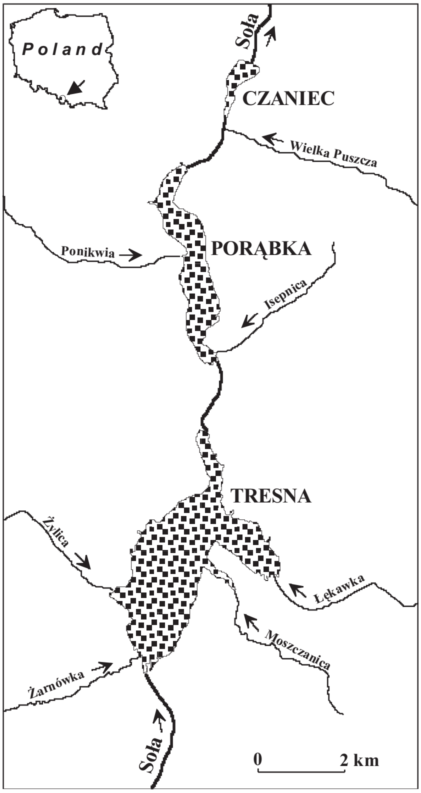

Fig. 1. Sketch of the Sola cascade

Physicochemical analyses of running waters were carried out once a month, which gave 36 measurement series. That made it possible to determine the trophic state according to the rules set forth in the Polish regulations, which require that mean yearly concentrations of some substances be determined [12]. The trophic state of running waters was also determined according to the ITS index (*Index of Trophical State*) suggested by Neverova-Dziopak [13]. The use of the ITS index consists in evaluation of concentrations of oxygen and carbon dioxide in water, expressed by oxygen saturation in water and its reaction. The index is only calculated if there is a linear relation between the values of reaction (pH) and percentage of oxygen saturation of water ($\%O_2$), according to the following formula [13]:

$$\mathrm{ITS} = \Sigma \mathrm{pH}/n + a \cdot (100 - \Sigma\%\mathrm{O}_2/n)$$

where: n – number of measurements;
a – coefficient of linear regression between pH and $\%O_2$.

According to the formula, the coefficient of correlation between pH and $\%O_2$ was calculated for each year. The test of correlation relevance was carried out using

Student's t-distribution table (for $n - 2 = 10$ and $\alpha = 0.05$). Then, a linear equation was worked out to describe the correlation between pH and oxygen saturation. Relevance of the described function was tested by means of multiple regression analysis using Snedecor's F-distribution table (for $n - 2 = 10$ and $\alpha = 0.05$).

The studies of reservoir waters were carried out in near-dam zones in summer seasons of years 2007–2009, which gave 3 measurement series. Thus, the trophic state of waters was determined according to the mentioned Polish legal norms [12], which require, in case of standing waters, measurement of physicochemical parameters during the vegetative season. Additionally, the trophic state was determined by calculating Carlson's three-variable *Trophic State Index* (TSI) [14], based on measurements of total phosphorus concentrations (TSI_{TP}), chlorophyll α concentrations (TSI_{Chl}) and water transparency measured using Secchi disc (TSI_{SD}). The following formulas were used in calculations [14]:

$$TSI_{TP} = 14.42 \cdot \ln(TP \cdot 1000) + 4.15$$

$$TSI_{Chl} = 9.81 \cdot \ln(Chl) + 30.6$$

$$TSI_{SD} = 60 - 14.41 \cdot \ln(SD)$$

where: TP – total phosphorus concentration [mg/dm^3];
Chl – chlorophyll α concentration [μg/dm^3];
SD – Secchi disc visibility [m].

The conditions are favorable when all three elements of the index (TSI_{TP}, TSI_{Chl}, TSI_{SD}) for three parameters of water measured at the same time have similar values. It is worth mentioning that the TSI index should not be used in estuary zones of water reservoirs (especially in areas with high relief) due to too high influence of inflowing debris on the state of parameters which are considered in calculations.

The trophic state of running waters

According to the directives for classification of running waters as eutrophic, included in the Regulation of the Minister of Environment [12], waters of the Sola river and other tributaries of the reservoirs did not show the eutrophic state. That is confirmed by the fact that the recorded mean yearly values of concentrations of index substances (Table 1) – total phosphorus, total nitrogen, nitrate(V)-nitrogen and nitrates(V), were lower than the set thresholds (it is also recommended that concentrations of chlorophyll α, whose threshold mean yearly concentration is 25 μg/dm^3, be measured). These waters, however, flowed into limnic water areas, which are the environment with higher vulnerability to eutrophication. The biogenic elements (P, N) present in running waters occurred in amounts which could stimulate the growth of biological life in limnic geosystems [15].

Table 1

The mean yearly values of eutrophication indices in the flowing waters related to the maximum values of eutrophication (based on data from WIOS in Katowice)

Total phosphorus [mg/dm^3]			Total nitrogen [mg/dm^3]			Nitrate(V)-nitrogen [mg/dm^3]			Nitrates(V) [mg/dm^3]*		
2007	2008	2009	2007	2008	2009	2007	2008	2009	2007	2008	2009
Sola											
0.034	0.032	0.053	1.165	1.222	1.408	0.861	0.954	1.006	3.808	4.221	4.450
Zylica											
0.043	0.050	0.065	1.866	2.126	2.130	1.567	1.851	1.767	6.972	8.188	7.816
Lekawka											
0.038	0.079	0.055	1.486	1.400	1.782	1.154	1.122	1.345	5.106	4.962	5.950
Ponikwia											
0.031	0.061	0.051	1.450	1.382	1.392	1.219	1.183	1.118	5.394	5.231	4.948
Wielka Puszcza											
0.031	0.045	0.043	1.210	1.062	1.151	0.988	0.861	0.955	4.369	3.808	4.225
Occurrence of eutrophication [12]											
> 0.25			> 5.0			> 2.2			> 10.0		

* Concentration of nitrates(V) ions.

Calculation of the ITS index was only possible for waters of the Sola and the Lekawka, as those cases showed the linear correlation between the values of pH and percentage of oxygen saturation in water. The results showed an unfavorable trophic condition of waters of the Sola and the Lekawka (Table 2).

Table 2

Correlation between pH and oxygen saturation ($n - 2 = 10$, $\alpha = 0.05$) and values of the ITS index for waters of the Sola and the Lekawka (based on data from WIOS in Katowice)

Correlation factors	Sola			Lekawka		
	2007	2008	2009	2007	2008	2009
Correlation coefficient	0.89	0.69	0.15	0.77	0.89	0.79
Correlation relevance	yes	yes	no	yes	yes	yes
Linear regression coefficient	0.032	0.032	0.003	0.030	0.040	0.026
Linear regression relevance	yes	yes	no	yes	yes	yes
ITS	8.217	8.297	—	7.998	8.252	8.047
Trophic state [13]	eutrophy	eutrophy	—	mesotrophy	eutrophy	eutrophy

Those waters, flowing to Tresna reservoir, presented eutrophic characteristics in two out of three years that were researched – the eutrophic state occurs when the value of ITS > 8.3 ± 0.3 [13]. All the researched running waters (Sola, Zylica, Lekawka, Ponikwia, Wielka Puszcza) were characterized by alkaline reaction. Mean yearly values of reaction ranged between pH 7.78 and 8.30. The highest pH values, generally exceeding 8, were reported in waters of the Sola and the Lekawka. Whereas oxygen saturation in the researched waters ranged close to normal saturation values – mean yearly values ranged from 91.96 to 101.29. All that proves the tendency of the environment towards biological production.

The trophic state of reservoir waters

With regards to the threshold values for eutrophication indices for standing water, as set forth in the Regulation of the Minister of Environment [12], waters of near-dam zones of reservoirs were not generally eutrophicated. Only transparency of water in Czaniec reservoir was unsatisfactory, thus suggesting eutrophication processes (Table 3). According to the norms by OECD [5], water transparency in Czaniec reservoir qualified it in subsequent years as the mesotrophic and eutrophic water area, while reservoirs Tresna and Porabka showed characteristics of oligotrohic and mesotrophic water areas in that respect. Concentrations of phosphorus and nitrogen compounds were similar in waters of all reservoirs. These elements occurred in amounts which allow for water blooming. According to Vollenweider [16], water blooming may occur with the concentration of nitrogen compounds over 0.3 mg TN/dm^3, and phosphorus compounds over 0.015 mg TP/dm^3, whereas waters of the reservoirs under discussion nitrogen concentrations were recorded at 0.74–1.31 mg TN/dm^3, and phosphorus concentrations at 0.03–0.05 mg TP/dm^3.

Table 3

Physicochemical parameters of the Sola cascade dam waters related to the maximum values of eutrophication (based on data from WIOS in Katowice)

Parameter	Year	Tresna reservoir	Porabka reservoir	Czaniec reservoir	Occurrence of eutrophication [12]
Total phosphorus [mg/dm^3]	2007	0.03	0.03	0.03	> 0.1
	2008	0.03	0.03	0.04	
	2009	0.05	0.04	0.05	
Total nitrogen [mg/dm^3]	2007	0.96	0.74	0.77	> 1.5
	2008	1.22	1.21	1.14	
	2009	0.98	0.96	1.31	
Chlorophyll α [μg/dm^3]	2007	6.2	12.7	10.3	> 25.0
	2008	—	—	—	
	2009	8.7	—	2.3	
Transparency [m]	2007	2.4	3.8	**1.8**	< 2.0
	2008	4.0	2.8	**1.4**	
	2009	3.2	3.0	3.0	

Calculations of the Carlson index [14] showed that the trophic state of the reservoirs was most frequently on the border of mesotrophic and eutrophic states (Table 4). That was particularly visible in the index calculated basing on the concentration of phosphorus in water, as its values exceeded 50 units in the following scale:

- TSI < 40 – oligotrophy;
- TSI from 40 to 50 – mesotrophy;
- TSI from 50 to 60 – meso-eutrophy;
- TSI > 60 (to 80) – eutrophy.

The index values calculated basing on the transparency, in turn, suggested the highest fertility of water in Czaniec reservoir. That is related to the smallest depth of this reservoir in comparison with the others, which fosters warming up of water and growth of phytoplankton. Mass occurrence of algae can be observed in all three reservoirs, however, which confirms their unfavorable trophic condition showed by index calculations.

Table 4

Trophic state of waters in Sola cascade dam reservoirs according to the Carlson index [14] (based on data from WIOS in Katowice)

Reservoir	Year	TSI_{TP}		TSI_{Chl}		TSI_{SD}	
		value	trophic state	value	trophic state	value	trophic state
Tresna	2007	53.2	meso-eutrophy	48.5	mesotrophy	47.4	mesotrophy
	2008	53.2	meso-eutrophy	—	—	40.0	mesotrophy
	2009	60.6	eutrophy	51.8	meso-eutrophy	43.2	mesotrophy
Porabka	2007	53.2	meso-eutrophy	55.5	meso-eutrophy	40.8	mesotrophy
	2008	53.2	meso-eutrophy	—	—	45.2	mesotrophy
	2009	57.3	meso-eutrophy	—	—	44.2	mesotrophy
Czaniec	2007	53.2	meso-eutrophy	53.5	meso-eutrophy	51.5	meso-eutrophy
	2008	57.3	meso-eutrophy	—	—	55.2	meso-eutrophy
	2009	60.6	eutrophy	38.8	oligotrophy	44.2	mesotrophy

Conclusions

1. According to the recommendations from legal regulations, regarding classification of eutrophy, the flowing and standing waters of the hydrographic system of the Sola were not considered eutrophicated.

2. Calculations of indices of the trophic state worked out according to scientific methodology showed that the researched waters were characterized by the mesotrophic or eutrophic state, which is particularly unfavorable for Czaniec reservoir, as it is part of the municipal water system. In particular, the eutrophic state concerned flowing waters feeding the reservoir.

3. Due to high socioeconomic importance of the reservoirs of the Sola river, it is important to reduce the load of wastewater coming from the catchment in order to improve the quality of retained water.

4. It is necessary to work out and popularize universal criteria for determining the trophic state of inland flowing and standing waters, which would be obligatory to use for national services and environment researchers.

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OCENA STANU TROFICZNEGO WÓD ŚRÓDLĄDOWYCH (NA PRZYKŁADZIE KASKADY SOŁY)

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Abstrakt: Celem badań było rozpoznanie stanu troficznego wód w systemie hydrograficznym kaskady Soły, położonej w obszarach karpackich Polski południowej. Analizowano wody dopływające oraz retencjonowane w zbiornikach zaporowych: Tresna, Porąbka i Czaniec. Na podstawie parametrów fizykochemicznych wód ustalono stopień ich eutrofizacji. Spośród stosowanych metod ustalania stanu trofii wybrano normy określone w polskich przepisach prawnych, wskaźnik Neverovej-Dziopak (ITS – *Index of Trophical State*) oraz wskaźnik Carlsona (TSI – *Trophic State Index*). Analizy danych z lat 2007–2009 wykazały, że jakość wód odpowiadała parametrom charakterystycznym dla mezotrofii oraz eutrofii. Niekorzystny stan trofii dotyczył niemal wszystkich badanych wód, w tym wód najniższego zbiornika kaskady – wodociągowego zbiornika Czaniec. Wskazuje to na potrzebę ochrony zlewni kaskady pod kątem ograniczenia ładunku zanieczyszczeń dostających się do wód powierzchniowych.

Słowa kluczowe: wody śródlądowe, kaskada Soły, jakość wód, eutrofizacja, wskaźnik trofii

ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 11 2011

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ASSESSMENT OF RESTORED WATER BODIES IN A RIVER-LAKE SYSTEM BASED ON PHOSPHORUS CONCENTRATIONS

OCENA FUNKCJONOWANIA ZRENATURYZOWANYCH ZBIORNIKÓW WODNYCH NALEŻĄCYCH DO SYSTEMU RZECZNO-JEZIORNEGO NA PODSTAWIE STĘŻEŃ FOSFORU

Abstract: Three water bodies restored around 30 years ago were studied: Lake Nowe Wloki, Lake Setalskie Duze and Lake Setalskie Male, connected by the Setal Stream into a single river-lake system in the Olsztyn Lakeland, approximately 25 km north of the city of Olsztyn, in the District of Dywity.

The objective of this study was to evaluate the functioning of three water bodies in a river-lake system restored around 30 years ago. Particular attention was paid to water quality and the trophic status of the analyzed lakes, assessed based on seasonal changes in phosphorus concentrations.

A river-lake system comprising restored water bodies in rural areas reduces the concentrations of biogens migrating from the catchment area, thus minimizing the effects of potential eutrophication in larger rivers and other water bodies to which the system's watercourses evacuate. As regards lake inflows, a drop in total phosphorus levels was noted after passage through the water body, and high concentrations of total P resulted from the polymictic character of the studied lakes.

The inflows to water bodies that form a chain system supply substantial amounts of total P to the lakes, leading to the retention of excessive phosphorus concentrations and speeding up processes which deteriorate water quality and lake functioning. Over a three-year experimental period, the average concentrations of phosphorus, – an element limiting primary production – varied from 0.22 to 0.34 mg $P_{total} \cdot dm^{-3}$ in the water bodies within the studied river-lake system. The absence of water stratification (hypolimnion) contributed to intensive phosphorus recirculation and very high trophy levels in the examined lakes. According to Nurnberg, the total phosphorus concentrations determined in the spring are indicative of their hypetrophy.

Keywords: river-lake system, polymictic lakes, primary production, hypertrophy

The migration and inflow of eutrophicating elements into water bodies from local sources is affected by natural and anthropogenic factors. Natural factors account for

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weather, land relief and inclination, the properties of soil and biogenic substances. Anthropogenic factors include the type of land use and the manner of farm estate management [1, 2].

Phosphorus, nitrogen and potassium form the "chemical trio" of nutrients which are highly demanded by plants [3]. Ecosystems deficient in phosphorus (oligotrophic) are characterized by low biomass production and high biodiversity. Phosphorus is readily absorbed and blocked in the ecosystem, therefore, it reaches water bodies in smallest quantities, and it is also most readily removed from water systems. The phosphorus content of water bodies is usually minimal, and this feature is used in measures aiming to restrict eutrophication. Excessive phosphorus levels in aquatic ecosystems increase water fertility and they are the main cause of eutrophication. The anthropogenic sources of water-borne and soil-borne phosphorus include fertilizers, wastewater and detergents [4].

Young glacial areas feature specific systems of hydrographic objects [5, 6]. Watercourses are connected with lakes, and they are referred to as river-lake systems. Water bodies are interconnected via sections of river water gaps (often intermittent watercourses), creating a cohesive drainage network. River sections linking lakes are short, and most of them are overflows. To a smaller extent and along smaller sections, they are supplied by underground streams, and excess water overflows from one water body to another [7]. The resulting ecosystem seasonally retains matter migrating from the catchment. The circulation of biophilic elements is a factor that contributes to water trophy [8, 9]. As part of a single river-lake system, a lake can therefore both trap and evacuate phosphorus [10, 11]. Research studies investigating agricultural catchment areas indicate that anthropogenic factors significantly contribute to the eutrophication of restored water bodies.

The objective of this study was to evaluate water bodies in a river-lake system restored around 30 years ago. Particular attention was paid to water quality and the trophic status of the analyzed lakes, assessed based on seasonal changes in phosphorus concentrations.

Materials and methods

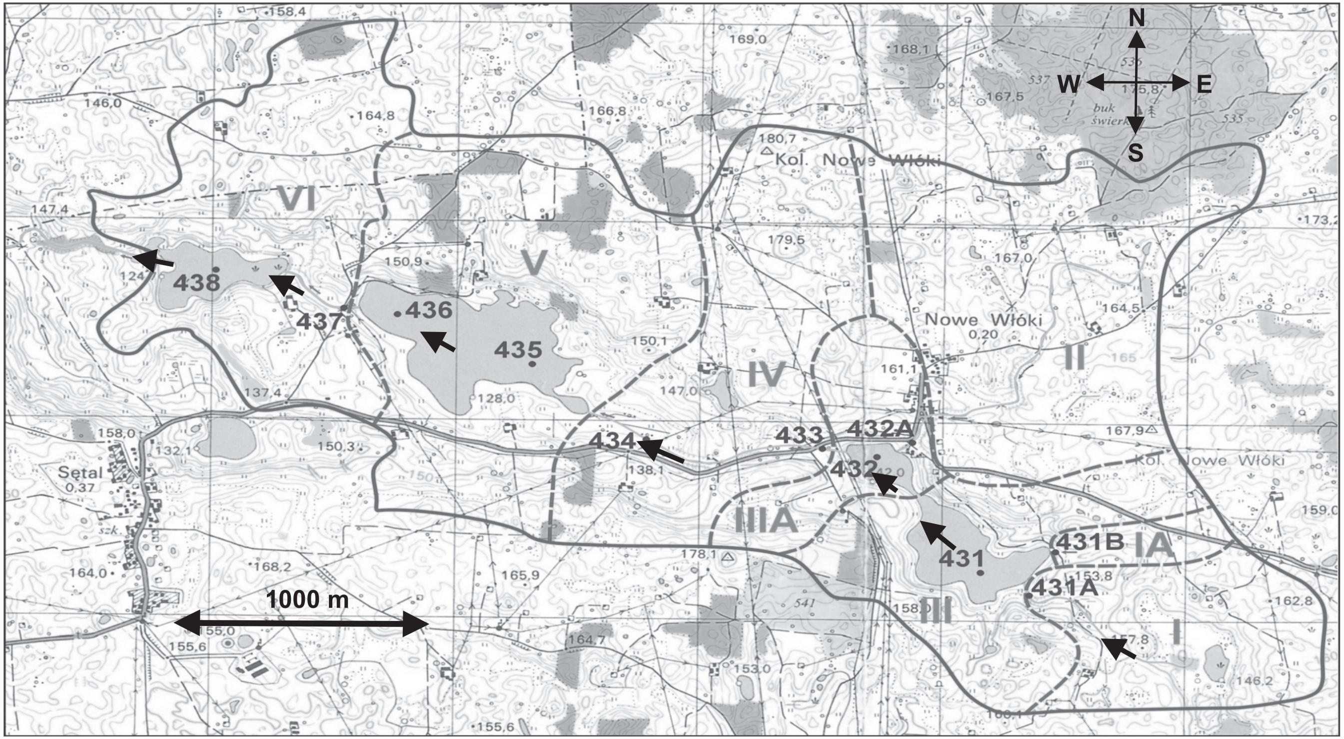
The study investigated three water bodies in the Protected Landscape Area in the Valley of Middle River Lyna, comprising Lake Nowe Wloki, Lake Setalskie Duze and Lake Setalskie Male, connected by the Setal Stream to form a single, cohesive river-lake system. The studied objects were drained in the 19th century during a comprehensive land improvement project to create agricultural grassland. In view of the need for small retention reservoirs and fire water reservoirs in rural areas, the discussed water bodies were restored at the turn of the 1970s and the 1980s. The lakes are situated along the Setalski drainage canal (presently referred to as the Setal Stream), and the restoration involved a water damming project on the Stream. The studied water bodies are polymictic lakes with a small average depth of 1.1 to 2.3 m.

Lake Nowe Wloki is situated near the village of Nowe Wloki, and the remaining water bodies, Lake Setalskie Duze and Lake Setalski Male, are found in the village of

Setal, Dywity District in the Olsztyn Lakeland, approximately 25 km north of the city of Olsztyn. The analyzed district is weakly afforested, it comprises mostly agricultural land with the predominance of brown soils. The local soils are cohesive, and they have developed mostly from heavy loamy sand underlain by a layer of light loam throughout the entire soil profile [Central Statistical Office 2003].

The analyzed catchment has a total surface area of 883.82 ha. It was initially divided into eight subcatchments which were assigned the following numbers: I, IA, II, III, IIIA, IV, V, VI. The location of each subcatchment and measuring points is presented in Fig. 1.

Lake Nowe Wloki comprises two sections: the southern section which is the main lake basin (point 431) and the northern bay (point 432) with a combined area of 19.67 ha. The main lake basin has an elongated profile, and it is adjacent to farmland on the right bank and meadows on the left bank. The northern bay has a much smaller area, and it is found in the vicinity of a road leading to Setal. In the north, the lake directly neighbors three farming estates without livestock. Both meander pools are connected by a characteristic contraction densely overgrown with sedge (*Carex* sp.) and common reed (*Phragmites australis* (Cav) Trin. Ex Steudel). The lake's catchment has a combined area of 408.19 ha, and it comprises smaller subcatchments. Catchment I features the upper course of the Setal Stream which reaches the lake, marked as number 431A. This subcatchment is occupied by arable land and grasslands in 89 %. Drainage canal 431B runs in the eastern part of the lake (main basin), and it evacuates water from subcatchment IA into the lake. This subcatchment has the inclination of 6.6 %, and 94 % of its area is occupied by farmland. The area was drained in September 2006. In the north, the lake neighbors the village of Nowe Wloki which does not operate a sewer system. This part of the lake constitutes subcatchment II which feeds into Lake Nowe Wloki (northern bay) via drainage ditch 432A. Subcatchment III constitutes the lake's direct catchment. Water is evacuated from the lake (433) via a watercourse marked by point 434 (in subcatchment IV) which feeds into Lake Setalskie Duze. Lake Setalskie Duze (its eastern section was assigned number 435, the western section – 436) is the largest of the studied objects with an area of 41.34 ha. It is situated in (direct) catchment V which is occupied by farmland in more than 54 %. The northern part of the catchment features three land plots with holiday cottages made of brick. The land plots enclose three fish ponds and two small farms, one of which raises 20 cows. Cattle are grazed on pastures on the north-eastern side of the lake. The eastern part of the lake has a small bay with a depth of 1.4 m and a gently sloping bottom. It is densely overgrown with common reed (*Phragmites australis* (Cav) Trin. Ex Steudel), reed canarygrass (*Phalaris arundinacea* L.), sedge (*Carex* sp.) and simplestem bur-reed (*Sparganium erectum* L.). Water is evacuated from the water body via a ditch (437), and it is carried by a drainage canal along farm fields to Lake Setalskie Male. Similarly to Lake Nowe Wloki, the stream supplying and evacuating water from the lake is also a seasonal watercourse (stagnant water) which is affected by weather conditions. Lake Setalskie Male is separated from Lake Setalskie Duze by a (straight line) distance of approximately 300 m, and it is situated at the lowest altitude (124.7 m above sea level). The lake has an area of 8.07 ha, and it is found in direct catchment VI. The northern section of the



Key: ● – sampling and measuring points; ⬮ – the investigated water bodies; **I, II** – subcatchment numbers; ‒ ‒ – subcatchment boundaries; ― – catchment boundary; ➔ – direction of water flow.

Fig. 1. Location of the studied water bodies and measuring points, scale 1:25 000
Location and description of measuring points: 431A – inflow to the main basin of Lake Nowe Wloki (Setal Stream), 431B – drainage canal inflowing to Lake Nowe Wloki, 432A – drainage ditch inflowing to Lake Nowe Wloki, 431 – main basin of Lake Nowe Wloki, 432 – northern bay of Lake Nowe Wloki, 433 – outflow from Lake Nowe Wloki, 434 – inflow to Lake Setalskie Duze, 435 – eastern part of Lake Setalskie Duze, 436 – western part of Setalskie Duze 437 – outflow from Lake Setalskie Duze and inflow to Lake Setalskie Male, 438 – Lake Setalskie Male

catchment is steeply inclined in the direction of the water body, and the southern part is a gently undulating area. The lake's banks feature no trees, and they are overgrown only with common reed (*Phragmites australis* (Cav) Trin. Ex Steudel). The lake has an inflow (connecting it to Lake Setalskie Duze) and an outflow which evacuates water all the way to the Lyna River (the outflow was not studied due to limited access).

During the three-year period of the experiment, the following crops were grown in the agricultural catchment of Lake Nowe Wloki: triticale in 2005, winter barley in 2006, rapeseed in 2007. The following crop regime was observed in the catchment of Lake Setalskie Duze: rapeseed in 2005, triticale in 2006 and rye in 2007. Arable land in the catchment of Lake Setalskie Male had the following crop structure: rapeseed in 2005, fallowing in 2006, rapeseed in 2007.

Water samples for laboratory analyses were collected once a month over a period of three years (2005–2007). Total phosphorus and inorganic phosphorus concentrations were determined in the samples. The analyses were performed by the standard method proposed by Hermanowicz et al [12]. The species composition of the described vegetation was determined on the site according to Rutkowski's classification key [13]. An analysis of variance and the determination of statistical differences between datasets were performed with the use of Duncan's test in the Statistica 7 application. The remaining results, including mean, minimum and maximum values, standard deviation, median and the coefficient of variation, were processed statistically using the EXCEL application.

Results and discussion

The trophic status of a water body is largely determined by its phosphorus content. In lake ecosystems, total phosphorus and inorganic phosphorus concentrations are subject to significant seasonal variation. In addition to the phosphorus load supplied from the catchment, phosphorus levels increase due to various internal mechanisms which are intensified with a rise in the lake's trophic state index. A drop in phosphorus concentrations is observed when the element is accumulated in bottom deposits and organisms, in particular macrophyte tissues [14].

Total phosphorus concentrations in the studied chain system lakes were marked by significant variations in successive hydrological years. The average concentrations noted throughout the entire experimental period were similar (except in the northern bay of Lake Nowe Wloki, point 431), reaching 0.22 to 0.34 mg $P_{total} \cdot dm^{-3}$, with significant variations in the course of the examined three-year period (0.03 to 2.27 mg $P_{total} \cdot dm^{-3}$). The median concentrations in the analyzed water bodies were determined in the range of 0.16 to 0.25 mg $P_{total} \cdot dm^{-3}$ (Table 1).

As regards inflow waters supplying Lake Nowe Wloki, significantly lower average total P concentrations were noted over the three-year period in field stream 431A (Stream) at 0.17 mg $P_{total} \cdot dm^{-3}$, which is indicative of water purity class I [15]. In waters evacuated from fields via the drainage canal (431B) and waters evacuated from the agricultural catchment with farm estates via the drainage ditch (432A), the average total P concentrations were more than 60 % higher, reaching 0.29 mg $P_{total} \cdot dm^{-3}$, which

Table 1

Annual and seasonal variations in total P concentrations in the studied water bodies in hydrological years 2005–2007 [mg · dm^{-3}]
A two-way analysis of variance (*Two-Way Anova p ≤ 0.001*) was performed using Duncan's test

Total P															
Site			Measuring point	2005	2006	2007	2005–2007					Seasonal average (over 3 years)			
				average			average	fluctuations	±SD	CV	median	winter	spring	summer	fall
Flow-through water bodies															
Lake Nowe Wloki	Inflows	Setal Stream	431A*	0.18^{a}	0.12^{a}	0.21^{a}	**0.17^{a}**	0.06–0.52	0.14	80	0.16	0.15^{ab}	0.19^{ab}	0.18^{ab}	0.22^{ab}
		drainage canal	431B	X	0.11^{a}	0.28^{a}	**0.29^{ab}**	0.04–0.84	0.23	115	0.19	0.36^{ab}	0.11^{a}	0.43^{ab}	0.18^{ab}
		drainage ditch	432A	0.23^{a}	0.31^{a}	0.33^{a}	**0.29^{ab}**	0.05–0.75	0.20	70	0.21	0.18^{ab}	0.17^{ab}	0.55^{b}	0.35^{ab}
	main basin		431	0.20^{a}	0.24^{a}	0.31^{a}	**0.25^{ab}**	0.04–0.78	0.21	84	0.20	0.17^{ab}	0.14^{a}	0.35^{ab}	0.36^{ab}
	northern bay		432	0.24^{a}	0.41^{b}	0.35^{a}	**0.34^{b}**	0.04–2.27	0.38	112	0.25	0.27^{ab}	0.41^{ab}	0.35^{ab}	0.31^{ab}
	outflow		433	0.31^{a}	0.25^{a}	0.27^{a}	**0.28^{ab}**	0.05–0.86	0.18	67	0.23	0.19^{ab}	0.17^{ab}	0.46^{ab}	0.28^{ab}
Lake Setalskie Duze	inflow		434	0.25^{a}	0.19^{a}	0.34^{a}	**0.26^{ab}**	0.04–1.08	0.20	77	0.20	0.20^{ab}	0.17^{ab}	0.43^{ab}	0.23^{ab}
	eastern part		435	0.19^{a}	0.23^{a}	0.24^{a}	**0.22^{ab}**	0.03–0.48	0.13	60	0.18	0.10^{a}	0.17^{ab}	0.37^{ab}	0.25^{ab}
	western part		436	0.17^{a}	0.23^{a}	0.31^{a}	**0.24^{ab}**	0.06–0.97	0.17	71	0.21	0.22^{ab}	0.18^{ab}	0.30^{ab}	0.25^{ab}
	outflow		437	0.16^{a}	0.22^{a}	0.34^{a}	**0.22^{ab}**	0.03–0.62	0.13	59	0.20	0.19^{ab}	0.16^{ab}	0.29^{ab}	0.25^{ab}
Lake Setalskie Male			438	0.16^{a}	0.23^{a}	0.27^{a}	**0.22^{ab}**	0.06–0.56	0.14	62	0.16	0.17^{ab}	0.27^{ab}	0.23^{ab}	0.18^{ab}

Key: X – the catchment was drained in 2006.
431A – inflow to the main basin of Lake Nowe Wloki (Setal Stream), 431B – drainage canal inflowing to Lake Nowe Wloki (14-month average), 432A – drainage ditch inflowing to the northern bay of Lake Nowe Wloki, 431 – main basin of Lake Nowe Wloki, 432 – northern bay of Lake Nowe Wloki, 433 – outflow from Lake Nowe Wloki, 434 – inflow to Lake Setalskie Duze, 435 – eastern part of Lake Setalskie Duze, 436 – western part of Setalskie Duze 437 – outflow from Lake Setalskie

corresponds to water purity class III, ie water of satisfactory quality (more than half of the analyzed samples were within the above range). The highest median concentrations were determined for drainage ditch 432A at 0.21 mg $P_{total} \cdot dm^{-3}$ (Table 1). Clear differences in total P concentrations were reported between the main (southern) meander pool and the northern meander pool in Lake Nowe Wloki. In the analyzed period, the average levels of total P reached 0.25 mg $P_{total} \cdot dm^{-3}$ in the main lake basin (431), and they were lower by more than 30 % (statistically non-significant) in comparison with the northern bay (432). The bay was characterized by the highest variation of 112 % with fluctuations in the range of 0.04–2.27 mg $P_{total} \cdot dm^{-3}$, and its average concentrations of total P reached 0.34 mg$P_{total} \cdot dm^{-3}$. Extreme concentrations of total P (2.27 mg $P_{total} \cdot dm^{-3}$) and N-NH_4 were reported in March 2006 when the lake remained under ice cover, creating a supportive environment for the release of phosphorus from deposits into the water. In general, high average concentrations of total P in the northern bay of Lake Nowe Wloki could point to the allochthonous origins of phosphorus, mostly surface runoffs from developed areas [16]. Water bodies situated at lower altitudes often receive matter and pollutants from extensive catchment areas of river tributaries, and they are subjected to the adverse effects of anthropogenic pressure [8, 17], as demonstrated by high total P levels in the drainage ditch (Table 1). In the outflow from Lake Nowe Wloki (point 433) and the inflow to Lake Setalskie Duze (point 434), the average total P concentrations were higher than in the bay, reaching 0.28 mg $P_{total} \cdot dm^{-3}$ and 0.26 mg $P_{total} \cdot dm^{-3}$, respectively. The above resulted mainly from phytosorption, as demonstrated by much lower total P levels in the spring (Table 1). In the eastern part of Lake Setalskie Duze (point 435), the average total P concentrations were somewhat lower (by approximately 8 %) in comparison with the western part (point 436) throughout the entire experiment. The above was largely due to heavy rainfall in 2007. According to Kajak [14], torrential rain may lead to the rapid runoff of substantial quantities of the annual nutrient load. The above theory is supported by high phosphorus concentrations noted in January (0.965 mg $P_{total} \cdot dm^{-3}$), June (0.395 mg $P_{total} \cdot dm^{-3}$) and July (0.415 mg $P_{total} \cdot dm^{-3}$) which were marked by heavy precipitation reaching 122 mm, 116 mm and 122 mm, respectively. In this part of the water body, the catchment features steeper slopes which probably contributed to a more intense supply of ground-borne phosphorus from the direct catchment occupied by holiday cottages. In the eastern section (435), the banks are overgrown with aquatic vegetation as well as shrubs and trees that inhibit runoffs from the catchment. In the outflow (437) from Lake Setalskie Duze, the average phosphorus concentrations were maintained at the level noted in the lake throughout the period of the study, implying that outflow waters were of purity class III. In Lake Setalskie Male, the average total P concentrations (0.22 mg $P_{total} \cdot dm^{-3}$) were identical to those reported in the eastern part of Lake Setalskie Duze, but the median concentration (0.16 mg $P_{total} \cdot dm^{-3}$) was lowest among the studied water bodies (Table 1).

The group of lakes situated along the river was characterized by an increase in total phosphorus concentrations in the summer (Table 1). Lower oxygen levels noted in the summer supported the release of phosphorus and its transfer to the water. As demonstrated by various authors [18–20], total phosphorus levels increase with a drop in the water table which decreases the volume of the water body, increases nutrient concentrations and restricts the dilution of biogenic elements. The above phenomenon often lowers water quality and increases total phosphorus concentrations, an indicator of the lake's trophic status. Summer variations in the phosphorus content of water also result from a rise in COD (Chemical Qxygen Demand) levels during that season (46.1–50.1 mg $O_2 \cdot dm^{-3}$).

In the group of flow-through water bodies, the lowest total P concentrations were observed in Lake Setalskie Male in the summer. The lake's surface is overgrown with vegetation in 20 % which limits wave motion and inhibits phosphorus release from the sediments. Phosphorus was additionally consumed by lush vegetation covering the lake bottom, mostly frogbit (*Hydrocharis morsus-ranae* L.) and spiked water milfoil (*Myriophyllum spicatum* L.) (Table 1).

In general, total phosphorus concentrations reached the highest values in all water bodies in the wet year 2007. High precipitation totals (822 mm) supported the leaching of phosphorus from the soil. In comparison with 2006, the atmospheric deposition of phosphorus was twice higher in 2007 (1.84 kg $\cdot$ $ha^{-1} \cdot yr^{-1}$), providing an additional source of total phosphorus [21]. The variations in dissolved phosphorus levels were similar to the changes noted in total phosphorus concentrations.

In the studied water bodies, the average inorganic phosphorus concentrations determined throughout the experimental period ranged from 0.03 mg $P\text{-}PO_4 \cdot dm^{-3}$ to 0.06 mg $P\text{-}PO_4 \cdot dm^{-3}$ in the northern bay (431) of Lake Nowe Wloki where the highest variations in $P\text{-}PO_4$ levels were also noted in the range of 0.003 to 1.07 mg $P\text{-}PO_4 \cdot dm^{-3}$ (Table 2).

In gauging sections in the subcatchments of Lake Nowe Wloki, drainage ditch 432A (0.15 mg $P\text{-}PO_4 \cdot dm^{-3}$) was marked by significantly higher average concentrations of inorganic phosphorus which had a 52 % share of total phosphorus (Table 2, Fig. 2). The above resulted from high $P\text{-}PO_4$ levels in the summer and fall (no phytosorption of phosphorus activated in the mineralization process towards the end of and after the growing season). The average $P\text{-}PO_4$ levels reported during the three-year period in watercourse 431A and drainage canal 431B were identical at 0.04 mg $P\text{-}PO_4 \cdot dm^{-3}$, but in 431A (Stream), the share of inorganic phosphorus in total P was 10 % higher in comparison with drainage canal 431B. In all lakes connected by the Setal Stream, considerably higher average concentrations of $P\text{-}PO_4$ were determined in the northern bay (432) of Lake Nowe Wloki at 0.06 mg $P\text{-}PO_4 \cdot dm^{-3}$. In those water bodies, $P\text{-}PO_4$ had a significantly smaller share of total phosphorus concentrations in comparison with flowing waters, at 12 to 18 %. The studied lakes' outflows were marked by considerable variations in the average levels of inorganic phosphorus. In the outflow (433) from Lake Nowe Wloki, the average $P\text{-}PO_4$ concentrations throughout the period of this experiment were significantly higher than in the outflow (437) from Lake Setalskie Duze. Higher levels of $P\text{-}PO_4$ (which had a 32 % share of total phosphorus) resulted from the mobilization of the studied element from organic matter accumulated in deposits (a broad, shallow and densely overgrown ditch), as demonstrated by its high concentrations in the summer at 0.20 mg $P\text{-}PO_4 \cdot dm^{-3}$ (Table 2, Fig. 2).

Table 2

Annual and seasonal variations in P-PO$_4$ concentrations in the studied water bodies in hydrological years 2005–2007 [mg · dm^{-3}]
A two-way analysis of variance (*Two-Way Anova p ≤ 0.001*) was performed using Duncan's test

P-PO$_4$															
Site			Measuring point	2005	2006	2007	2005–2007					Seasonal average (over 3 years)			
				average			average	fluctuations	±SD	CV	median	winter	spring	summer	fall
Flow-through water bodies															
Lake Nowe Wloki	Inflows	Setal Stream	431A*	0.04^{a}	0.05^{a}	0.05^{a}	**0.04^{a}**	0.014–0.19	0.04	94	0.03	0.06^{a}	0.04^{a}	0.06^{a}	0.03^{a}
		drainage canal	431B	—	0.04^{a}	0.04^{a}	**0.04^{a}**	0.023–0.07	0.01	33	0.04	0.04^{a}	0.03^{a}	0.06^{a}	0.04^{a}
		drainage ditch	432A	0.09^{a}	0.26^{b}	0.10^{a}	**0.15^{c}**	0.020–0.35	0.11	75	0.08	0.05^{a}	0.10^{ab}	0.25^{c}	0.14^{abc}
	main basin			0.03^{a}	0.04^{a}	0.03^{a}	**0.03^{a}**	0.002–0.08	0.02	52	0.03	0.02^{a}	0.04^{a}	0.04^{a}	0.04^{a}
	northern bay		432	0.04^{a}	0.12^{a}	0.02^{a}	**0.06^{ab}**	0.003–1.07	0.18	293	0.03	0.03^{a}	0.14^{abc}	0.04^{a}	0.03^{a}
	outflow		433	0.14^{a}	0.10^{a}	0.04^{a}	**0.09^{b}**	0.001–0.46	0.10	117	0.04	0.04^{a}	0.03^{a}	0.20^{bc}	0.08^{ab}
Lake Setalskie Duze	inflow		434	0.04^{a}	0.06^{a}	0.03^{a}	**0.04^{a}**	0.010–0.14	0.03	67	0.03	0.04^{a}	0.03^{a}	0.05^{a}	0.05^{a}
	eastern part		435	0.04^{a}	0.04^{a}	0.02^{a}	**0.03^{a}**	0.003–0.08	0.02	63	0.03	0.02^{a}	0.03^{a}	0.04^{a}	0.04^{a}
	western part		436	0.04^{a}	0.04^{a}	0.03^{a}	**0.03^{a}**	0.006–0.06	0.02	47	0.03	0.03^{a}	0.04^{a}	0.04^{a}	0.04^{a}
	outflow		437	0.04^{a}	0.05^{a}	0.03^{a}	**0.04^{a}**	0.004–0.14	0.02	53	0.03	0.04^{a}	0.03^{a}	0.04^{a}	0.04^{a}
Lake Setalskie Male			438	0.02^{a}	0.04^{a}	0.02^{a}	**0.03^{a}**	0.004–0.27	0.04	159	0.02	0.03^{a}	0.03^{a}	0.02^{a}	0.02^{a}

Key: refer to Table 1.

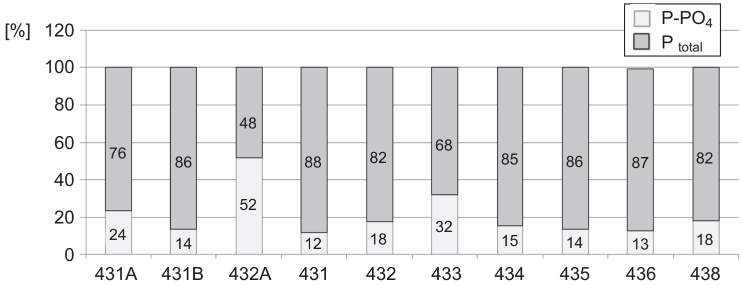


Fig. 2. Percentage share of P-PO$_4$ in P concentrations in the river-lake system
431A – inflow to the main basin of Lake Nowe Wloki (Setal Stream), 431B – drainage canal inflowing to Lake Nowe Wloki (14-month average), 432A – drainage ditch inflowing to the northern bay of Lake Nowe Wloki, 431 – main basin of Lake Nowe Wloki, 432 – northern bay of Lake Nowe Wloki, 433 – outflow from Lake Nowe Wloki, 434 – inflow to Lake Setalskie Duze, 435 – eastern part of Lake Setalskie Duze, 436 – western part of Setalskie Duze 437 – outflow from Lake Setalskie Duze and inflow to Lake Setalskie Male, 438 – Lake Setalskie Male

According to prior experiments investigating the role of river-lake systems [9, 11, 23], biogenic substances migrating with water in the form of mineral compounds and suspensions are readily captured and retained by ecosystems of the type which also produce substantial amounts of organic matter. The variations in total P concentrations in a chain system, expressed by differences in the studied element's percentage content, are shown in Fig. 3. Total phosphorus concentrations in the upper section of the Stream which feeds into the main basin of Lake Nowe Wloki and opens the studied system represent 100 %. The noted results (Fig. 3) indicate that areas where river and lake waters mix [22] play an important role in a chain system where lakes are intersected by river sections and other watercourses (Fig. 3). The average total phosphorus values in inflows (drainage canal 431B, drainage ditch 432A, river section between two lakes – 434) were higher, and they decreased after passage through the lake. A significant increase in total phosphorus concentrations (from 129 % to 165 %) was observed along the course of the Setal Stream. It was particularly high in the outflow from the northern bay (433) of Lake Nowe Wloki (65 % higher than in the upper section of the stream – 431A) which receives water via the drainage ditch from the village with no sewer system. The noted increase was clearly affected by the dry year 2006 when the water body had limited supply. In the peak of the growing season of 2006, which was marked by a drought, higher hydrological stability and reduced water flow, the water body exported phosphorus accumulated in deposits under layers of oxygen-deficient water, as shown by very high average concentrations of total phosphorus (Table 1, Fig. 3). Despite the noted increase in phosphorus levels in the Stream, the results of this study indicate that in view of total P levels in all inflows to the lakes, the analyzed water bodies act as thresholds in the transport process where phosphorus is accumulated in deposits, as shown by total phosphorus concentrations of 129 % in Lake Setalskie Male (Fig. 3).

In reference to the studied lakes' unquestioned role of biogeochemical barriers, the results of this experiment show that despite the negative processes observed in the

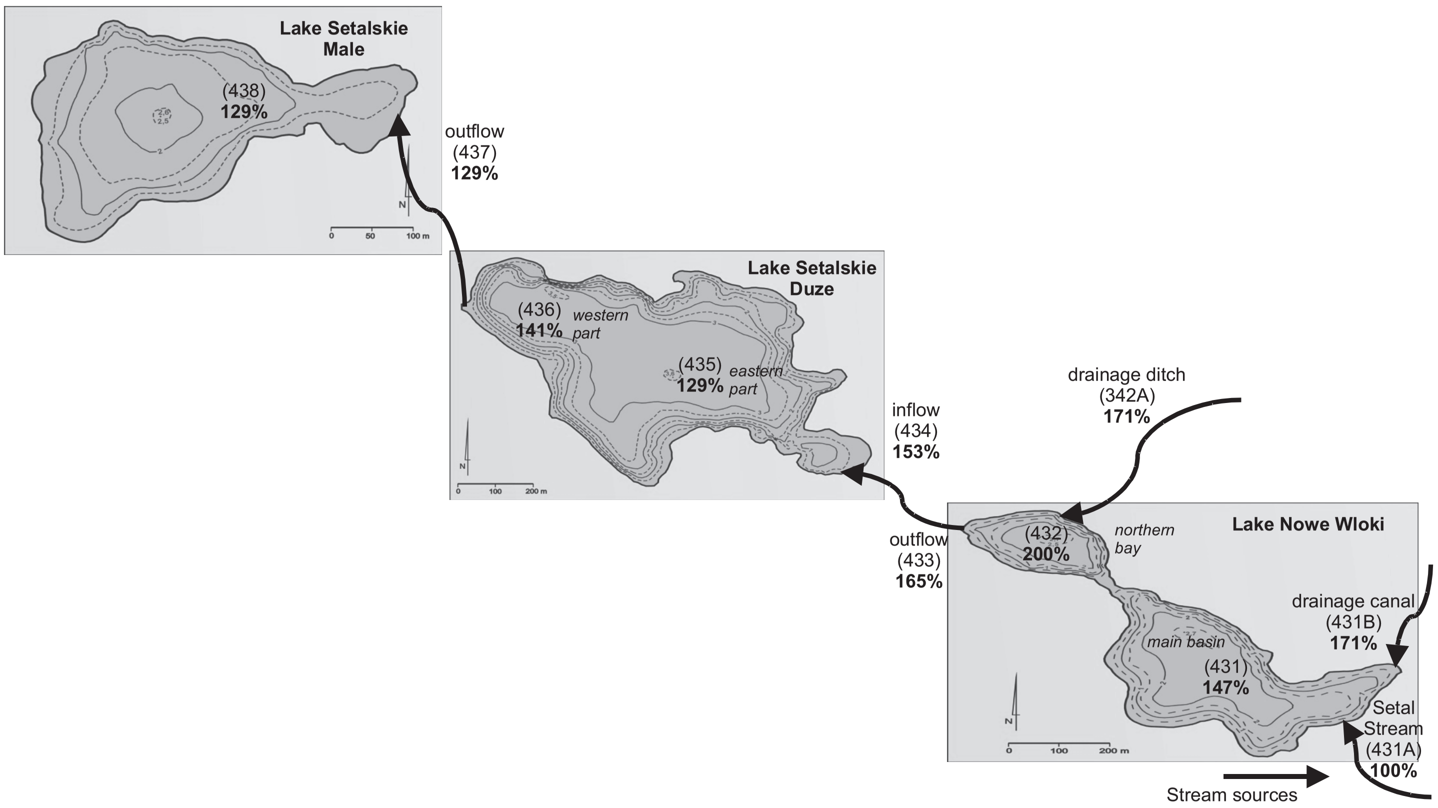


Fig. 3. The effect of the restored water bodies on phosphorus concentrations in the river-lake system in rural areas (phosphorus concentrations in the source section of the watercourse represent 100 %)

analyzed water bodies, chain systems minimize the potential consequences of eutrophication in large rivers and other water bodies to which the system's waters evacuate.

As regards variations in phosphorus concentrations, it has been noted that in shallow lakes with a high share of active bottom area, bottom deposits come into frequent contact with surface water, supporting the release of phosphorus accumulated at the bottom of the lake [9, 14, 24]. As shown by the study investigating seasonal variations in the analyzed element's concentrations, the above process is most intense in the summer, and the levels of released P may actually exceed external supply. Similar conclusions were formulated by Provini and Premazzi [25]. The absence of water stratification (hypolimnion) contributed to intensive phosphorus recirculation and very low trophy levels [26]. Throughout the three-year period of the experiment, the average concentrations of phosphorus, an element limiting primary production, in the restored water bodies were within the range reported for lakes in agricultural regions [27]. According to Nurnberg [28], total phosphorus concentrations determined in the spring are indicative of their hypetrophy (Table 3). Similar results were reported by Kawara et al [29], Szyperek [30] and Skwierawski [31] who argued that shallow water bodies are at an immense risk of eutrophication due to their contribution to reducing the concentrations of biogenic elements supplied from the catchment. Research studies investigating water trophy demonstrate that in addition to the eutrophication of polymictic water bodies situated in agricultural catchments, a serious risk is also posed by rural settlements without sewer systems which are the main source of biogenic substances responsible for high trophy levels [16, 32–35].

Table 3

Assessment of trophic status of the studied water bodies based on the spring concentrations of total P in view of Nurnberg criteria [1996]

Water body	Spring concentrations of total P							
	2005		2006		2007		Average for 2005–2007	
	Index	Trophic status	Index	Trophic status	Index	Trophic status	Index	Trophic status
Lake Nowe Wloki								
431 (main basin)	0.12	H	0.14	H	0.15	H	0.14	H
432 (northern bay)	0.12	H	0.84	H	0.28	H	0.41	H
Lake Setalskie Duze (average for 435, 436)	0.10	E	0.25	H	0.17	H	0.17	H
Lake Setalskie Male 438	0.22	H	0.26	H	0.29	H	0.27	H

E – eutrophic; H – hypertrophic.

While analyzing the trophic status of water bodies, the N:P ratio has to be determined to indicate which of the two biogenic elements stimulates algal growth [36, 37]. The N:P ratio calculated in this study (Table 4) indicates that phosphorus did not inhibit the development of algae in the analyzed flow-through water bodies [21]. In view of the above, primary production could have been determined mainly by the presence of nitrogen [8, 38]. The only exception was the largest water body (Lake Setalskie Duze) where primary production levels were affected by both nitrogen and phosphorus.

Table 4

Total nitrogen to total phosphorus ratio in the studied water bodies according to [Criteria... 2003]

	Water body			
Ratio	Lake Nowe Wloki (main basin)	Lake Nowe Wloki (northern bay)	Lake Setalskie Duze (average for 435, 436)	Lake Setalskie Male
N:P	9.2	8.1	10.7	9.1

Conclusions

1. The river-lake system comprising restored lakes on the Setal Stream reduces the concentrations of phosphorus migrating from the catchment areas, thus minimizing the effects of potential eutrophication in larger rivers and other water bodies to which the system’s watercourses evacuate.

2. As regards lake inflows, a drop in total phosphorus levels was noted after passage through the water bodies, and high concentrations of total phosphorus (especially in the summer) resulted from the polymictic character of the studied lakes where nutrients are released from interstitial waters.

3. The relatively high average spring concentrations of total phosphorus noted over the three-year period of the experiment (0.14–0.41 mg $P_{total} \cdot dm^{-3}$) were determined at the hypertrophy level, pointing to the extreme eutrophication of the restored lakes.

4. The pollutants supplied by a drainage ditch from rural settlements with no sewer system had a clearly negative effect on water quality in the studied system. The highest P_{total} and P-PO_4 concentrations were noted in the northern bay of Lake Nowe Wloki.

5. A rapid increase in the trophic levels of the lakes restored along the Setal Stream could lead to the accumulation of deposits and the gradual shallowing of the lakes, thus preventing those water bodies from fulfilling their initial functions.

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OCENA FUNKCJONOWANIA ZRENATURYZOWANYCH ZBIORNIKÓW WODNYCH NALEŻĄCYCH DO SYSTEMU RZECZNO-JEZIORNEGO NA PODSTAWIE STĘŻEŃ FOSFORU

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Abstrakt: Badaniami objęto trzy zbiorniki wodne odtworzone przed około 30 laty: jezioro Nowe Włóki, jezioro Setalskie Duże i jezioro Setalskie Małe, połączone Strugą Setal w jeden system rzeczno-jeziorny, położone na Pojezierzu Olsztyńskim około 25 km na północ od Olsztyna w gminie Dywity.

Celem pracy była ocena funkcjonowania odtworzonych przed około 30 laty zbiorników wodnych, należących do systemu rzeczno-jeziornego, ze szczególnym uwzględnienie jakości wody i stanu troficznego jezior na podstawie stężeń fosforu i jego sezonowych zmian.

Istnienie systemu rzeczno-jeziornego, dzięki odtworzonym zbiornikom na terenach wiejskich pozwala na redukcję stężeń (kumulacji związków biogennych) migrujących ze zlewni, zmniejszając w ten sposób skutki potencjalnej eutrofizacji większych rzek i innych akwenów, do których cieki systemu uchodzą.

W przypadku wód dopływających do jezior zaobserwowano poprawę w zakresie obniżenia stężeń fosforu ogólnego, po ich przepłynięcie przez akweny, a utrzymywanie się dużych koncentracji P_{og} w wodach badanych jezior należy wiązać także z ich polimiktycznym charakterem.

Z dostawy zanieczyszczeń (P_{og}) do zbiorników układu paciorkowego wynika, iż wody dopływów wnoszą do jezior znaczne jego ilości, powodując ponadnormatywne stężenia P_{og} w wodzie akwenów i przyspieszając w ten sposób procesy, które pogarszają jej jakość oraz funkcjonowanie jezior. Stwierdzono, że w wodzie odtworzonych zbiorników średnie z trzech lat stężenia fosforu – pierwiastka limitującego produkcję pierwotną, mieściły się w zakresie od 0,22 do 0,34 mg $P_{og} \cdot dm^{-3}$. Brak stratyfikacji wód (hypolimnionu), wpłynął na intensywną recyrkulację fosforu i bardzo wysoką trofię wód. Według Nurnberga wiosenne koncentracje P_{og}, wskazują na stan ich skrajnego przeżyźnienia czyli hipertrofii.

Słowa kluczowe: system rzeczno-jeziorny, jeziora polimiktyczne, produkcja pierwotna, hipertrofia

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CHEMICAL AND GRANULOMETRIC PARAMETERS OF BOTTOM SEDIMENTS IN THE ASSESSMENT OF FLOODPLAIN WATER BODIES OF THE LOWER BUG RIVER

PARAMETRY CHEMICZNE I GRANULOMETRYCZNE OSADÓW DENNYCH W OCENIE ZBIORNIKÓW WODNYCH TERENÓW ZALEWOWYCH DOLNEGO BUGU

Abstract: Usefulness of basic chemical and granulometric parameters of bottom sediments in the assessment of successional stage and condition of floodplain water bodies was analyzed, as well as some aspects of nutritional quality of bottom sediments. *Organic matter* (OM), nitrogen and phosphorus content and granulometric parameters differed between permanent and temporary, as well as between old and young water bodies. In some habitats despite of relatively low C/N ratio and high OM content sediments were not favourable for detritivores. Organic matter content in sediments of floodplain water bodies may be used in the assessment of C_{org} and N with high probability.

Keywords: floodplain water bodies, bottom sediments, granulometry, organic matter, C/N ratio

Riverine floodplains are regarded as one of the most heterogenous and dynamic ecosystems [eg 1, 2]. Despite some transformations (especially flood control embankments construction) the lower Bug River floodplain retained relatively high diversity of habitats [3, 4 and literature cited there]. The lower Bug River valley is characterized by the occurrence of numerous water bodies differing in hydrological connectivity, permanence of flooding and representing various successional stages. Previous investigations conducted in floodplain water bodies by the author concerned the occurrence, diversity and abundance of molluscs, environmental factors shaping malacocoenoses, as well as possibility of using aquatic molluscs in describing a condition and successional stage of these habitats.

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Bottom sediments, especially their organic matter content and granulometry have been found to be useful in characterizing floodplain water bodies [eg 5, 6]. Grain size distribution can be used as the record of hydrologic dynamics, whereas organic matter content may reflect ecosystem metabolism.

Nutritional quality of bottom sediments, especially organic matter contained in their upper layer, may be very important factor for macrozoobenthos, including molluscs, but data are rather scarce. High organic matter content in bottom sediments may be unfavourable for bottom macrofauna, eg when its decomposition leads to anoxic conditions. Composition of decaying matter and its nutritional value change during decomposition processes [eg 7–9]. C/N ratio in bottom sediments is frequently used to describe the quality of food. Food quality is negatively correlated with the C/N ratio. Critical C/N value of about 17 was recognized by Bretschko and Leichtfried [10], whereas Tockner and Bretschko [6] proposed even lower C/N value (below 15) as indicating digestible matter.

The aim of the present study was evaluation of usefulness of basic chemical and granulometric analyses of bottom sediments in the assessment of successional stage and condition of floodplain water bodies of a lowland river. Some aspects of nutritional quality of bottom sediments were also analyzed.

Materials and methods

Samples of bottom sediments were collected in the years 2007–2009 in 113 water bodies located within the lower Bug river valley, between 190 and 50 km of the river course counting from the mouth ($52^{o}21.520'$–$52^{o}41.991'$ N, $21^{o}36.379'$–$22^{o}50.820'$ E) and within the terminal section, where the Bug River constitutes a part of the Zegrzynski Reservoir ($52^{o}31.333'$–$52^{o}31.289'$ N, $21^{o}12.326'$–$21^{o}12.404'$ E). Study sites were located within fragments of natural floodplain, the ‘active’ floodplain constrained by the flood control embankment and the ‘former’ floodplain situated outside the embankment. They represented earlier and advanced successional stages, as well as temporarily and permanently flooded habitats. Their geographic co-ordinates were measured with GPS.

The samples of bottom sediments were dried in *ca* 105 ^{o}C to the constant weight. Grain sizes were determined by sieving technique (grain size fractions: < 0.063, 0.063–0.1, 0.1–0.2, 0.2–0.5, 0.5–1.0, 1.0–2.0, > 2.0 mm). *Mean grain size* (GSS) and *sorting degree* (GSO) being a measure of substrate heterogeneity were calculated with a graphic method [11].

Organic matter (OM) content in bottom sediments was determined as loss of weight on ignition (ashed in 530 ^{o}C for 4 hours). *Organic carbon* (C) and *total nitrogen* (TN) content in a chosen part of the samples were measured using elemental analyzer CHNS+O (model 1108, Fisons Instruments) in the Centre for Ecological Studies, PAS. In the other samples organic carbon content was assessed based on the relation between organic matter content determined as loss of weight on ignition and C content measured with elemental analyzer CHNS+O. The Ca concentration was determined by titrimetric method.

Subsamples of bottom sediments were digested with persulphate [10] enabling simultaneous determination of nitrogen and phosphorus. In resulting solutions *Kjeldahl* *nitrogen* (KN) was determined with the indophenol blue method [12] and phosphorus with molibdenum blue method with ascorbic acid as a reducing agent [13], using spectrophotometer (Novaspec 2, Pharmacia LKB). C/N ratio was calculated in bottom sediments to describe the quality of food.

Regression analysis (Statistica 6.0) was used to describe the relations between organic carbon and organic matter (OM), total nitrogen (TN) and Kjeldahl nitrogen (KN), organic matter and total nitrogen. Nonparametric Kruskal-Wallis ANOVA was applied to compare the analyzed parameters of bottom sediments in water bodies differing in permanence of flooding and successional stage owing to not normal distribution of variables.

Results

Organic matter content in bottom sediments of the investigated water bodies, as well as N and P concentrations ranged within broad limits: 0.36 to 76.61 % d.m., 0.13–24.80 $mg \cdot g^{-1}$ and 0.05–4.83 $mg \cdot g^{-1}$ d.m. respectively. In temporary habitats significantly higher mean values of these parameters were stated than in permanent ones (Fig. 1A, B, C, $p < 0.05$), however no significant differences were found between habitats representing advanced successional stages in both permanence groups. Within permanent water bodies OM, N and P concentrations were significantly higher in older ones than in those representing earlier successional stages ($p < 0.01$), whereas such differences were not observed within temporary habitats.

C/N ratio ranged from about 8 to over 40, mean value amounted to 14.72 ± 3.92. It was similar in water bodies representing earlier and more advanced successional stages, as well as in permanent and temporary habitats (Fig. 1D). In most of the investigated habitats (about 85 %) C/N ratio did not exceed 17 recognized as critical value for food quality [10].

The Ca concentration in bottom sediments ranged from 1.20 to 76.15 $mg \cdot g^{-1}$ d.m., mean value was significantly higher in permanent water bodies as compared to temporary ones (Fig. 1E, $p = 0.004$), the difference was especially distinct within older habitats.

Granulometric composition of sediments varied between water bodies. Generally sandy fractions ($0.1 < \varphi < 0.5$ mm) dominated (Fig. 2A). Significantly higher percentage of sand was found in younger permanent habitats than in older ones ($p = 0.0001$). The share of coarse particles (with the diameter > 1mm) ranged from 1.1 to 69.5 % with higher values in older water bodies, especially permanent ones (Fig. 2B). High organic matter content in coarse fraction (Fig. 2C) showed, that it consisted mainly of coarse particulate organic matter (CPOM).

Mean substrate particle size ranged from 0.08 to 1.7 mm (mean value ±SD was 0.46 ± 0.28). It was significantly higher in older water bodies as compared to young ones ($p = 0.0000$, Fig. 2D). Sorting degree ranged from 0.23 to 2.48 (with the mean value of 1.29 ± 0.44). Generally lower values (ie better sorting) were found in young water bodies as compared to old and usually more isolated ones ($p = 0.012$). Within young habitats sediments in permanent water bodies were better sorted than in temporary ones ($p = 0.057$) (Fig. 2E). Over 75 % of the investigated habitats had badly or very badly sorted sediments (i.e. sorting degree was ≥ 1).

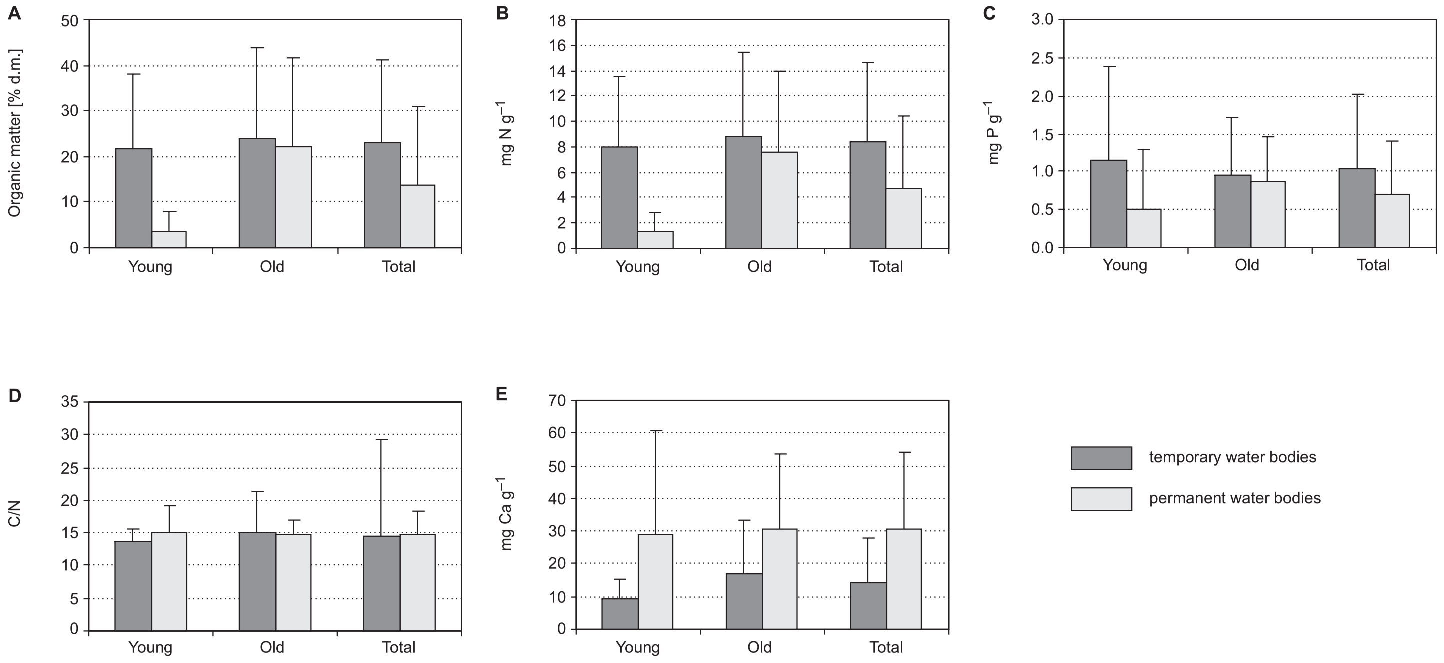

Fig. 1. Mean values (±SD) of chemical parameters of bottom sediments in water bodies differing in successional stage (young and old) and permanence of flooding (temporary and permanent): organic matter content(A), concentration of nitrogen (B) and phosphorus (C), C/N ratio (D), concentration of Ca (E)

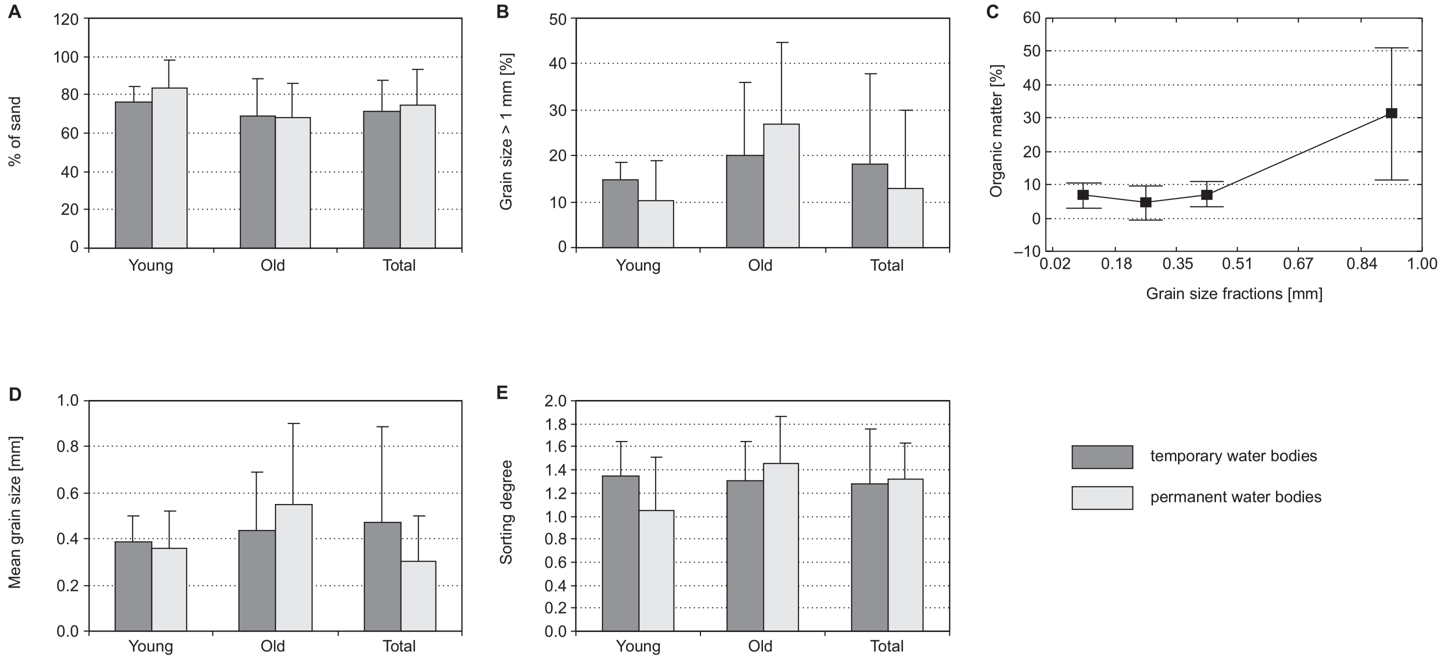

Fig. 2. Fig. 2. Granulometric parameters of bottom sediments in water bodies differing in successional stage (young and old) and permanence of flooding (temporary and permanent): percentage of sand (A), contribution of grain size fraction > 1 mm (B), organic matter content in different grain size fractions (C), mean grain size (D), sorting degree (E)

The relation between organic C and organic matter (Fig. 3A) was described by the equation: C = 0.50 OM + 0.01 ($R^2 = 0.96$). Organic matter seems to be a good predictor of organic carbon in bottom sediments of the investigated water bodies containing a wide range of organic carbon (0.18–39.84) % d.m.

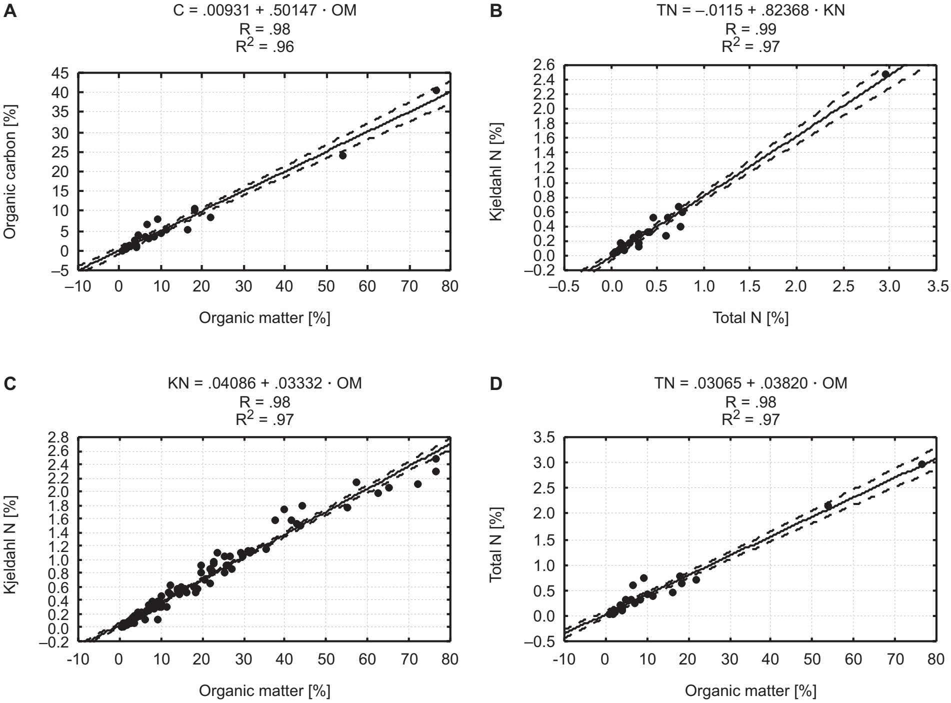

Fig. 3. The relationship between organic carbon and organic matter (A), Kjeldahl N and total N (B), KN and OM (C), TN and OM (D) in the investigated sediments

The relation between KN and TN (Fig. 3B) was described by the equation: KN = 0.82 TN – 0.01 ($R^2 = 0.97$). Kjeldahl method recovered approximately 82 % of total nitrogen in the investigated sediments. KN can be a reliable predictor of TN in sediments containing a wide range of KN (0.01–2.48) % d.m.

The relations between KN and OM, as well as TN and OM (Fig. 3C, D) were described by the equations: KN = 0.03 OM + 0.04 and TN = 0.04 OM + 0.03. The high determination coefficients ($R^2 = 0.97$ in both relations) indicate that it is possible to estimate KN and TN concentrations using OM content (measured as loss of ignition) with high probability.

Discussion

The range of organic matter (and organic carbon) and nitrogen content in sediments of the investigated water bodies was wider, than reported from a number of aquatic environments and marsh soils [eg 5, 6, 14]. Concentrations of phosphorus were relatively high as compared to lake sediments [15] and similar to the values found in wetlands [16].

Relatively high content of organic matter, nitrogen and phosphorus in substratum of temporary water bodies and in permanent ones representing advanced successional stages may be related to the presence of much remains of *Carex* spp. and another wetland plants in the former habitats, as well as remains of aquatic macrophytes, woody debris and leaf litter in the latter ones. Decomposition of such kind of detritus proceeds relatively slowly [eg 17–19].

The values of C/N ratio in sediments of a majority of the investigated water bodies were comparable to the data from peat bogs, some lakes and small water bodies [6, 20–22], as well as marsh soils [23, 24]. The cause of relatively uniform C/N ratio found in habitats representing different successional stages and permanence of flooding may be related to the parallel decomposition of hydrocarbonic and nitrogenous compounds [5]. C/N values in most of the investigated bottom sediments were lower than C/N ratio in vascular plants (ie > 20 according to [8, 9]). C/N ratio in celulose-rich vascular plants may decrease during diagenesis owing to considerable contribution of microorganisms to N content in coarse detritus [9] or selective degradation of carbon-rich sugars and lipids [eg 8]. An increase of nitrogen content in some vascular plant detritus during later stages of decomposition was observed [7], but it occurred mostly as non-labile humic nitrogen, which is not available to consumers. It follows, that relatively low values of C/N ratio occurring in old detritus cannot be regarded as a measure of nutritional value, but rather the stage of humification. Relatively low C/N ratios in sediments of some water bodies may suggest a subequal mixture of algal and vascular plant contributions. C/N ratio in algae is usually much lower than in vascular plants [eg 8].

Detritivorous invertebrates feed on fresh, labile detritus [25]. As the ratio of microbial biomass to plant tissue increases, detritus become more nutritious for them [26]. Some animals consuming detritus use rather microorganisms not dead plant tissues [27, 28]. During aging deposited organic matter is transformed from relatively labile forms to less assimilable heterocyclic aromatic forms typical of mature humic material [7]. The proportion of organic matter resistant to degradation and biologically unavailable is much higher in anoxic conditions [29] which frequently occur in water bodies with sediments rich in OM. Old and refractory materials (structurally complex and aromatic macromolecules, eg lignin and complex lipids) resist anaerobic decomposition [30].

Some habitats investigated in the present study hold poor malacofauna [31] despite relatively low C/N ratio and high organic matter content. Mollusc species richness was lowest, when organic matter content in bottom sediments was high (ie > 40 % d.m., Fig. 4A). The highest abundance of molluscs was found in habitats with medium organic matter content in bottom sediments (ie 5–40 % d.m., Fig. 4B). Bottom sediments of older water bodies contain much refractory matter and humic substances, which are indigestible to most detritivores [26]. Relatively high abundance of malacofauna in some temporary water bodies, especially young ones reported by the author [32] may be related to higher nutritional quality of detritus within these habitats. High protein content and nutritional value of detritus were found especially by the end of waterless period [33], thus in the beginning of hydroperiod in temporary water bodies the highest food quality occurs.

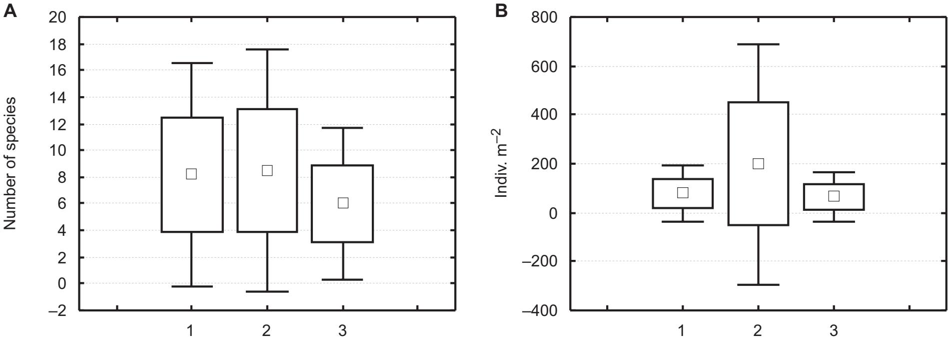

Fig. 4. Number of species (A) and density of molluscs (B) dependence on OM content (%) in sediments. OM content was expressed in 3 classes: 1 – < 5 %, 2 – 5–40 %, 3 – > 40 % d.m.. Numbers of mollusc species and their densities in the investigated water bodies according to the earlier study of the author [31]

Mean grain size and sorting degree of the analyzed sediments indicated low hydrologic dynamics and considerable heterogeneity of substratum in most of the investigated water bodies. It was consistent with the results of Rostan et al [5], who reported the lowest heterogeneity of sediments in frequently connected floodplain waters. The highest organic matter content found in large size fractions (> 1 mm) and relatively high content of organic matter in sediments of more isolated water bodies (temporary or older permanent ones) confirm the results of Tockner and Bretschko [6], who found that in isolated water bodies particular organic matter was mostly composed of CPOM and relative contribution of organic matter was positively correlated with the degree of isolation of floodplain waters.

Conversion factor for estimating organic carbon from organic matter in bottom sediments of the investigated water bodies was in close agreement with the values published for bottom sediments of abandoned river channels, as well as wetland and upland soils [5, 23 and literature cited there]. There was high compatibility between organic matter and organic carbon, as well as total N and Kjeldahl N, which makes possible using OM in the assessment of organic carbon and KN in the assessment of TN concentration in bottom sediments. This may be useful in monitoring, where simplicity and low costs of analyses are important. Strong relation between OM measured as lost of ignition and concentration of TN, as well as between OM and KN enables the assessment of nitrogen (TN and KN) concentration basing on OM content in sediments.

Conclusions

1. Permanent habitats representing advanced successional stages contained significantly more organic matter, N and P in bottom sediments, than young ones. It was

related to accumulation of detritus with the age of water body. This rule did not apply to temporary habitats, where large amounts of fresh detritus derived from vascular plants occurred.

2. Sediments of the investigated water bodies were mostly characterized by considerable heterogeneity resulting from low hydrological connectivity or isolation.

3. The highest contribution of organic matter in the grain size fraction of > 1 mm indicates, that this fraction is mainly composed of CPOM.

4. In some habitats despite of relatively low C/N ratio and high OM content bottom sediments were not favourable for detritivores because of low digestibility. This was the case of old water bodies.

5. High compatibility between organic matter and organic carbon, as well as total N and Kjeldahl N makes possible using OM in the assessment of organic carbon and KN in the assessment of TN concentration in bottom sediments. Strong relation between OM measured as lost of ignition and concentration of TN and KN enables the assessment of N concentration basing on OM content in sediments.

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PARAMETRY CHEMICZNE I GRANULOMETRYCZNE OSADÓW DENNYCH W OCENIE ZBIORNIKÓW WODNYCH TERENÓW ZALEWOWYCH DOLNEGO BUGU

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Abstrakt: Analizowano przydatność podstawowych chemicznych i granulometrycznych badań osadów dennych w ocenie stadium sukcesji oraz kondycji zbiorników wodnych terenów zalewowych, jak również niektóre aspekty jakości pokarmowej osadów. Zawartość materii organicznej, azotu i fosforu oraz parametry granulometryczne osadów dennych różniły się w zbiornikach trwałych i okresowych, a także w zbiornikach starych i młodych. W niektórych biotopach pomimo stosunkowo niskiego stosunku C/N i wysokiej zawartości materii organicznej osady były niekorzystne dla detrytusożerców. Zawartość materii organicznej w osadach zbiorników terenów zalewowych może być z dużym prawdopodobieństwem wykorzystywana w ocenie zawartości C i N.

Słowa kluczowe: zbiorniki wodne terenów zalewowych, osady denne, granulometria, materia organiczna, stosunek C/N

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SOME MODELS OF SEDIMENTS TRANSPORT IN GRAVITATIONAL SANITATION SYSTEMS

WYBRANE MODELE TRANSPORTU OSADÓW W SYSTEMACH KANALIZACJI GRAWITACYJNEJ

Abstract: The sediments in gravitational sanitation systems appear when the velocity of flow decreases below the value of hydraulic self-purification. These sediments have the significant influence on the processes occurring in the sanitation systems, causing inter alia the periodical fluctuation of loads entering the wastewater treatment plants. The sediments deposited in the channel are also causing the changes of the shape of pipe cross-section thus influencing the changes of physical and hydrodynamic parameters of the whole system. The sediments are also influencing the development of the sulphuric corrosion of pipes and intensity of biological biodegradation of wastewater in sanitation conduits. The research concerning the wastewater sediments and the connected processes are pretty costly so they are only being conducted in countries in which the biding law requires the mathematical modeling of mass transport to the wastewater plants and storm spillways. The results of this research give the necessary data to calibration of hydraulic models. The general description of structure and properties of sediments should be known at the stage of the consideration of minimal inclinations of conduits. It is also very important during the modeling of pollutants load transport in sanitation system and the process of wastewater biodegradation, because for different type and properties of sediments different model of transport should be used. The classification of sediments based on literature research and the results of classification research in sanitary systems in Chelm, Poland, as well as models often used for describing of sediment transport in gravitational conduits were presented.

Keywords: gravitational sewer system, sludge in sewer system, sludge classification, sludge transport in sewer system

The sediments in gravitational sanitation systems appear when the velocity of flow decreases below the value of hydraulic self-purification. The sediments have the significant influence on the processes occurring in the sanitation systems, causing inter alia the periodical fluctuation of loads entering the wastewater treatment plants. The deposited sediments during the phase of low canal filling and low flow velocity reduce the pollutants load, thus during the phase of high filling and high flow velocity the

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deposited pollutants are being washed away, rapidly increasing the concentrations and loads of transported pollutants. This phenomenon directly influences the pollutants load entering the wastewater treatment plant or storm spillway and sewage discharge receiver. The sediments deposited in the channel are also causing the changes of the shape of pipe cross-section, thus influencing the changes of physical and hydrodynamic parameters of the whole system [1–4]. The sediments are also influencing the development of the sulphuric corrosion of pipes and intensity of biological biodegradation of wastewater in sanitation conduits [5–9].

The actually applied techniques of sampling and measurements allow to obtain the results only partially reflecting the properties of sediments in their natural environment [9, 10].

The researches focused on the susceptibility of the analyzed sediments on pollutants release suggest that infringement of the sampled sediments basic structure causes the problems of the lack of proper mapping of sediments properties.

The reologic properties are influenced by the sediments accumulation just beneath the wastewater surface. This is, probably, one of the major reasons causing the increased resistance of the sediments to the shear stress noted in the laboratory conditions. The research of sanitation sediments properties are usually conducted in order to obtain the knowledge about the level of pollutants release and description of reologic properties, particularly the shear stress determining the sediments erosion.

Studies concerning the wastewater sediments and the connected processes are pretty costly so they are only conducted in countries in which the biding law requires the mathematical modeling of mass transport to the wastewater plants and storm spillways [9]. The results of this research give the necessary data to calibration of hydraulic models.

Classification of sediments forms in sewer systems

The following classification of sediments is used in EU [9–13]:

A – non-organic and non-cohesive sediments,

B – sediments of A type non-organic structure but agglomerated by oil derivatives and characterized by cohesive properties,

C – organic sediments, moving over the surface of A and B sediments with lower velocity than flowing sewages,

D – biofilm developed on pipe walls,

E – sediments in storage tanks.

Sometimes, two another groups of sediments are distinguished [9]:

F – storm conduits sediments,

G – pressure pipes sediments (after pressure sanitation attachment).

The A and B sediments are mostly noted in wastewater systems, thus, the highest load of COD is being accumulated in it, although the concentration of pollutants in these sediments is lower than in case of C type [9].

The highest content of organic pollutants was noted in C group sediments, in which the COD content reaches level of up to several hundred (even 300–500 gO_2 dm^{-3}).

These sediments move over the surface of A and B group during the phase of sewage low level flow in a wastewater pipe. The presence of C and D sediments in sanitation systems results in the occurrence of biodegradation processes, because these sediments are consisting of heterotrophic organisms being the process factor of mentioned transformations.

The D group sediments are consisting of heterotrophic living organisms so the organic content in this sediments group is high. The D group layer thickness is usually low (generally not exceeding 2 mm) but the anaerobic conditions are possible. Which, in turn, contributes to hydrogen sulfide creation, influencing the sulphuric corrosion of pipes surface, attacking in sequence the vault and side walls of the canal.

The E group sediments are characterized by a high degree of fragmentation so the grains surface area in the unit volume of sewage is significant. This allows the extensive adsorption of practically insoluble organic pollutants and heavy metals.

The F group sediments indicated in wastewater and storm systems are characterized by the variable, time dependant (seasonal) composition. Particularly during the late autumn there are a lot of leaves falling down from the trees in it. Pressure pipes sediments (G group) commonly occur at the pipe slope and contain huge amounts of organic compounds, especially fats.

The general description of structure and properties of sediments should be known at the stage of the consideration of minimal inclinations of conduits. It is also very important during the modeling of pollutants load transport in sanitation system and the process of wastewater biodegradation, because for different type and properties of sediments different model of transport should be used [9].

The sediments transported in the sanitation are often the subject of physical and biochemical analysis and the proper way of sampling is necessary to obtain the credible results, for instance by the sediment trap installed at the bottom of pipes. The exemplary measurements results are presented in Table 1.

Table 1

Near-bed sediments characteristics inside egg-shaped conduits
(1 – 1030 × 686 mm; 2 and 3 – 1780 × 1625 mm) [5, 9]

No.	Particles diameter d_{50} [mm]	Wet state density [$kg \cdot m^{-3}$]	Volatile components content [%]	Mean COD value [$gO_2 \cdot m^{-3}$]	Mean BOD_5 value [$gO_2 \cdot m^{-3}$]	Mean daily flow rate [$m^3 \cdot d^{-1}$]
1	0.5–11.0	1143–1998	1.4–28.6	87 522	28 594	1900
2	0.5–4.0	1000–1066	31.8–68.1	214 000	82 758	6700
3	0.09–2.5	1000–1108	55.6–91.2	124 246	96 119	7500

The Polish researches [9] showed that phenomena connected to sediments transport and pollutants release are greatly dependent on the relations among the particular sediments properties – the most important are: density, moisture and porosity.

Sediments transport in gravity sewer system

The proper exploitation of sanitation system requires the assurance of hydraulic conduits self-purification conditions. Such conditions appear with adequate incidence when the canal inclinations were chosen properly. But, the economic conditions limit the pipes designing which would eliminate any sediments deposition, affirming their transport throughout the all day. So, the binding rules of sanitation systems design assert the periodical transport of the best part of sediments, transmitting the maximal yearly sewage flow rates and effective channels ventilation [9, 14]. Thus, in the real conditions of sanitation systems functioning the sediments are periodically accumulated in the pipes and then are washed away during the high rates phases of wastewater flow.

The field and literature studies show that particles concentration is non-uniform in the whole stream of flowing sewages and its value rapidly increases close to the pipe bottom [5, 9]. Taking into account the existence of one more increase of constant phase concentration connected to the sediments deposited on the pipe bottom, the suspension transport in the layer placed between two mentioned layers of constant phase densification is determined as the near bed transport [9, 15]. It is connected to the following phenomenon appearance: turning, displacement and saltation.

Information presented in widely used engineering literature [14, 16] suggest that to obtain the proper working conditions of the sanitation system, at the designing phase, the assurance of the pipes inclinations enabling the lowest velocity of channel self-purification are necessary. This notion is understood as velocity which stops the creation of sediment bed at the canal bottom. It is also advisable that velocity of self-purification should occur even during the flow of the lowest flow rate and filling.

The mentioned velocities are understood in two ways: as non silting velocity as well as the terminal velocity [17].

The convection velocity is a mean velocity in the active cross-section at which all particles are being transported in the channel, partially in the suspended form and partially dragged near the bottom. In this case, the processes of sediments deposition and creation of sediments bed do not occur. This terminology is accepted in literature focused on the processes occurring in sanitation systems and originated in the research description of debris transport in rivers and the other watercourses [9, 15, 17].

The terminal velocity is a mean velocity in the stream cross-section which triggers the process of erosion of sediments deposited during the lowest filling of the canal. The laboratory researches showed that the uniform sediments are completely removed after the excess of described flow velocity by more than 10 % [18–20]. The literature sources do not present the universal value of required terminal velocity because its value depends to the sewage composition, type and shape of the sediment particles as well as the hydraulic radius value – the shape, geometric characteristics and filling of the sanitation canal [9, 14, 20, 21].

It is assumed, when the mean velocities are in use, that the flow velocity is equal in all points of given cross section. But in reality, the flow velocity is different in every point – the lowest near the canal bottom, which is presented in Fig. 1.

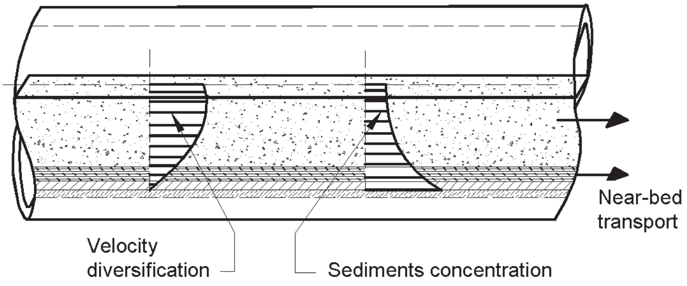

Fig. 1. Sediments transport in sanitation conduit – constant sewage level [12]

The close preservation of wastewater flow velocity at the level of 1 m · s^{-1}, which seems to be the simplest method of designing, would result, in some cases, in too high inclination of pipes leading to too high and economically unjustified pipe depression. Though, the sewage flow velocity in sanitation and storm canals should not be lower than 0.8 m · s^{-1} during the phase of the maximum canal filling. In specific cases, when there is no possibility to assert the self-purification velocity of flow, the capability of pipes flushing should be available.

The third essential in sanitation exploitation practice value of the flow velocity is connected to the beginning of conduit side walls erosion. To prevent the mechanical damages of pipes inner surface the flow velocity should be lower than 3.0 m · s^{-1} for concrete and ceramics pipes as well as 5.0 m · s^{-1} for cast iron pipes. The maximum admissible velocity of sewage flow inside the storm conduits equals 7.0 m · s^{-1} [14].

The recent approach to the problem of sanitation conduits self-purification is based on the shear stress method [22–24].

The both mentioned methods – based on the self-purification velocity and critical shear stress, allow to gain the same purpose, which is to prevent the transported sediments deposition inside the gravitational sanitation conduits. This matter is very important because the cohesive properties of transported sediments [24–26]. The shear stress of about 1.8 N · m^{-2} is required to remove the layer of freshly deposited sediments while the stress value of 800–1000 N · m^{-2} is necessary to remove the sediments after a long-lasting pipe exploitation. To illustrate the problem scale we would like to add that during the rainy weather the values of shear stress of 20 N · m^{-2} were noted inside the pipes constructed with relatively high inclinations (apart from sanitation systems in mountain regions). The inclination of sanitary conduit should ensure daily cyclical removal of deposited sediments occurring during the phase of the maximum flow rate. In case of the storm systems the removal of sediments should occur during the rainfall event of a required intensity. If this condition is not fulfilled after some years of the sanitary system exploitation only the special methods of conduit rehabilitation may restore the hydraulic capacity of the pipe.

The technical activities aimed to deposited sediments removal are often very costly so the proper choice of the minimal conduits inclination leading to the self-purification velocity (the suitable values of shear stress) occurrence becomes an important matter at the stage of sanitation system design. Besides, the sediments deposited at the canals bottom become a serious threat for the receiver of storm spillway wastewater and cause the heterogeneity of wastewater treatment plant strain by the pollutants load.

Modeling of sediments transport in gravitational sanitation

The hydraulic transport of solid particles inside the sanitation systems may occur by floating by the sewage stream and dragging along the canal bottom. The movement of single A group sediment particle is induced by the forces of hydrodynamic pressure force. The component of gravitation force parallel the conduit bottom may be insufficient because the commonly used low conduits bottom angle of inclination. This situation may be graphically presented as shown in Fig. 2 [14].

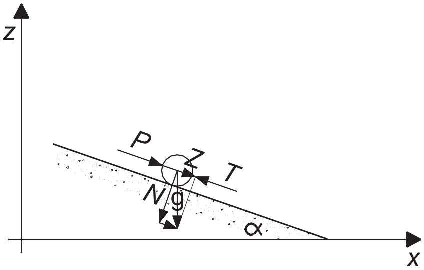

Fig. 2. Forces influencing the spheroid particle of group A at the bottom of gravitational conduit [14]

The particle presented in Fig. 2 is influenced by the following forces: P – hydrodynamic pressure force [kg · m · s^{-2}], Z – gravitational force component [kg · m · s^{-2}], T – friction force dependent to the friction factor and normal component of gravitational force $T = f N$ [kg · m · s^{-2}]. The inertial force and the congruency of the particle to bottom are neglected. The required mean sewage flow velocity, authoritative for the inorganic and incohesive sediment particle of diameter d [m], dragged along the bottom of a sanitation pipe of diameter D [m] may be calculated basing in Fig. 2 [14]:

$$U = \frac{u_d}{\varepsilon} \tag{1}$$

where: U – mean cross-section velocity [m · s^{-1}],
ε – velocity distribution factor [-].

The ε factor is described as:

$$\varepsilon = m - \frac{2}{3}(m-1)\ln\frac{1.25D}{d} \tag{2}$$

where: m – relation of maximum cross-section velocity to the mean velocity value [-].

The other commonly cited equation has a following form [9]:

$$\frac{v_c}{\sqrt{gd\,(s_\rho - 1)}} = a\left(\frac{d}{R_h}\right)^b \tag{3}$$

where: v_c – limit velocity [m · s^{-1}],
a, b – dimensionless factors: a = 0.61 for the smooth circular cross section, a = 0.54 for the smooth rectangular cross-section, a = 0.50 for the smooth rectangular cross-section, b = –0.38 for the smooth circular cross-section,
d – particle diameter [m],
g – acceleration of free fall [m · s^{-2}],
R_h – hydraulic radius [m],
s_ρ – comparative density of dry mass suspended in relation to water [-].

The presented equation (3) shows that the limit velocity depends to hydraulic radius, but is independent to the suspension concentration. This shows why there is no universal value of sewage flow velocity.

The following formula describing the convection velocity in the circular pipe may be used during the sediments transport modelling [20]:

$$\frac{v_c}{\sqrt{gd\,(s_\rho - 1)}} = 3.08 d_{gr}^{-0.09}\, C_v^{0.21} \left(\frac{R_h}{d_{50}}\right)^{0.53} \lambda_s^{-0.21} \tag{4}$$

where: s_ρ – relative density of solid phase $\rho_s\rho^{-1}$,
ρ_s – density of constant phase dry mass [kg · m^{-3}],
d_{50} – particles diameter, accounting for, with the smaller ones, 50 % of mass [m],
d_{gr} – dimensionless diameter of d_{50} particles $((s_\rho - 1)\, g v^{-2})^{1/3} d_{50}$,
v – kinematics viscosity factor [m^2 · s^{-1}],
C_v – volumetric concentration of sediments [ppm].

The friction factor of water suspension flow resistance λ_s calculations may be calculated basing on the friction factor for clear water λ:

$$\lambda_s = 1.13 \lambda^{0.98}\, C_v^{0.02}\, D_{gr}^{0.01} \tag{5}$$

where: λ – clear water friction factor [-].

The acknowledgement of sediments deposited inside the sanitation pipes is necessary during the determination of old canals capacity. The sediments settled inside the sanitation conduits influence the hydraulic resistance of flow by three different manners: decreasing the inner cross-section area, changing the roughness coefficient of pipe walls and decrease the flow energy caused by the work load during elution of deposited sediments.

The changes of roughness coefficient value, influencing the flow resistance, are difficult to predict because the sediments bed surface usually forms spatially different shapes, dependent to dimensionless Froud number. For Fr < 0.2 the most probable is the smooth shape of sediments surface, for Fr = 0.2–0.35 the noticeable ripples and Fr = 0.35–0.6 dunes were observed. Thereafter, the sediments surface re-smoothing occurs for Fr = 0.6–1.0, and anti-dunes appear for Fr > 1.0 [9].

Summary and conclusions

The presented information concerning transport and quality of sediments along with pipes inclination in sanitation systems are the key factors during designing and modeling of the sewage systems in the variable environmental conditions.

The most frequently occurring type of sediments during our research in Chelm, Poland was the B group. The biofilm developed beneath the water level was classified as the D group. The biofilm development was not observed above the sewage surface. The G group sediments were observed in gravitational sanitation pipes in Chelm, at location of pressure sanitation attachment.

Our paper presents different models of solids transport in sanitation pipes, based on various approach to the problem and of variable complexity. The number of required input data resulting in intricacy and research or design costs increases for the more complex approaches. The simplest attitude to sediments transports is based on the self-purification velocity of constant value. The most advanced of the presented variants of sediments transports modeling concerns the convection velocity dependant to hydraulic conditions of flow and parameters of the dispersed phase.

The proper model of solid substances transport at gravitational sanitation should be chosen according to the type and properties of sediments.

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Abstrakt: Osady w kanalizacji grawitacyjnej występują w przypadku, gdy prędkość przepływu ścieków spada poniżej prędkości hydraulicznego samooczyszczania przewodów. Osady mają duży wpływ na procesy przebiegające w systemie kanalizacyjnym, powodując m.in. znaczne okresowe wahania ładunku w dopływie do oczyszczalni. Gromadzące się na dnie przewodów osady powodują również zmianę kształtu i pola powierzchni przekroju czynnego przewodu, a tym samym wpływają na zmianę parametrów fizycznych i hydrodynamicznych całego systemu. Osady wpływają też w dużej mierze na rozwój korozji siarczanowej kanałów oraz na intensywność procesów biodegradacji ścieków w przewodach kanalizacyjnych. Badania dotyczące osadów ściekowych oraz związanych z nimi procesów są dość kosztowne, więc prowadzi się je na szerszą skalę jedynie w tych krajach, gdzie regulacje prawne wymagają matematycznego modelowania transportu masy zanieczyszczeń do oczyszczalni ścieków oraz przelewów burzowych. Wyniki takich badań dostarczają danych niezbędnych do kalibracji odpowiednich modeli matematycznych. Ogólna charakterystyka struktury i właściwości osadów powinna być znana na etapie rozważania metody doboru minimalnych spadków dna kanałów grawitacyjnych, ma także duże znaczenie podczas modelowania transportu ładunków zanieczyszczeń w sieci kanalizacyjnej oraz powiązanych z tym zagadnieniem procesów biodegradacji ścieków. Właściwości osadów muszą być uwzględnione przy doborze modelu opisującego ich transport. Przedstawiono klasyfikację osadów na podstawie literatury krajowej i zagranicznej, modele stosowane do opisu transportu osadów w kanalizacji grawitacyjnej oraz zaprezentowano wyniki badań klasyfikacyjnych osadów zlokalizowanych w sieci kanalizacyjnej Chełma.

Słowa kluczowe: kanalizacja grawitacyjna, osady w kanalizacji, klasyfikacja osadów, transport osadów w kanalizacji

ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 11 2011

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IMPACT OF THE PULSED HIGH MAGNETIC FIELD ON *Fusarium culmorum* (W.G. Smith) Sacc.

WPŁYW IMPULSOWEGO, WYSOKIEGO POLA MAGNETYCZNEGO NA *Fusarium culmorum* (W.G. Smith) Sacc.

Abstract: The aim of the investigations was an assessment of the impact of the pulsed high magnetic field on a concentrated spore suspension of *F. culmorum* fungus, which is a dangerous pathogen of many crops. 5, 10, 15 and 20 pulses of 9 Tesla induction were applied. The pulsed magnetic field limited germination of the tested strain. A significant difference was found for 15 and 20 pulses. Mycelial linear growth was also reduced, as was found both for the inoculation and logarithmic phase of growth in Petri dish culturing, however, no limited mycelium sporulation was observed. There is a potential for the application of the tested physical method – the pulsed high magnetic field to limit the development and harmfulness of *F. culmorum*.

Keywords: pulsed magnetic field, *F. culmorum*

The magnetic field is one of physical factors which influence life processes of microorganisms [1]. Magnetic field may modify fungi sporulation, which is connected with disturbance of calcium ion flow playing an important role in this process [2, 3]. Albertini et al [4], who studied the effect of the constant high magnetic field on the observed physiological and morphological changes in *Fusarium culmorum*, ie weakening of mycelial growth, spore germination and a decrease in enzymatic activity. They described the occurring morphological changes as similar to those caused by the contact of these fungi with chemical pesticides. Similarly, while applying the constant magnetic field, Nagy and Fischl [5] registered even 83 % limited spore production in *F. oxysporum* species in comparison with the control. In their studies on *Saccharomyces cerevisae* Novak et al [6] observed that 20-minute exposure to 10 mT caused the death of some yeast cells, whereas the ones which survived did not lose the growth ability. On the other hand Ruiz-Gomez et al [7] did not register any significant effect on cell

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viability exposed to the constant magnetic field (0.35 and 2.45 mT) for 24 and 72 hours. The high constant magnetic field also reveals an antibacterial effect [8–11]. It was found that the magnetic field modifies bacteria sensitivity to antibiotics [12, 13]. Gaafar et al [14] found that antibacterial activity of the constant magnetic field depends on the applied exposure time. In some specific conditions, the constant magnetic field may be a factor stimulating bacteria [15, 16]. Studies conducted on the effect of the pulsed high magnetic field on microorganisms produced different results. Harte et al [17], who researched *Escherichia coli* and *S. cerevisiae* did not observe any inactivation of the microorganisms as a result of the pulsed magnetic field of 18 Tesla induction. On the other hand, San Martin et al [18] point to a potential *E. coli* deactivation by 50 pulses of 19 Tesla magnetic field, combined with other physical factors – ultrasounds, high hydrostatic pressure and the pulsed electric field. *In vitro* experiments conducted by Lipiec et al [19] on the effect of pulsed magnetic fields of 5, 10, 15 and 20 Tesla on potato pathogens *Ervinia carotovora*, *Streptomyces scabies* and *Alternaria solani* revealed a significant reduction of the number of formed colonies in comparison with the control, however bacteria revealed greater sensitivity than fungi. *In vivo* experiments demonstrated a statistically significant reduction of the number of surviving microorganism colonies (bacteria and fungi) on germinating oat kernels subjected to the field activity in comparison with the control. It was also observed that the tested magnetic field caused a change of enzymatic processes. The same research team pointed to potential application of the pulsed magnetic field in the process of food stabilization for storage. The use of the oscillating magnetic field for microorganism deactivation is covered by an American patent [21].

Fusarium fungi occur commonly in nature and are polyphagous parasites infesting many plant species. Apart from that they play an important role in pathogenesis of many plant diseases and their metabolites may cause poisoning in people and animals. Therefore, they are the object of interest of phytopathologists all over the world. The imperfect stage of *Fusarium* is numbered among *Deutromycetes* type, *Hyphomycetales* order and *Tuberculariaceae* family. Their sexual forms are *Ascomycota* sac fungi. One of the commonest species occurring in Europe is *F. culmorum* classified to *Discolor* section [22].

The investigations aimed to assess the effect of the pulsed high magnetic field on concentrated suspension of *F. culmorum* fungus spores.

Material and methods

The apparatus used for the experiment had been constructed at the Department of Physics, University of Agriculture in Krakow. The battery of high-voltage capacitors with a total capacity of 1.5 mF was charged to the required voltage by the HV (*high-votage*) power supply with the maximum working voltage 5 kV and 0.3 kW power. Solenoid generating the magnetic field consists of a single layer copper Bitter coil with the external diameter of 30 mm and internal 12 mm. The number of coils is 12. The intercoil insulation is made of epoxy-glass laminate. The coil is placed inside a coven made of beryllium bronze to ensure an adequate mechanical strength. The condenser battery is discharged by means of a solenoid with the spark gap regulated by a step motor. The system is operated by a remote control panel situated, for safety reasons, in a separate room. The magnetic field generated in the solenoid has the character of strongly damped vibration of ca 3 kHz frequency and maximum induction amplitude of about 20T. Precise measurement of the parameters of the field is possible owing to an induction coil positioned inside the solenoid and coupled with digital oscilloscope.

F. culmorum strain used for the presented experiments was isolated from red cabbage in 1997 and purchased from the collection of the Plant Protection Institute in Poznan. The fungus was cultured on solid PDA medium until intensively sporulating mycelium developed.

A concentrated water suspension of the fungus spore ($3.7 \cdot 10^6$ pcs./cm^3) was prepared, 5 cm^3 of it was put into glass test tubes which were then subjected to 5-time, 10-time, 15-time and 20-time action of pulsed 9 Tesla induction magnetic field. The control was provided by the initial suspension, which was not subjected to the magnetic field action. Spore germination obtained after the magnetic field action was tested, therefore, the spore suspension was placed on concave microscope slides, on racks in covered containers filled with water to prevent evaporation. After 24 hours 25 photographs of each preparation were taken using Moticam 1000 camera and Nickon Eclipse E200 microscope with 40 times magnification. The photographs were computer analyzed using UTHSCA Image tool programme. The percentage of germinating spores and an average sprout length were computed.

After subjecting to the magnetic field action the suspension was also inoculated on the solid PDA medium in order to assess mycelial linear growth. The mycelial sporulation was also tested by collecting a 10 mm disc from each Petri dish by the end of culturing to prepare spore suspension in sterile distilled water. Spore concentrations in the suspensions were measured by means of Spekol 21 spectrophotometer made by Carl Zeiss Jena. Analytical wavelength (λ = 460 nm) was determined on the basis of absorption spectra analysis of spore mixture in water. In order to avoid errors due to spore sedimentation, all measurements were conducted at a fixed moment – 5 seconds after spore suspension pouring into the measuring cuvettes. All experiments were conducted in 7 replications. Measuring unreliability was estimated using the standard deviation considering the Student coefficient for the confidence level 0.997.

Results and discussion

The pulsed high magnetic field of 9 Tesla induction weakened germination of *F. culmorum* strain used in the experiments. The obtained results were presented in Figs. 1 and 2. In the control samples after 24 hours an average percentage of germinated spores exceeded 40 %. A significantly lower percentage of germinating spores ca 20 % was obtained at 15 and 20 pulses of the generated magnetic field. Spores subjected to 5-time and 10-time action of the magnetic field were germinating similarly to the control (on average 35 % germinating spores per sample). Sprout lengths measured in the samples were significantly shorter in comparison with the control only for 20 pulses

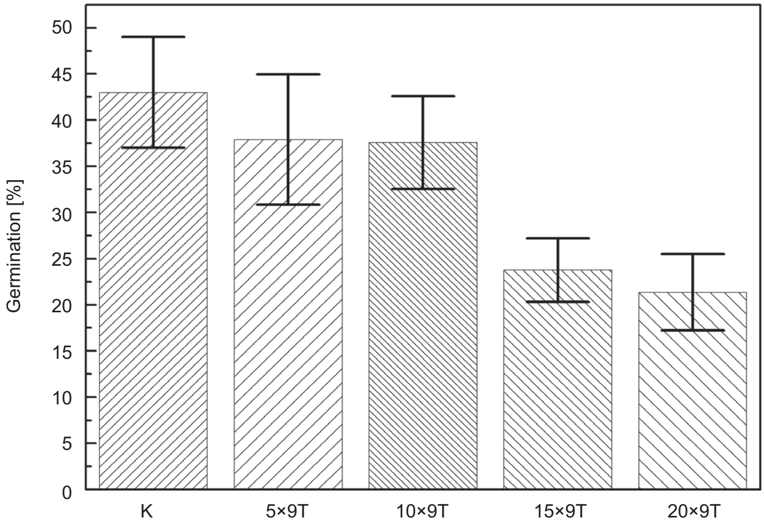

Fig. 1. Number of *F. culmorum* spores germinating after the action of pulsed magnetic field in comparison with the control

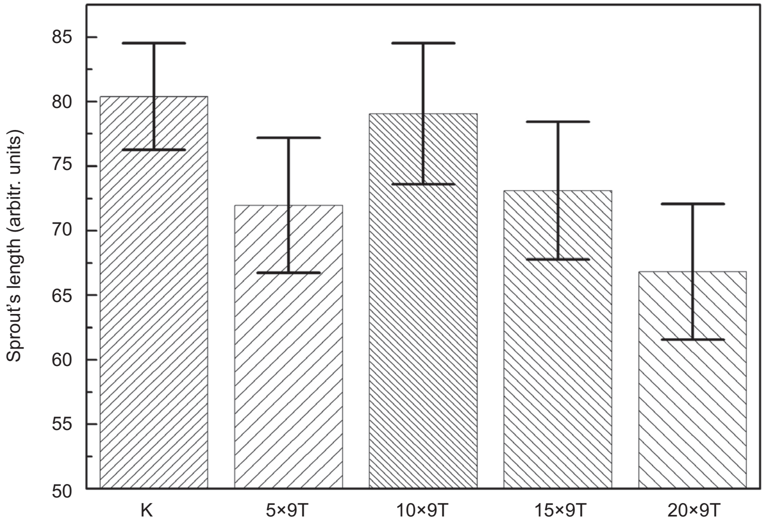

Fig. 2. Average length of *F. culmorum* sprout in the control and in sample after pulsed magnetic field action

of the 9 Tesla field. In the samples subjected to the action of 5, 10 and 15 pulses of the generated field the sprout length was slightly shorter in comparison with the control, but the registered differences were statistically insignificant.

The pulsed magnetic field also weakened the mycelia linear growth of the tested *F. culmorum* strain. Spores subjected to the action of magnetic field inoculated to the solid medium revealed poorer growth, the inoculation process was slower and at the 40th hour of culturing significantly smaller mycelium diameters were noted in comparison with the control. The obtained results were presented in Fig. 3. The mycelial growth rate observed at the logarithmic phase was also weaker in culturing of spores subjected to the action of the magnetic field. Limiting of the linear growth depended on the number

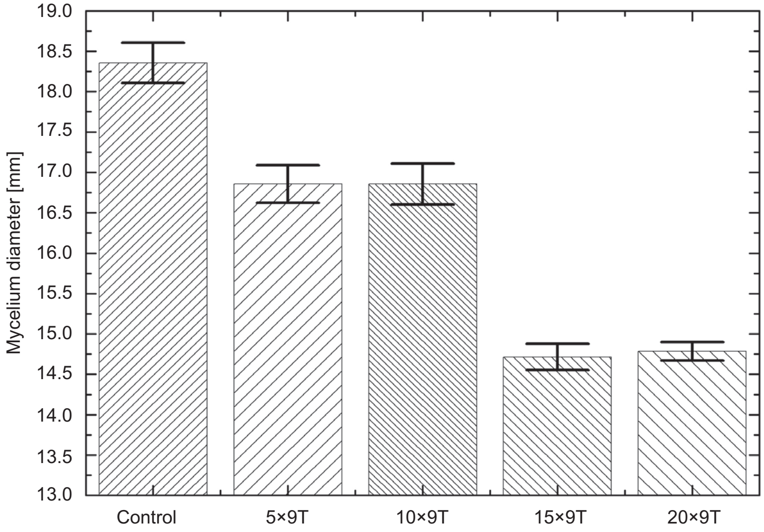

Fig. 3. *F. culmorum* inoculation to solid PDA medium expressed by mycelium diameter obtained 40 hours after suspension inoculation

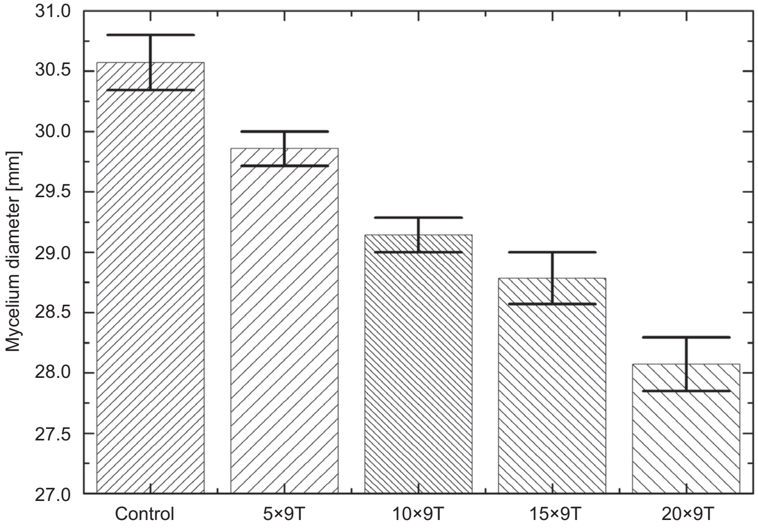

Fig. 4. *F. culmorum* mycelium diameter on solid PDA medium obtained at logarithmic phase of fungus growth

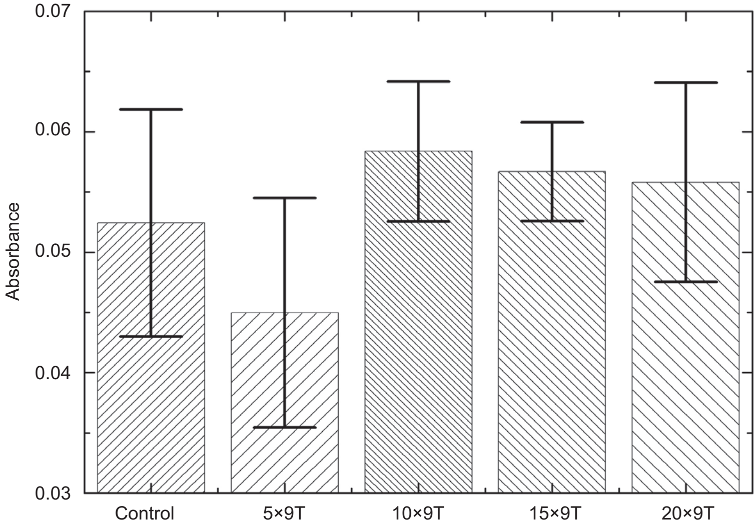

Fig. 5. Effect of pulsed magnetic field on *F. culmorum* sporulation obtained in consecutive culturing

of applied magnetic field pulses. Inhibition of growth was more apparent with growing number of pulses. The results were shown in Fig. 4. The fungus sporulation analyzed after completion of the culturing was uniform. The fluctuations fell within the range of the measuring error (Fig. 5).

Conclusions

1. The pulsed magnetic field limits germination of the tested *F. culmorum* strain. A significant difference was assessed for 15 and 20 pulses of 9 Tesla field.
2. Inoculation and linear growth of the mycelium were weakened in comparison with the control after the action of the pulsed magnetic field.
3. No reduced mycelial sporulation was registered for the tested fungus strain.
4. There is a potential for the application of the tested physical method – the pulsed high magnetic field – for limiting the development and harmfulness of *F. culmorum*.

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WPŁYW IMPULSOWEGO, WYSOKIEGO POLA MAGNETYCZNEGO NA *Fusarium culmorum* (W.G. Smith) Sacc.

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Abstrakt: Celem przeprowadzonych badań była ocena wpływ impulsowego, wysokiego pola magnetycznego na skoncentrowaną zawiesinę zarodników grzyba *F. culmorum*, groźnego patogena wielu roślin uprawnych. Zastosowano 5, 10, 15 i 20 impulsów pola magnetycznego o indukcji 9 Tesli. Impulsowe pole magnetyczne ograniczyło kiełkowanie badanego szczepu. Istotną różnicę stwierdzono dla 15 i 20 impulsów. Wzrost liniowy grzybni również ulegał ograniczeniu, co stwierdzono zarówno dla inokulacji, jak i fazy logarytmicznej wzrostu w hodowli szalkowej. Nie zaobserwowano jedynie ograniczenia sporulacji grzybni. Istnieje możliwość wykorzystania testowanej metody fizycznej – impulsowego wysokiego pola magnetycznego – do ograniczania rozwoju i szkodliwości *F. culmorum.*

Słowa kluczowe: impulsowe pole magnetyczne, *F. culmorum*

ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 11 2011

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SOIL POLLUTION WITH ARSENIC VERSUS THE CONCENTRATION OF MAGNESIUM IN PLANTS

WPŁYW ZANIECZYSZCZENIA GLEBY ARSENEM NA ZAWARTOŚĆ MAGNEZU W ROŚLINACH

Abstract: A study has been carried out in order to determine the effect of soil pollution with arsenic on the concentration of magnesium in plants. Soils under yellow lupine were contaminated with arsenic at the rates of 10, 20, 30 and 40 mg As $\cdot$ kg^{-1} and those sown with maize, cocksfoot, spring barley and swedes received 25, 50, 75 and 100 mg As $\cdot$ kg^{-1}. The following substances were used to neutralize the effect of arsenic on plants: compost, lime, charcoal, loam and natural zeolite in the trials with maize and, additionally, synthetic zeolite in the experiments on cocksfoot and yellow lupine or peat, loam, pinewood bark, dolomite and synthetic zeolite in the trials with spring barley and swedes. The influence of increasing soil pollution with arsenic on the concentration of magnesium in particular organs of the test plants was varied. In general, the content of magnesium in plant parts tended to be positively correlated with the degree of soil contamination with arsenic. It also depended on the plant's species and organ as well as the type of a neutralizing agent applied. Positive correlation was discovered for the roots and aboveground parts of maize, cocksfoot and yellow lupine as well as grain, straw and roots of spring barley. Changes in the magnesium levels caused by arsenic pollution were larger in the roots than in the aboveground parts of plants, especially in the case of spring barley. A decrease in the magnesium concentration in plant tissues caused by soil contamination with arsenic was noticed only in the roots and aboveground parts of swedes. The neutralizing substances produced the strongest positive effect on the content of magnesium in the aboveground parts of maize and roots of cocksfoot. With regard to the remaining plant species, this effect was much weaker.

Keywords: arsenic contamination, neutralizing substances, plants, magnesium content

Human activity is the main source of environmental pollution with arsenic. Han et al [1] distinguish two anthropogenic paths of introducing arsenic to matter cycling in nature. One relies on extracting arsenic from geological deposits rich in this element. The other one is when arsenic is introduced to environment as a by-product of extracting metal ores or bioliths which contain arsenic compounds. By using and

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recycling products comprising arsenic as well as non-iron metals and combustion of bioliths we release arsenic to environment. Point accumulation of excessive arsenic levels in nature is caused by a variety of human actions, including industrial activities, and particularly metallurgy, energy generation, glass production and chemical industry. Other essential sources of arsenic in nature include agriculture and improper municipal or industrial waste dumping [2, 3]. According to the WHO [3], the main cause of water, air and soil pollution with arsenic is extraction and processing of non-iron metals, especially copper, lead, silver and gold. Adverse effects produced by arsenic on plants depend in several factors, of which the major ones are the level of contamination, plant species and type of soil [4, 5]. One of the most typical symptoms of the toxic effect of arsenic is severe dwarfing of plants [2]. Arsenic contamination of soil can modify very extensively plant germination, growth and development; it can also raise concentration of arsenic in plant tissues and cause disorders in the uptake of macro- and micronutrients. In conclusion to the above, it can be stated that the uptake of arsenic by plants should be limited.

The objective of the present study has been to determine the effect of soil pollution with arsenic on the content of magnesium in plants. Soil contamination with arsenic and its consequences were examined in conjunction with the addition of several neutralizing agents to soil.

Material and methods

The study was based on 5 pot experiments, which were performed in a greenhouse at the University of Warmia and Mazury in Olsztyn (Poland). The soils taken for the trials were similar in physicochemical properties (Table 1). All the soils were derived from the Ap humus layer of typical brown soil characterized by the granulometric composition of light loamy sand. The reaction of the soils was acidic or slightly acidic. The pots were filled with 9 kg soil each. The effect produced by arsenic (as an aqueous solution of sodium arsenate) was tested on: maize (*Zea mays* L.) cv. Scandia, cocksfoot (*Dactylis glomerata* L.) cv. Nawra, yellow lupine (*Lupinus luteus* L.) cv. Juno, spring barley (*Hordeum vulgare* L.) cv. Ortega and fodder swedes (*Brassica napus* var. *napobrassica*) cv. Sara. In all the trials (except yellow lupine) soil contamination with arsenic was at the level of 0, 25, 50, 75 and 100 mg As $\cdot$ kg^{-1} soil. For the experiments on yellow lupine the soil contamination rates were: 0, 10, 20, 30 and 40 mg As $\cdot$ kg^{-1} soil. The neutralizing agents introduced to soil in the experiments involving cocksfoot and yellow lupine were: lime, natural zeolite, charcoal, loam, compost and synthetic zeolite. The same substances but synthetic zeolite were used in the studies on maize. In the trials on barley and swedes the following neutralizing substances were applied: peat, pinewood bark, loam, dolomite and synthetic zeolite. All the neutralizing agents were added to soil at a ratio of 3 % to the soil mass in a pot, except lime and dolomite, which were used in quantities corresponding to 1 hydrolytic acidity (Hh). In order to provide for the nutritional demands of the crops, the soils also received NPK fertilization. Nitrogen was added to the soils as urea, phosphorus in the form of triple superphosphate and potassium as potassium salt. Prior to the application, all the fertilizers had been

Table 1

Some chemical properties of soils used for pot trials

Trials	pH		Hh [mmol · kg^{-1}]	C	N	Total forms										Available forms		
	in H_2O	in KCl				P	K	Mg	Ca	Na	As	Cu	Zn	Mn	Fe	P	K	Mg
				[g · kg^{-1} d.m.]		[g · kg^{-1} d.m.]					[mg · kg^{-1}]				[g · kg^{-1}]	[mg · kg^{-1}]		
With maize	6.07	5.91	19.5	5.01	0.61	0.43	0.52	0.41	1.10	0.09	2.71	1.58	24.34	272.22	10.70	53.2	94.5	34.0
With cocksfoot and yellow lupine	5.75	4.53	33.1	5.41	0.69	0.47	0.96	0.51	1.41	0.11	3.58	1.44	22.81	253.83	12.50	49.8	87.2	34.2
With barley and swedes	5.53	4.16	28.2	5.48	0.51	0.45	0.88	0.55	1.35	0.08	2.21	1.51	23.15	258.77	12.59	52.2	91.8	29.9

Table 2

Chemical composition of materials (supplements) used for arsenic inactivation

Materials	Elements									
	P	K	Mg	Ca	Na	As	Fe	Mn	Cu	Zn
	[g · kg^{-1} d.m.]					[mg · kg^{-1} d.m.]				
Compost	2.72	1.58	1.56	18.21	0.14	2.55	368	72.55	15.22	129.82
Charcoal	0.72	9.33	2.58	7.29	0.81	—	125	325	8.22	31.25
Lime (CaO)	0.16	0.67	2.32	421.16	0.13	1.92	630	295	2.15	11.17
Dolomite	0.11	0.52	28.5	269.81	0.18	—	1120	233	3.25	13.23
Loam	0.41	21.60	17.3	23.87	8.00	3.2	38000	451	43.2	98.13
Zeolite (natural) type MHZ	0.11	23.21	0.32	15.28	16.12	1.33	7950	342	5.52	32.22
Zeolite (synthetic) type RBZ	0.15	32.37	0.17	21.12	4.31	—	8940	286	6.39	28.18
Pinewood bark	0.18	0.44	0.62	0.55	0.15	—	153	112	16.23	19.30
Peat	0.52	1.18	0.82	7.23	2.32	3.1	938	39.25	5.23	62.38

prepared as aqueous solutions. All the substances: the fertilizers, sodium arsenate and the neutralizing agents, once added to soil, they were thoroughly mixed with it and then transferred to pots. The soil used for maize trials had pH of 6.07 in H_2O and 5.91 in KCl. Its hydrolytic acidity was 19.5 mmol $\cdot$ kg^{-1}. This soil was moderately abundant in available phosphorus, potassium and magnesium. Cocksfoot and lupine were grown on soil of the reaction equal 5.75 in H_2O and 4.53 in KCl. Its hydrolytic acidity was 33.1 mmol $\cdot$ kg^{-1}. Barley and swedes grew on soil of the reaction 5.53 in H_2O and 4.16 in KCl. Its hydrolytic acidity corresponded to 28.2 mmol $\cdot$ kg^{-1}. In terms of their content of plant available phosphorus, potassium and magnesium, the soils were moderately abundant. The levels of carbon and nitrogen in all the test soils were comparable. The concentration of arsenic in the test soils was small and did not exceed the norms set for farmland soils. The highest concentration of As, 3.58 mg As $\cdot$ kg^{-1}, was found in the soil under cocksfoot and yellow lupine. The smallest one, 2.21 mg As $\cdot$ kg^{-1}, occurred in soil under barley and swedes. The soil used for trials on maize contained 2.71 mg As $\cdot$ kg^{-1}. With respect to other trace elements, they were determined in very small amounts in all the soils. Having filled all the pots with the appropriate components, whose chemical composition can be found in Table 2, the test crops were sown. The plant stand per 1 pot was as follows: 10 maize plants, 8 cocksfoot plants, 8 yellow lupine plants, 15 spring barley plants and 5 swedes plants. Soil moisture in the plants was maintained at 60 % water capillary capacity. The plants were harvested during the technological maturity stage.

While harvesting the plants, plant material was sampled for laboratory analyses. The plant samples were fragmented, dried at 60 ^{o}C and ground. Having mineralized the samples, AAS method was used to determine their content of magnesium. The results were processed statistically with the Statistica software package [6], using single- and two-factor analysis of variance. Dependencies between the dose of arsenic and concentration of magnesium in plants were determined using Pearson's simple correlation.

Results and discussion

The effect of increasing contamination of soil with arsenic on the concentration of magnesium in the test crops was varied. The content of magnesium in the plant material sampled tended to be correlated with the level of soil contamination with arsenic. In addition, magnesium content depended on the plant's species, analyzed part and type of a neutralizing substance applied (Tables 3–7).

The pollution of soil with arsenic caused strong increase in the content of magnesium, both in aboveground parts and in roots of maize (Table 3). In a series without neutralizing agents, this increase equalled 61 % in aboveground parts and 71 % in roots. The substances used to inactivate arsenic in soil significantly modified the concentration of magnesium. Regarding the aboveground parts, the level of magnesium rose by 30 % ($r = 0.792$) in the objects receiving loam to 200 % ($r = 0.976$) in the combinations treated with charcoal and 233 % ($r = 0.975$) in the pots which were enriched with natural zeolite. In maize roots, the increase in magnesium observed in the above series oscillated from 71 % (r = 0.965) in the objects without neutralizing additives to 225 % (r = 0.921) when charcoal had been added. The substances used to neutralize arsenic in soil affected the content of magnesium in both parts of maize. For example, charcoal added to soil produced a clear positive effect on the concentration of magnesium in aboveground parts of maize. The second best results were produced by compost and natural zeolite. Reverse relationships, especially when analyzing the impact of loam and compost, were observed in the case of maize roots.

Tabela 3

Magnesium concentration in aboveground parts and roots
of maize (*Zea mays* L.) [$g \cdot kg^{-1}$ d.m.]

Dose of arsenic [$mg\ As \cdot kg^{-1}$ soil]	Type of neutralizing agent					
	no neutralizing agents	compost	charcoal	loam	lime	natural zeolite
Aboveground parts						
0	1.8	2.4	2.7	2.3	2.0	2.1
25	2.0	3.0	3.7	2.5	2.6	2.4
50	2.7	4.6	5.9	3.2	4.3	3.6
75	2.9	6.6	7.9	3.3	5.4	5.6
100	2.9	5.4	8.1	3.0	5.1	7.0
Average	2.5	4.4	5.7	2.9	3.9	4.1
r	0.938^{**}	0.882^{**}	0.976^{**}	0.792^{**}	0.941^{**}	0.975^{**}
LSD	a – 0.3; b – 0.3; a · b – 0.7					
Roots						
0	1.7	1.2	1.2	1.1	1.5	1.3
25	2.0	1.3	1.7	1.3	1.5	1.8
50	2.6	1.7	1.9	1.7	2.5	2.6
75	2.8	2.1	2.3	1.9	2.7	2.6
100	2.9	2.4	3.9	2.3	3.2	2.5
Average	2.4	1.7	2.2	1.7	2.3	2.2
r	0.965^{**}	0.987^{**}	0.921^{**}	0.993^{**}	0.962^{**}	0.864^{**}
LSD	a – 0.2^{**}; b – 0.2^{**}; a · b – 0.4^{**}					

a – type of neutralizing agents; b – arsenic contamination; significant for: * p = 0.05, ** p = 0.01; r – correlation coefficient.

Soil contamination with arsenic also caused elevated concentrations of magnesium in aboveground parts and organs of cocksfoot (Table 4). In the aboveground parts this increase ranged from 15 to 36 % and in the roots – from 7 to 146 %. The highest rise in the concentration of magnesium in parts of cocksfoot plants was observed in the control series (without any neutralizing substances) and in the objects which received zeolite and charcoal. The substances used during the experiments in order to inactivate arsenic in soil caused more variation in the concentration of magnesium in roots than in aboveground parts of cocksfoot. Depending on the neutralizing agent applied, the average magnesium level was from 1.4 to 1.7 g Mg · kg^{-1} d.m. in aboveground parts and from 1.1 to 2.8 g Mg · kg^{-1} in roots.

Table 4

Magnesium concentration in aboveground parts and roots
of cocksfoot (*Dactylis glomerata* L.) [g · kg^{-1} d.m.]

Dose of arsenic [mg As · kg^{-1} soil]	Type of neutralizing agent						
	no neutralizing agents	natural zeolite	lime	tree coal	loam	compost	synthetic zeolite
Aboveground parts							
0	1.4	1.4	1.4	1.4	1.3	1.5	1.5
25	1.5	1.6	1.5	1.5	1.4	1.5	1.7
50	1.8	1.7	1.6	1.6	1.5	1.5	1.7
75	1.9	1.7	1.7	1.7	1.5	1.5	1.7
100	1.9	1.9	1.7	1.8	1.5	1.8	1.8
Average	1.7	1.7	1.6	1.6	1.4	1.6	1.7
r	0.944**	0.957**	0.970**	1.000**	0.884**	0.707*	0.866**
LSD	a – 0.1**; b – 0.1**; a · b – n.s.						
Roots							
0	1.0	1.7	0.8	1.3	1.4	2.1	1.3
25	1.1	1.7	0.8	1.4	1.6	2.3	1.3
50	1.2	2.8	1.2	1.8	1.5	2.4	1.5
75	1.4	3.1	1.3	2.3	1.4	3.4	2.1
100	1.5	2.9	1.2	3.2	1.5	3.8	2.4
Average	1.2	2.4	1.1	2.0	1.5	2.8	1.7
r	0.991**	0.878**	0.853**	0.955**	0.000	0.947**	0.945**
LSD	a – 0.3**; b – 0.2**; a · b – 0.6**						

a – type of neutralizing agents; b – arsenic contamination; significant for: * p = 0.05, ** p = 0.01; n.s. – differences non-significant; r – correlation coefficient.

The effect of soil pollution with arsenic on the concentration of magnesium in yellow lupine was much weaker than in maize or cocksfoot (Table 5). Regarding the aboveground parts of maize, soil contamination with arsenic raised their content of magnesium in most series. This increase was most evident in the objects treated with lime (r = 0.834), followed by those receiving compost (r = 0.990) and natural zeolite (r = 0.930), reaching 71, 38 and 26 %, respectively. The aboveground parts of yellow lupine obtained from the control series (r = 0.938) and the ones with synthetic zeolite (r = 0.926) and charcoal (r = 0.243) showed rather stable levels of magnesium and only very weakly dependent on the application of arsenic to soil. Changes in the concentration of magnesium in yellow lupine roots were less evident than in aboveground parts of this crop. In the above series, the average amount of magnesium in the roots of yellow lupine ranged from 1.1 to 1.5 g Mg · kg^{-1} d.m.

Table 5

Magnesium concentration in aboveground parts and roots of yellow lupine (*Lupinus luteus* L.) [g · kg^{-1} d.m.]

Dose of arsenic [mg As · kg^{-1} soil]	Type of neutralizing agent						
	no neutralizing agents	tree coal	natural zeolite	synthetic zeolite	loam	compost	lime
Aboveground parts							
0	2.2	2.2	1.9	1.9	1.8	1.6	1.7
10	2.2	2.1	2.0	1.9	1.8	1.8	2.6
20	2.3	2.0	2.2	2.0	1.9	1.9	2.8
30	2.5	1.9	2.5	2.3	1.8	2.0	2.8
40	2.5	2.2	2.4	2.3	1.7	2.2	2.9
Average	2.3	2.1	2.2	2.1	1.8	1.9	2.6
r	0.938**	–0.243	0.930**	0.926**	–0.447	0.990**	0.834**
LSD	a – 0.1**; b – 0.1**; a · b – 0.3**						
Roots							
0	1.2	1.1	1.3	1.3	1.4	1.7	1.2
10	1.3	1.1	1.2	1.3	0.9	1.7	1.3
20	1.3	1.1	1.4	1.2	0.9	1.6	1.0
30	1.4	1.3	1.5	1.5	1.0	1.3	1.3
40	1.5	0.9	1.7	1.5	1.4	1.3	1.5
Average	1.3	1.1	1.4	1.4	1.1	1.5	1.3
r	0.971**	–0.224	0.904**	0.707*	0.061	–0.926**	0.522
LSD	a – 0.1**; b – 0.1**; a · b – 0.3**						

a – type of neutralizing agents; b – arsenic contamination; significant for: * p = 0.05, ** p = 0.01; r – correlation coefficient.

The trials involving swedes showed that the simulated poisoning of soil with arsenic modified the concentration of magnesium in this crop, too, but the aboveground parts of swedes in the series treated with peat (r = 0.930), bark (r = 0.933) and synthetic zeolite (r = 0.839) responded to the contamination by increasing the levels of Mg, whereas the roots of this crop, under analogous conditions, contained lower quantities of this nutrient (Table 6). Besides, the concentration of magnesium in swedes was found to be dependent on the inactivation substances applied. The largest concentrations of magnesium in the aboveground parts of swedes were found in the series treated with dolomite (on average, 2.6 g Mg · kg^{-1} d.m.) and in the roots in the series with pinewood bark (1.6 g Mg · kg^{-1} d.m.). In the other series, the magnesium content was 2.3–2.4 g Mg · kg^{-1} d.m. of leaves and 1.4–1.5 g Mg · kg^{-1} d.m. of roots.

Table 6

Magnesium concentration in aboveground parts and roots
of swedes *(Brassica napus* L. var. *napobrassica* (L.) Rchb.) [g · kg^{-1} d.m.]

Dose of arsenic [mg As · kg^{-1} soil]	Type of neutralizing agent					
	no neutralizing agents	peat	bark	loam	dolomite	synthetic zeolite
Aboveground parts						
0	2.4	2.2	2.2	2.2	2.8	2.3
25	2.4	2.2	2.2	2.2	2.5	2.3
50	2.3	2.5	2.4	2.3	2.6	2.4
75	2.2	2.5	2.5	2.4	2.6	2.4
100	2.2	2.6	2.9	2.2	2.6	2.8
Average	2.3	2.4	2.4	2.3	2.6	2.4
r	–0.949**	0.930**	0.933**	0.354	–0.433	0.839**
LSD	a – n.s.; b – 0.2**; a · b – 0.4*					
Roots						
0	1.7	1.5	1.5	1.5	1.8	1.5
25	1.6	1.5	1.7	1.5	1.4	1.5
50	1.3	1.5	1.6	1.5	1.4	1.3
75	1.4	1.4	1.5	1.4	1.6	1.4
100	1.4	1.3	1.5	1.2	1.5	1.5
Average	1.5	1.4	1.6	1.4	1.5	1.4
r	–0.770*	–0.884**	–0.354	–0.849**	–0.378	–0.177
LSD	a – 0.2**; b – 0.2**; a · b – 0.4**					

a – type of neutralizing agents; b – arsenic contamination; significant for: * p = 0.05, ** p = 0.01; n.s. – differences non-significant; r – correlation coefficient.

With respect to spring barley, the highest magnesium content was discovered in roots, with lower amounts of this element occurring in grain and straw (Table 7). These concentrations were, on average, from 1.7–2.2 g Mg · kg^{-1} d.m. of roots and from 1.2 to 1.6 g Mg · kg^{-1} d.m. of grain and straw. The effect of higher doses of arsenic introduced to soil on magnesium levels in plant tissues was weaker in the case of barley grains than its straw or roots. Among the neutralizing substances tested, the strongest effect on the content of magnesium in barley plants was recorded in the series with dolomite and synthetic zeolite (Mg in roots) as well as the series treated with synthetic zeolite, pinewood bark or grain (Mg in barley straw). In the other series and in barley grain, modifications in the content of magnesium observed after the application of any of the neutralizing substances were small, not exceeding 10 %.

Scientific reports on the influence of arsenic on concentrations of microelements, including magnesium, in plants are scarce. The positive relationships we discovered between arsenic contamination of soil and content of magnesium in roots and aboveground parts of some of the test plants seem to confirm the results obtained by

Table 7

Magnesium concentration in grain, straw and roots of spring barley (*Hordeum vulgare* L.) [$g \cdot kg^{-1}$ d.m.]

Dose of arsenic [$mg\ As \cdot kg^{-1}$ soil]	Type of neutralizing agent					
	no neutralizing agents	peat	bark	loam	dolomite	synthetic zeolite
Grain						
0	1.3	1.4	1.7	1.5	1.7	1.3
25	1.4	1.4	1.3	1.4	1.6	1.6
50	1.4	1.3	1.2	1.3	1.5	1.7
75	1.6	1.3	1.2	1.3	1.4	1.5
100	1.5	1.6	1.3	1.1	1.5	1.3
Average	1.4	1.4	1.3	1.3	1.5	1.5
r	0.832^{**}	0.387	-0.686^{*}	-0.959^{**}	-0.832^{**}	–0.088
LSD	a – n.s.; b – n.s.; a · b – n.s.					
Straw						
0	1.0	1.1	1.5	1.3	1.6	1.6
25	1.1	1.1	1.5	1.4	1.7	1.6
50	1.4	1.2	1.6	1.4	1.6	1.5
75	1.4	1.3	1.7	1.5	1.5	1.6
100	1.8	1.3	1.5	1.8	1.4	1.7
Average	1.3	1.2	1.6	1.5	1.6	1.6
r	0.960^{**}	0.949^{**}	0.354	0.904^{**}	-0.832^{**}	0.447
LSD	a – 0.02; b – n.s.; a · b – n.s.					
Roots						
0	1.1	1.3	1.6	1.3	1.7	1.7
25	1.3	1.5	1.4	1.8	2.0	2.0
50	1.9	1.8	1.6	1.9	2.2	2.3
75	1.9	2.1	2.1	2.1	2.3	2.3
100	2.2	2.2	2.4	2.2	2.5	2.5
Average	1.7	1.8	1.8	1.9	2.1	2.2
r	0.962^{**}	0.990^{**}	0.877^{**}	0.947^{**}	0.985^{**}	0.960^{**}
LSD	a – n.s.; b – n.s.; a · b – n.s.					

a – type of neutralizing agents; b – arsenic contamination; significant for: * p = 0.05, ** p = 0.01; n.s. – differences non-significant; r – correlation coefficient.

Paivoke and Simola [7], who conducted a study on seed pea. It should be added, however, that the exact effect of arsenic contamination of soil on microelements in plant tissues depends on the species of a plant. In the present study, apart from higher magnesium concentrations in plant tissues under the effect of arsenic contamination of soil, we also noticed depressed levels of this element in leaves and roots of swedes.

Gorlach and Gambus [8] as well as Kabata-Pendias [2] discovered that arsenic found in toxic concentrations in plants depressed their content of magnesium. Adding substances which buffer the influence of heavy metals on plants plays an important role in establishing the level of Mg in plant tissues [9–11]. This influence tends to be positive, as they raise the availability of magnesium, originating from the neutralizing substances themselves and from partly mineralized organic matter, eg from compost earth [12]. Zeolite produces a similar effect – it improves the amounts of plant available forms of magnesium in soil and their uptake by plants [13]. The references indicate that application of compost soil, charcoal and, in part, lime to soil raises the concentration of magnesium in particular organs of triticale, spring oilseed rape, maize [9, 11] and other crops [10]. In an experiment conducted by Ciecko et al [14], by introducing to soil compost earth, lime, bentonite and especially charcoal, it was possible to obtain higher content of magnesium in most parts of the test plants. Charcoal produced the strongest effect, as it raised Mg concentration from 20 % (oats grain), 78–81 % (oats straw and yellow lupine roots) up to 216 % in aboveground parts of radish. In contrast, depressed levels of magnesium were determined in roots of radish as a result of the application of bentonite and in aboveground parts of yellow lupine after the application of lime and bentonite. Analogous effects produced by lime were found by Hahn and Marschner [15] in their analyses of spruce roots. Regarding maize, lime and magnesium are most often determined to be antagonist to each other, which means that Mg concentration in plants is depressed when lime has been added to soil [14].

Conclusions

1. The concentration of magnesium in plants was in most cases positively correlated with the degree of soil contamination with arsenic. The content of magnesium in plant tissues also depended on the plant's species and test organ and on the type of a neutralizing agent applied to inactivate arsenic.
2. Positive correlation between soil contamination with arsenic and content of magnesium in plant tissues was established for roots and aboveground parts of maize, cocksfoot and yellow lupine, and for grain, straw and roots of spring barley. Changes in the content of magnesium were bigger in roots than in aboveground parts of plants, particularly in the case of spring barley. Swedes was the only plant which responded to arsenic pollution of soil by depressing the concentration of magnesium in both roots and aboveground parts.
3. The neutralizing agents used to inactivate arsenic produced the strongest effect on the concentration of magnesium in aboveground parts of maize and roots of cocksfoot. With the remaining plants, this effect was much weaker.

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WPŁYW ZANIECZYSZCZENIA GLEBY ARSENEM NA ZAWARTOŚĆ MAGNEZU W ROŚLINACH

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Abstrakt: Przeprowadzone badania wykonano w celu określenia wpływu zanieczyszczenia gleby arsenem na zawartość magnezu w roślinach. Zanieczyszczenie gleby arsenem w dawkach 10, 20, 30 i 40 mg As · kg^{-1} gleby testowano na łubinie żółtym, a w ilości: 25, 50, 75 i 100 mg As · kg^{-1} gleby na kukurydzy, kupkówce pospolitej, jęczmieniu jarym oraz brukwi pastewnej. Do neutralizacji oddziaływania kadmu na rośliny do gleby dodano: kompost, wapno, węgiel drzewny, ił i zeolit naturalny – w doświadczeniach z kukurydzą, te same materiały i zeolit syntetyczny – w badaniach z kupkówką i łubinem żółtym oraz torf, ił, korę sosnową, dolomit i zeolit syntetyczny w doświadczeniu z jęczmieniem i brukwią. Oddziaływanie wzrastającego zanieczyszczenia gleby arsenem na zawartość magnezu w poszczególnych organach testowanych roślin było zróżnicowane. Zawartość magnezu w roślinach była przeważnie dodatnio skorelowana z poziomem zanieczyszczenia gleby arsenem. Jego zawartość w roślinach zależała ponadto od gatunku rośliny, rozpatrywanego organu, jak również od rodzaju zastosowanej substancji do neutralizacji arsenu. Dodatnią korelację wykazano w odniesieniu do korzeni i części nadziemnych kukurydzy, kupkówki i łubinu żółtego oraz ziarna, słomy i korzeni jęczmienia jarego. Większe zmiany stwierdzono w korzeniach niż częściach nadziemnych roślin, zwłaszcza w przypadku jęczmienia jarego. Jedynie części nadziemne i korzenie brukwi zareagowały spadkiem zawartości magnezu na zanieczyszczenie podłoża arsenem. Zastosowane dodatki neutralizujące najsilniej dodatnio działały na zawartość magnezu w częściach nadziemnych kukurydzy i korzeniach kupkówki. W przypadku pozostałych gatunków roślin ten wpływ był znacznie mniejszy.

Słowa kluczowe: zanieczyszczenie arsenem, substancje neutralizujące, rośliny, zawartość magnezu

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EFFECT OF SOME SUBSTANCES ON CONTENT OF SELECTED COMPONENTS IN SOILS CONTAMINATED WITH CHROMIUM

WPŁYW NIEKTÓRYCH SUBSTANCJI NA ZAWARTOŚĆ WYBRANYCH SKŁADNIKÓW W GLEBACH ZANIECZYSZCZONYCH CHROMEM

Abstract: The effect of soil contamination with increasing doses of tri- and hexavalent chromium (0, 25, 50, 100 and 150 mg Cr $\cdot$ kg^{-1} of soil) was determined on various properties of soil after cultivation of plants and the neutralizing effect of compost (3 %), zeolite (3 %) and calcium oxide (1 HA) on the contamination. Tri- and hexavalent chromium in soil, as well as the substances added to it significantly modified its basic physicochemical properties. Contamination of soil with tri- and hexavalent chromium reduced soil acidity and increased total exchangeable base cations, cation exchange capacity and base saturation. Hexavalent chromium had a greater effect on pH and hydrolytic acidity (but not on the total exchangeable base cation or cation exchange capacity) than trivalent forms of the metal. An addition of calcium oxide to the soil effectively neutralized the effect of contamination on the tested properties as it significantly decreased hydrolytic acidity. However, it also reduced total exchangeable base cations and cation exchange capacity – only with chromium(III) as compared with the control series (with no additives). The effect of the other substances was weaker and more positive in the case of compost than zeolite, especially in the objects with hexavalent chromium.

Keywords: contamination, chromium(III), chromium(VI), compost, zeolite, calcium oxide, soil, acidity, sorption properties

Dynamic industrial development, technological progress and agrochemization of agriculture have increased pollution of the environment with xenobiotics, which include heavy metals. One of the metals which is not neutral to the environment or humans is chromium, which, when present in excessive amounts, is a destructive factor, with a highly toxic effect on the biological properties of the soil [1]. The growing demand for chromium and its compounds along with the mining processes of this metal and other raw materials in which it is an accompanying metal, now pose a serious ecological threat [2]. In the soil it is found at various degrees of oxidation; the most durable are compounds of Cr(III), whereas the most toxic to plants are soluble forms of Cr(VI) [3].

The aim of the experiment was to determine the effect of soil contamination with increasing doses of tri- and hexavalent chromium on various soil properties after plant

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cultivation and the neutralizing effect of compost, zeolite and calcium oxide on the contamination.

Material and methods

A pot experiment was conducted at the vegetation hall of the University of Warmia and Mazury in Olsztyn in polyethylene pots with a capacity of 9.5 kg each, on soil with a granulometric composition of light loamy sand with the following properties: pH_{KCl} – 4.8, *hydrolytic acidity* (HA) – 33.75 $mmol(H^+) \cdot kg^{-1}$ of soil, total *exchangeable base cations* (EBC) – 62.20 $mmol \cdot kg^{-1}$, *cation exchange capacity* (CEC) – 95.95 $mmol \cdot kg^{-1}$, *base saturation* (BS) – 64.80 %, $C_{org.}$ – 7.13 $g \cdot kg^{-1}$, content of available: phosphorus – 46.6 $mg \cdot kg^{-1}$, potassium – 8.2 $mg \cdot kg^{-1}$ and magnesium – 33.9 $mg \cdot kg^{-1}$. Under natural conditions it is brown soil. The soil was contaminated with aqueous solutions of chromium(III) as $KCr(SO_4)_2 \cdot 12H_2O$ and chromium(VI) as $K_2Cr_2O_7$ in the following amounts: 0, 25, 50, 100 and 150 $mg\ Cr \cdot kg^{-1}$ of soil. Substances neutralizing the effect of chromium were also introduced to the soil: compost and zeolite at 3 % of the soil mass, and calcium oxide in the amount equivalent to 1 hydrolytic acidity (HA), as well as basic macro- and microelements in the following amounts [$mg \cdot kg^{-1}$ of soil]: N – 110 [$CO(NH_2)_2 + (NH_4)_6Mo_7O_{24} \cdot 4H_2O + (NH_4)_2HPO_4$], P – 50 [$(NH_4)_2HPO_4$]; K – 110 [$KCl + KCr(SO_4)_2 \cdot 12H_2O + K_2Cr_2O_7$], Mg – 50 [$MgSO_4 \cdot 7H_2O$], Mn – 5 [$MnCl_2 \cdot 4H_2O$], Mo – 5 [$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$] and B – 0.33 [$H_3BO_3$]. The following crops were cultivated in the experiment: spring barley (*Hordeum vulgare* L.) – the main crop, and maize (*Zea mays* L.) – the successive crop. The barley density was 15 plants per pot and for maize it was 8 plants per pot. During the vegetation of spring barley and maize, the soil humidity was maintained at 60 % of the capillary capacity with distilled water. Spring barley was harvested during the ear formation phase and maize was harvested during the stem elongation phase, after 56 and 67 days of vegetation, respectively. Samples of soil material for the laboratory analyses were taken during the maize harvest (123 days following contamination of the soil).

The following were determined in the soil samples: reaction (pH) of soil – by the potentiometric method in an aqueous solution of KCl at the concentration of 1 $mol \cdot dm^{-3}$, hydrolytic acidity (HA) and total exchangeable base cations (EBC) – by Kappen's method [4]. The hydrolytic acidity (HA) and total exchangeable base cations (EBC) were used to calculate the cation exchange capacity (CEC) and base saturation (BS) according to the following formulae: $CEC = EBC + HA$; $BS = EBC \cdot CEC^{-1} \cdot 100$. The results were analyzed statistically with STATISTICA [5] software using a three-factor analysis of variance (ANOVA). The relationship was also determined between the contamination of soil with chromium and acidity and its other properties with the use of Pearson's simple correlation.

Results and discussion

Contamination of soil with tri- and hexavalent chromium significantly affected the pH value, hydrolytic acidity, total exchangeable base cations, cation exchange capacity and base saturation of the examined soil (Tables 1, 2). In the series without neutralizing additives, small amounts of tri- and hexavalent chromium brought about a gradual increase in the pH value (Table 1). Such relationships were observed up to the dose of 50 mg of Cr(III) and Cr(VI) per 1 kg of soil, while the relationships were negative in the soil with a higher chromium content. Slightly higher values of pH were measured in the soil contaminated with trivalent chromium. In the series without the neutralizing additives, increasing doses of tri- and hexavalent reduced the hydrolytic acidity (Table 1). The reduction was greater in the objects with hexavalent chromium than in the pots with trivalent chromium. The neutralizing additives – compost, zeolite and calcium oxide – significantly affected the pH value of the soil, both in pots with trivalent and with hexavalent chromium. The best results were achieved when calcium oxide was applied to the soil, both in the objects with trivalent and in those with hexavalent chromium; it considerably increased the pH value and reduced hydrolytic acidity as compared with the control variant. Zeolite and compost in the objects with trivalent chromium also produced good results.

Increasing doses of chromium(III) also positively affected the other properties of soil (Table 2). They produced an increase in total exchangeable base cations, cation exchange capacity and base saturation in soil. The highest dose of chromium(III) ($150 \text{ mg} \cdot \text{kg}^{-1}$ of soil) resulted in their increase by 54 %, 43 % and 8 %, respectively, as compared with the control object (without chromium(III) addition to the soil). More ambiguous changes were observed when soil was contaminated with hexavalent chromium, although the highest values of total exchangeable base cations, cation exchange capacity and base saturation were observed in the soil with the highest dose of chromium(VI).

The examined properties were significantly affected by the applied neutralizing additives – compost, zeolite and calcium oxide (Table 2). Total exchangeable base cations, cation exchange capacity and base saturation in the objects with trivalent chromium were higher than in those with hexavalent chromium. In the case of chromium(III), an addition of compost, zeolite and calcium oxide to the soil reduced total exchangeable base cations and cation exchange capacity compared to the control series (without additives), with the action of zeolite and calcium oxide being stronger. In the objects with hexavalent chromium, the effect of those substances (except compost) was weaker, but more positive. In the case of chromium(VI), the cation exchange capacity was most strongly affected by an addition of compost and less so by calcium oxide, with a higher mean value of total exchangeable base cations and cation exchange capacity than in the series without additives. The weakest effect of additives was observed for base saturation.

Cation exchange capacity and the reaction of soil are important factors which determine the growth and development of plants as well as the accumulation of heavy metals in their tissues [6]. The reaction of soil plays an essential role in controlling the share of bioavailable heavy metals by regulating their uptake and influence on plant growth and development [7]. A change in the reaction of soil may reduce the effect of heavy metals, including chromium, on plants. There is a close relationship between the soil sorptive properties and the population of soil microorganisms and their enzymatic activity. This in turn is closely related to microbiological transformations of metals of restricted availability to plants into their more easily available forms. However, soil

Table 1

The pH and hydrolytic acidity of soil after harvest of the experimental plants

Dose [mg · kg^{-1} of soil]	Chromium(III)					Chromium(VI)				
	Without additions	Compost	Zeolite	Calcium oxide	Average	Without additions	Compost	Zeolite	Calcium oxide	Average
pH$_{KCl}$										
0	6.60	7.50	7.12	7.45		6.60	7.50	7.12	7.45	
25	6.90	7.32	7.20	7.70		7.36	7.22	7.21	7.53	
50	7.37	7.13	7.20	7.79		7.50	7.13	6.95	7.60	
100	7.23	7.14	7.20	7.78		7.30	7.30	7.15	7.57	
150	7.25	7.20	7.53	7.70		7.05	7.09	6.66	7.47	
Hydrolytic acidity (HA) [mmol · kg^{-1}]										
0	15.00	6.38	9.75	10.13	10.32	15.00	6.38	9.75	10.13	10.32
25	10.88	7.88	9.00	6.38	8.54	9.00	8.63	10.13	8.63	9.10
50	10.13	11.25	10.88	6.75	9.75	8.63	11.63	11.25	6.75	9.57
100	9.75	9.38	9.75	4.88	8.44	7.88	10.88	9.00	7.98	8.94
150	10.13	10.50	4.88	7.50	8.25	7.50	12.00	13.98	10.50	11.00
Average	11.18	9.08	8.85	7.13	9.06	9.60	9.90	10.82	8.80	9.78
LSD	a – 0.18**, b – 0.28**, c – 0.25**, a · b – 0.40**, a · c – 0.36**, b · c – 0.56**, a · b · c – 0.79**									

LSD for: a – kind of chromium, b – chromium dose, c – kind of neutralizing substance; ** – significant for p = 0.01, * – significant for p = 0.05, r – correlation coefficient.

Table 2

Total exchangeable base cations (EBC), cation exchange capacity (CEC) and base saturation (BS) of soil after harvest of the experimental plants

Dose [mg · kg^{-1} of soil]	Chromium(III)					Chromium(VI)				
	Without additions	Compost	Zeolite	Calcium oxide	Average	Without additions	Compost	Zeolite	Calcium oxide	Average
	Total exchangeable base cations (EBC) [mmol · kg^{-1}]									
0	104.40	157.80	123.20	98.00	120.85	104.40	157.80	123.20	98.00	120.85
25	144.80	137.20	125.20	121.60	132.20	85.20	137.00	131.80	140.80	123.70
50	144.00	128.80	125.40	124.80	130.75	90.00	133.60	124.80	142.60	122.75
100	159.20	120.20	128.60	145.20	138.30	114.20	133.60	90.20	133.80	117.95
150	161.00	132.40	140.00	152.40	146.45	124.40	121.00	65.80	59.80	92.75
Average	142.68	135.28	128.48	128.40	133.71	103.64	136.60	107.16	115.00	115.60
LSD	a – 3.58**, b – 5.66**, c – 5.07**, a · b – 8.01** , a · c – 7.17**, b · c – 11.33**, a · b · c – 16.02**									
	Cation exchange capacity (CEC) [mmol · kg^{-1}]									
0	119.40	164.18	132.95	108.13	131.17	119.40	164.18	132.95	108.13	131.17
25	155.68	145.08	134.20	127.98	140.74	94.20	145.63	141.93	149.43	132.80
50	154.13	140.05	136.28	131.55	140.50	98.63	145.23	136.05	149.35	132.32
100	168.95	129.58	138.35	150.08	146.74	122.08	144.48	99.20	141.68	126.86
150	171.13	142.90	148.63	159.90	155.64	131.90	133.00	79.68	70.30	103.72
Average	153.86	144.36	138.08	135.53	142.96	113.24	146.50	117.96	123.78	125.37
LSD	a – 3.56**, b – 5.64*, c – 5.04**, a · b – 7.97**, a · c – 7.13**, b · c – 11.27**, a · b · c – 15.94**									

Table 2 contd.

Dose [mg · kg^{-1} of soil]	Chromium(III)					Chromium(VI)				
	Without additions	Compost	Zeolite	Calcium oxide	Average	Without additions	Compost	Zeolite	Calcium oxide	Average
Base saturation (BS) [%]										
0	87.44	96.12	92.67	90.64	91.72	87.44	96.12	92.67	90.64	91.72
25	93.01	94.57	93.29	95.02	93.97	90.45	94.08	92.87	94.23	92.91
50	93.43	91.97	92.02	94.87	93.07	91.25	92.00	91.73	95.48	92.62
100	94.23	92.76	92.95	96.75	94.17	93.55	92.47	90.93	94.44	92.85
150	94.08	92.65	94.20	95.31	94.06	94.31	90.98	82.59	85.06	88.24
Average	92.44	93.61	93.03	94.52	93.40	91.40	93.13	90.16	91.97	91.66
LSD	a – 0.52**, b – 0.83**, c – 0.74**, a · b – 1.17** , a · c – 1.05**, b · c – 1.66**, a · b · c – 2.34**									

Explanations under Table 1.

contamination with heavy metals may modify the relations negatively. In the experiments conducted by Kizilkaya et al [8] with soil contaminated with metals, only the activity of urease was strongly correlated with cation exchange capacity; on the other hand, a significant negative correlation was observed between heavy metal content in soil and microbiological properties of soil. In the present experiment, contamination of soil with tri- and hexavalent chromium reduced the acidity of soil and increased its pH value, cation exchange capacity, total exchangeable base cations and base saturation. The application of calcium oxide increased the pH value after the crop harvest, confirming the positive effect of liming on the soil reaction, as reported in other papers, eg Czekala [9] and Kuziemska and Kalembasa [10]. The strong correlation between chromium content in soil and its reaction is indicated by Zarcinas et al [11]. Their findings include a positive correlation between the content of the metal and application of organic substances to soil, for example, compost and manure. The positive effect of zeolite results from its high porosity and cation exchange capacity [12]. The soil reaction, organic matter content and soil cation exchange capacity have a great effect on the bioavailability of metals and their influence on plants [13]. Pils et al [14] also indicate pH and cation exchange capacity as the main factors which determine metal retention in soil. According to Karathanasis and Pils [15], the bonds between chromium and the organic fraction of the soil are stronger than those of any other heavy metals, therefore, the application of calcium and organic matter to soil should produce a positive effect on its properties, which has been confirmed in previous studies by the authors. Wyszkowska [16] also showed an improvement in the sorptive properties of soil following the application of straw. In a laboratory experiment conducted by Castilhos et al [17], the application of organic substance as cattle manure to soil completely reduced Cr(VI) to Cr(III) within 42 days, with microbiological activity in non-sterilized soil decreased chromium content by 16 % as compared with sterilized soil. Organic substances in soil create durable combinations with heavy metals, thereby decreasing their uptake by plants. Liming and the addition of organic substance to soil may be effective methods (*in-situ*) of restricting the effect of hexavalent chromium on the properties of soil and on plants.

Conclusions

1. Tri- and hexavalent chromium in soil, as well as the substances added to it, significantly modified its basic physicochemical properties.
2. Contamination of soil with tri- and hexavalent chromium reduced soil acidity and increased total exchangeable base cations, cation exchange capacity and base saturation.
3. Hexavalent chromium had a greater effect on pH and hydrolytic acidity (but not on total exchangeable base cations or cation exchange capacity) than trivalent forms of the metal.
4. An addition of calcium oxide to the soil effectively neutralized the effect of contamination on the tested properties as it significantly decreased hydrolytic acidity. However, it also reduced total exchangeable base cations and cation exchange capacity, but only with chromium(III) as compared with the control series (with no additives).

The effect of the other substances was weaker and more positive in the case of compost than zeolite, especially in the objects with hexavalent chromium.

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WPŁYW NIEKTÓRYCH SUBSTANCJI NA ZAWARTOŚĆ WYBRANYCH SKŁADNIKÓW W GLEBACH ZANIECZYSZCZONYCH CHROMEM

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Abstrakt: W doświadczeniu wazonowym badano wpływ zanieczyszczenia gleby wzrastającymi dawkami chromu trój- i sześciowartościowego (0, 25, 50, 100 i 150 [mg Cr · kg^{-1} gleby]) na wybrane właściwości gleby po zbiorze roślin oraz oddziaływania kompostu (3 %), zeolitu (3 %) i tlenku wapnia (1 Hh) na łagodzenie skutków tego zanieczyszczenia. Zanieczyszczenie gleby chromem trój- i sześciowartościowym miało duży wpływ na pH, kwasowość hydrolityczną i pozostałe właściwości badanej gleby. Zanieczyszczenie gleby chromem trój- i sześciowartościowym spowodowało zmniejszenie zakwaszenia gleby oraz zwiększenie sumy wymiennych kationów zasadowych, całkowitej pojemności wymiennej i stopnia wysycenia kationami zasadowymi. Chrom sześciowartościowy w stosunku do trójwartościowego znacznie silniej oddziaływał na pH i kwasowość hydrolityczną, w odróżnieniu od sumy wymiennych kationów zasadowych i całkowitej pojemności wymiennej. Dodatek do gleby tlenku wapnia skutecznie łagodził oddziaływanie zanieczyszczenia gleby chromem na badane właściwości gleby, gdyż znacznie zmniejszył kwasowość hydrolityczną. Jednakże ograniczył także sumę wymiennych kationów zasadowych oraz pojemność wymienną – tylko w przypadku chromu(III), w porównaniu z serią kontrolną (bez dodatków). Wpływ pozostałych substancji był mniejszy i bardziej korzystny w przypadku kompostu niż zeolitu, szczególnie w obiektach z chromem sześciowartościowym.

Słowa kluczowe: zanieczyszczenie, chrom(III), chrom(VI), kompost, zeolit, tlenek wapna, kwasowość, właściwości sorpcyjne

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EFFECT OF BOTTOM SEDIMENT SUPPLEMENT TO SOIL ON YIELD AND CHEMICAL COMPOSITION OF MAIZE

WPŁYW DODATKU OSADU DENNEGO DO GLEBY NA PLON I SKŁAD CHEMICZNY KUKURYDZY

Abstract: A two-year pot experiment was conducted to assess the effect of bottom sediment, used as a supplement to the light soil, on the yield and contents of macroelements in maize. The bottom sediment was added to light soil in the proportion of 5 and 10 %. The material was classified to a group of ordinary silt deposit. Moreover, the analyzed sediment revealed alkaline reaction, organic matter content of 25.8 g · kg^{-1}, low content of bioavailable phosphorus and potassium and natural content of heavy metals. After the experiment completion the amount of maize dry matter yield was assessed. The contents of minerals in the plant mass was determined after dry mineralization and the ash dissolving in HNO_3 (1:3), K, Mg, Ca, and Na were determined using AAS and P with ICP-AES technique. Nitrogen content was determined by means of Kjeldahl distillation method.

The experiment demonstrated a positive effect of bottom sediment supplement to light soil on the amount of produced maize biomass. The greatest maize biomass was obtained on the treatment with a 5 % admixture of bottom sediment. However, the plant shoot biomass did not meet the criteria for good quality fodder because of too low contents of most macroelements. It was found that the analyzed bottom sediment may be used as an admixture to light and acid soils to improve their productivity, owing to a considerable share of silt and clay fractions in its composition, neutral reaction and low content of heavy metals. However, each agricultural application of bottom sediment requires a supplementary mineral fertilization because of low contents of fertilizer elements in the sediment and in the obtained maize biomass.

Keywords: bottom sediment, light soil, yield, macroelements

Chemical composition and properties of bottom deposits are shaped in result of physical, chemical and biological processes occurring in a water reservoir and within its catchment, and usually are important indicators of anthropopressure [1]. Therefore,

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identification of bottom sediment chemical composition is important not only for an assessment of water reservoir degradation but also for determining potential applications of extracted deposit [2]. Bottom sediments are drawn in some countries (Germany, Holland, Belgium, United Kingdom and USA) from bottoms of rivers, retention reservoirs, channels, ports and ponds in order to maintain their navigability, increase their retention capacity and to improve their recreational and aesthetic values [3–7]. Because the phenomenon of silting and shallowing of water reservoirs is inevitable, it seems reasonable to manage the portions of sediments which do not contain harmful amounts of heavy metals or macroelements contents but may affect the quality of crops cultivated in the soil with their supplement. An important aspect of bottom sediment removal is reducing the unfavourable effect of impurities accumulated in them on the quality of water ecosystem [2]. Methods and techniques of bottom sediment removal from water reservoirs, as well as their in-situ and ex-situ remediation were the subject of numerous papers [2, 3, 8, 9]. If the material extracted from the bottom of silted water reservoir does not pose a hazard for the environment, the environmentally justified method of the sediments management is their use as structure and soil forming material on soilless grounds and wastelands [3, 10]. Bottom sediments, particularly these revealing neutral or alkaline reaction and high contents of silt and clay fractions, may be used for improving physicochemical properties of light and acid soils to improve their productivity [11, 12]. Investigations on their environmental potential, including agricultural applications were conducted among others by Niedzwiecki and Van Chinh [6, 13, 14], Fonseca et al [4, 5, 15], Rahman et al [16], Pleczar et al [17].

Presented experiment was conducted to assess the effect of bottom deposit supplement to light soil on yielding and selected parameters of maize chemical composition, as well as to identify potential use of the produced biomass for forage.

Material and methods

The two-year pot experiment (2006–2007) was conducted on light soil with granulometric composition of weakly loamy sand, neutral pH and organic matter content of 16.0 g · kg^{-1} (Table 1 and 2). The applied bottom sediment originated from small retention reservoir localized in Zeslawice village on the Dlubnia river (Malopolska province). The reservoir was constructed in 1966 in order to intake water for the metallurgical plant in Nowa Huta. The river catchment has a loess substratum, little resistant to erosion, therefore an intensive silting of the reservoir was observed. Detailed

Table 1

Selected properties of soil and bottom sediment

Component	Share of ∅ [mm] fraction			pH_{KCl}	Total N	Bioavailable forms		
	1–0.1	0.1–0.02	< 0.02			P_2O_5	K_2O	Mg
	[%]				[g · kg^{-1} d.m.]	[mg · kg^{-1} d.m.]		
Soil	78	13	9	6.21	0.3	78.7	165.9	—
Bottom sediment	8	66	26	7.35	1.0	44.6	69.7	117.4

Table 2

Heavy metal content in soil and bottom sediment

Component	Cr	Zn	Pb	Cu	Cd	Ni	Fe	Mn
	[mg · kg^{-1} d.m.]						[g · kg^{-1} d.m.]	
Soil	5.93	62.00	29.75	4.00	0.68	4.15	3.01	0.15
Bottom sediment	15.0	76.31	12.85	12.23	0.35	11.0	7.55	0.14
Norm[a]	< 200	< 1000	< 200	< 150	< 7.5	< 75	—	—
Norm (grounds B)[b]	150	300	100	150	4	100	—	—
IUNG	—	< 100	< 70	< 40	< 1	< 50	—	—

[a] Journal of Laws of 2002, No. 55, item 498, [b] Journal of Laws of 2002, No. 165, Item 1359.

characteristics of the reservoir and methods of bottom sediment collecting were presented by Tarnawski [18]. The sediment was classified to a group of ordinary silt deposits with alkaline pH. The material was characterized by low concentrations of bioavailable phosphorus and potassium, high content of magnesium and contained 25.8 g · kg^{-1}of organic matter (Table 1). Bottom sediment was added to the soil in the first year of the research. The experimental design comprised 3 treatments: soil without the sediment admixture (control), soil + 5 % sediment supplement and soil + 10 % sediment admixture to the soil. Equal NPK fertilization with a dose of respectively: 1.8 g N; 1.1 g P and 2.2 g K per pot (8 kg d.m. of soil) was applied on all treatments. Mineral salts: NH_4NO_3; KH_2PO_4 and KCl were added once before the test plant sowing. The quality of bottom sediment was assessed on the basis of the Decree of the Minister of the Natural Environment of 15 April 2002 on the kind and concentrations of substances which cause that the spoil is polluted [19], and the way of its management was determined according to IUNG criterion [20] and the Decree of the Minister of the Natural Environment of 9 September 2002 on the soil and ground quality standards [21]. According to the above-mentioned decrees heavy metal concentrations in the researched deposit did not exceed the values admissible for the spoil [19] and for soil or B group soil [21]. In IUNG assessment which comprises 6 degree soil classification with respect to heavy metal content, considering the reaction and granulometric structure, the researched deposit, like mentioned above, revealed their natural contents (degree 0). The test plant was maize (*Zea mays*), “Bora” c.v. During the vegetation period the plants were watered with de-mineralized water and constant moisture of the substratum was maintained, initially on the level of up to 50 % and then up to 60 % of maximum water capacity. After the harvest the plant material was dried at 65 ^{o}C in a dryer with forced air flow and the amount of dry mass yield was determined (the shoots and roots). Subsequently the plant material was crushed in a laboratory mill and subjected to chemical analysis. The mineral contents in the plant material were assessed after dry mineralization and ash dissolving in HNO_3 (1:3). The concentrations of potassium, magnesium and calcium were assessed in the obtained extracts using AAS method, and phosphorus using ICP-AES method. Nitrogen content was determined using Kjeldahl distilling method. Plant material analyses were conducted in four replications. The above-mentioned macroelement uptake with maize yield was computed as well as interrelations between them. The paper presents: K:Mg, K:Ca, K: (Mg + Ca) molar ratios and Ca : P and Ca : Mg weight ratios.

The obtained results were verified statistically by means of one factor ANOVA and Tukey test at significance level $\alpha = 0.05$ using Statistica 7.1 programme.

Results

Maize yields were on a similar level in individual years of investigations, therefore they were presented in the paper as total for the 2006–2007 experiment period (Table 3).

Table 3

Yield of maize dry mass (total for two years)

Treatment	Shoots	Roots	Whole plant
	$[g \cdot pot^{-1}]$		
Soil without sediment	294.17^{b*}	34.32	328.49^{a}
Soil+ 5 % sediment	320.25^{c}	35.20	355.45^{b}
Soil +10 % sediment	298.44^{b}	30.48	328.92^{a}
$LSD_{0.05}$	9.87	n.s.	12.88

* Homogenous groups according to Tukey test, $\alpha = 0.05$, n.s. – statistically non-significant.

The data show that irrespective of the plant part and year of the research, the greatest biomass was produced on the treatment with a 5 % bottom sediment supplement. On this treatment maize was characterized by about 7 % (shoots) and 8 % (roots) greater biomass production in comparison with the yields from the other treatments. On treatments with a 10 % bottom sediment admixture to the soil, maize yields were approximate to the ones obtained on the control (Table 3). The presented experiment also assessed the effect of bottom sediment supplement to the soil on macroelement content because their concentration in plants is the basic criterion of plant fodder destination. Both macroelement content and interrelations between them may considerably change plant chemical composition. According to literature [22–24] the following quantities are considered the optimal amounts, meeting plant requirements for individual elements: 3.0 g P; 17–20 g K; 2.0 g Mg; 7.0 g Ca; 1.5–2.5 g Na $\cdot$ kg^{-1} d.m. of fodder. Table 4 shows weighted average macroelement contents for the whole period of investigations. Total nitrogen content in maize yields ranged from 6.81 to 9.96 g $\cdot$ kg^{-1} d.m. The highest content of nitrogen both in maize shoot and root biomass was noted on the treatment with a 10 % supplement of bottom deposit in the substratum (Table 4). On this treatment maize contained almost 20 % more nitrogen (shoots) and 2 % more (roots) in comparison with the treatment receiving a 5 % sediment admixture, and by 32 % more (shoots) and 9 % more (roots) in relation to the treatment without the added sediment. On the treatments where bottom deposit was added in both doses, root biomass contained on average by 11 % less nitrogen than shoots. Phosphorus content in the test plant ranged from 1.16 to 2.26 g $\cdot$ kg^{-1} d.m. (Table 4). Bottom sediment added to

Table 4

Macroelement content in maize

Treatment	N	P	K	Mg	Ca
	$[\mathrm{g} \cdot \mathrm{kg}^{-1}$ d.m.]				
Shoots					
Soil without sediment	6.81^{a*}	2.26^{b}	14.53^{a}	1.80	1.10^{a}
Soil + 5 % sediment	8.01^{ab}	1.65^{a}	14.09^{a}	1.70	1.95^{b}
Soil + 10 % sediment	9.96^{b}	172^{a}	18.34^{b}	1.62	2.11^{b}
$\mathrm{LSD}_{0.05}$	1.72	0.25	2.42	n.s.	0.30
Roots					
Soil without sediment	7.25	2.05^{b}	9.82^{ab}	1.90^{a}	1.87^{a}
Soil + 5 % sediment	7.79	1.16^{a}	7.89^{a}	1.83^{a}	6.00^{b}
Soil + 10 % sediment	7.97	1.23^{a}	12.40^{b}	2.20^{b}	7.65^{c}
$\mathrm{LSD}_{0.05}$	n.s.	0.16	2.64	0.20	1.27

* Homogenous groups according to Tukey test, $\alpha = 0.05$, n.s. – statistically non-significant.

the soil had a notable effect on a decrease in this element content in maize biomass in comparison with the treatment without this deposit. It also caused a decline in phosphorus content by about 25 % in the shoots and by 55 % in maize roots as compared with the control. Relatively greater phosphorus contents in the test plant shoots and roots were registered on treatments with a 10 % supplement of bottom sediment than on treatments with a 5 % addition, however the differences were not statistically significant (Table 4). Maize on all experimental treatments revealed greater phosphorus content in shoot biomass in comparison with the roots. Bottom sediment admixture to light soil worsened the quality of obtained biomass from the viewpoint of its use for forage because of diminished phosphorus content as regards its optimal concentrations in forage plants. Maize abundance in potassium fluctuated between 7.89 and 18.34 $\mathrm{g} \cdot \mathrm{kg}^{-1}$ d.m. (Table 4). Significantly highest content of this macroelement, similarly as for nitrogen, was assessed in maize grown in the soil with a 10 % supplement of bottom sediment. On this treatment maize contained almost 22 % more of potassium (shoots) and 29 % (roots) in comparison with the other experimental variants. Plants on treatments with a 5 % sediment addition revealed the lowest content of potassium both in their shoots and roots. Considering the variant with a 10 % sediment supplement, maize on this treatment contained by 23 % less of potassium in shoots and by 36 % less in roots. Like in case of phosphorus, plants contained more potassium in their shoots than roots. According to the previously mentioned criterion, potassium content in maize shoot biomass on treatments with a 10 % addition of bottom sediment was on the optimal level. Investigations conducted by various authors [25] show that in plants this element occurs in excess and in most cases no apparent deficiencies for plants are noted. High contents of potassium and deficient amounts of magnesium and calcium most frequently change the quality of plants destined for ruminants [26]. Depending on the treatment, calcium content in maize ranged from 1.10 to 7.65g $\cdot$ kg^{-1}d.m. (Table 4). Bottom sediment supplement to the soil significantly affected the increase in calcium content in maize biomass as compared with the soil without the sediment. It was also found that maize roots on treatments containing bottom sediment accumulated between 3 and 3.5 times more Ca in comparison with shoots on these treatments. Both in shoot biomass and in maize roots the greatest calcium content was registered on variant with a 10 % share of the sediment. In comparison with the treatment with a 5 % sediment admixture, on this treatment maize contained 7 % more of calcium (shoots) and by 22 % more in roots. On the other hand, considering the control plants, maize on a substratum with a 10 % sediment supplement revealed almost 48 % (shoots) and 76 % (roots) higher contents calcium. Calcium content in maize shoot biomass was on a very low level in comparison with the optimal values. Because of too high decrease in this macroelement content, the obtained biomass did not meet the criteria for good quality fodder. Magnesium content in the test plant fluctuated between 1.62 and 2.20g Mg $\cdot$ kg^{-1}d.m. and admixture of bottom sediment to the soil had no unanimous influence on maize biomass abundance in this element. The highest magnesium content in shoots was detected in plants on the control treatment but the differences between the experimental objects were not statistically significant (Table 4). On the other hand in roots the greatest quantity of magnesium was determined on the treatment with a 10 % share of bottom sediment in the soil. In comparison with the other experimental variants roots on this treatment accumulated over 15 % more of magnesium. Moreover it is worth noticing that both maize shoots and roots on the treatment with a 5 % sediment addition revealed the lowest magnesium content. Close to optimal magnesium content was assessed in maize from the treatments without the sediment added to the soil, whereas its supplement negatively affected the quality of obtained biomass visible as gradual decline in magnesium content with increasing sediment admixture to the soil.

The amount of elements taken up with the maize yield depended on the crop yield and contents of individual minerals (Table 3 and 4). Total uptake of individual macroelements by maize, depending on the experimental treatment, was presented in Table 5. The greatest quantities of potassium, calcium and nitrogen absorbed by maize were assessed on treatments with a 10 % supplement of bottom sediment. Significantly smaller amounts were absorbed on the control treatment (Table 5). A reverse relationship was demonstrated for magnesium and phosphorus. The greatest amounts of magnesium and phosphorus were taken up with maize biomass on the variant without the sediment, whereas on treatments with a 10 % share of bottom sediment the amounts of absorbed magnesium and phosphorus were smaller by over 11 % (Mg) and 25 % (P). Irrespective of the sediment share in the soil, N, P, K, Mg and Ca uptake by maize shoot biomass was bigger than by roots (Table 5). The structure of the above mentioned element uptake by the plant shows that maize shoots were absorbing respectively: 89–92 % N; 90–93 % P; 93–95 % K; 86–92 % Mg and 73–84 % Ca.

An important measure of fodder feeding quality are interrelations between mineral components. Good quality forage should reveal the optimal proportions of: Ca:P (2:1); Ca:Mg (2–3:1); K:(Ca+Mg) (1.6–2.2); K:Mg (6:1) and K:Ca (2:1) [22, 23]. The interrelations of the above-mentioned elements in maize shoot biomass were presented in Table 6.

Table 5

Macroelement uptake (shoots + roots) by maize

Treatment	Nitrogen	Phosphorus	Potassium	Magnesium	Calcium
	[g · pot^{-1} d.m.]				
	Shoots				
Soil without sediment	2.00^{a*}	0.66^{b}	4.27^{a}	0.55	0.32^{a}
Soil + 5 % sediment	2.56^{ab}	0.53^{a}	4.51^{ab}	0.53	0.63^{b}
Soil + 10 % sediment	2.97^{b}	0.51^{a}	5.48^{b}	0.48	0.63^{b}
$LSD_{0.05}$	0.53	0.08	0.81	n.s.	0.10
	Roots				
Soil without sediment	0.25	0.07^{b}	0.34^{ab}	0.07	0.06^{a}
Soil + 5 % sediment	0.26	0.04^{a}	0.26^{a}	0.06	0.20^{b}
Soil + 10 % sediment	0.24	0.04^{a}	0.37^{b}	0.07	0.23^{b}
$LSD_{0.05}$	n.s.	0.01	0.07	n.s.	0.05
	Whole plant				
Soil without sediment	2.25^{a}	0.73^{b}	4.61^{a}	0.62	0.39^{a}
Soil + 5 % sediment	2.82^{ab}	0.57^{a}	4.77^{a}	0.59	0.82^{b}
Soil + 10 % sediment	3.22^{b}	0.55^{a}	5.86^{b}	0.55	0.86^{b}
$LSD_{0.05}$	0.51	0.08	0.77	n.s.	0.13

* Homogenous groups according to Tukey test; $\alpha = 0.05$, n.s. – statistically non-significant.

Table 6

Quantitative relations between macroelements in maize shoot biomass

Treatment	Ca:P	Ca:Mg	K:(Ca+Mg)	K:Mg	K:Ca
Soil without sediment	0.49^{a*}	0.63^{a}	2.32	4.3	10.07^{b}
Soil + 5 % sediment	1.18^{b}	1.17^{b}	2.20	2.99	5.63^{a}
Soil + 10 % sediment	1.24^{b}	1.33^{b}	2.65	4.27	6.84^{ab}
$LSD_{0.05}$	0.12	0.15	n.s.	n.s.	4.25

* Homogenous groups according to Tukey test, $\alpha = 0.05$, n.s. – statistically non-significant.

Ca:P weight ratio in maize dry mass, irrespective of the treatment, assumed values lower than optimal (Table 6). The highest Ca:P ratio was characteristic for maize on the treatment with a 10 % supplement of bottom sediment, whereas the control plants had too low value of this ratio, therefore it may be assumed that bottom sediment added to the soil improved the quality of obtained plant biomass. However, it should be emphasized that the values of Ca:P ratio in maize on the treatments with bottom sediments oscillated within the admissible value limits, because beside the optimal values 2:1, Underwood [27] also stated ratios 1:1 and 7:1 as admissible. Because Ca:P proportion in osseous system is 2:1, many authors consider it as the right one. Ca and Mg antagonism is commonly known, therefore the optimal ratio of these macroelements in fodder for ruminants should fluctuate between 2–3:1 [22]. The value of Ca:Mg ratio in the test plant was between 2 and 5 times lower than stated optimal value (Table 6). However, like in case of Ca:P relation the test plants had very low Ca:Mg ratio, so bottom sediment added to the soil, particularly in a 10 % dose improved the quality of obtained plant biomass. An important criterion of feed quality assessment is K:(Ca+Mg) relation and its value should not exceed 2.2. From the perspective of the obtained biomass use for forage, plants from all experimental treatments revealed over the norm value of this ratio, and a 10 % sediment admixture to the soil caused the highest almost two-fold increase in the value of K: (Ca+Mg) ratio. Ionic ratios: K:Mg and K:Ca are considerably important for feeding reasons. Bottom sediment applied to light soil did not reveal a unanimous effect on K:Mg ratio value, because the 10 % sediment share in the substratum caused a widening, whereas the 5 % admixture led to a narrowing of K:Mg relation in maize in relation to the optimal value 6:1. Data compiled in Table 6 show that K:Ca proportion in the analyzed plant was above the assumed optimum. On the treatment with added bottom sediment the value of K:Ca ratio in maize biomass was about between 3.5 and 4.5 times bigger than the optimal value. The maximum value for this ratio was registered in maize from the control treatment. The control plants were characterized by almost 7 times higher value of K:Ca ratio, which in good quality feeds should be 2:1. Undoubtedly, relatively high content of potassium in maize shoot biomass but deficient amounts of calcium and magnesium (Table 4) noted in the presented experiment caused a disadvantageous change of relations between the above-mentioned macroelements. Research conducted by other authors also demonstrated that an excess of potassium changes K:Ca and K:Mg ratio [22, 25]. According to the above-mentioned authors at an excess of potassium K:Ca and K:Mg ratios may reach the value of between 9:1 and 20:1, whereas K:Mg relation is 5:1.

Discussion

Investigations conducted by Niemiec [11] showed than a supplement of sediment dragged from the Roznow Reservoir to very acid soil favourably affected the amount of biomass produced by plants (barley, maize, faba bean and lupine). The author demonstrated that only the highest dose of sediment, between 14 and 16 % added to the substratum caused an apparent decline in yield of the above-mentioned plants. Additionally, the same research demonstrated that under the influence of increasing share (0–10 %) of the sediment in the substratum, maize was the plant which most strongly responded by an increase in yield. A positive effect of bottom sediment on biomass production was also registered in the presented experiment and the greatest maize yield was obtained on the treatment with a lower – 5 % dose of bottom sediment. A positive effect of the substrata prepared from soil and bottom sediments originating from the reservoirs Maranhao and Monte Novo (Portugal) was also noted by Fonesca et al [4, 5], while investigating their influence on growth and development of tulips and paprika. Presented research demonstrated that increasing share of bottom sediment supplement to light soil affected a decrease in the contents of magnesium and phosphorus but an increase in the contents of potassium, calcium and nitrogen in maize biomass. Niemiec [11] obtained similar results. The author revealed that with increasing share of bottom sediment in the substratum phosphorus content in plants was decreasing but calcium content was increasing. Rahman et al [16, 28] revealed that bottom sediment originating from fish ponds may be a potential source of nitrogen, phosphorus and potassium for fodder plants. The author [28] demonstrated that bottom sediment originating from fish ponds supplied about 62 %N, 67 % bioavailable P and 64 % bioavailable K to plants. Presented research results show that bottom sediment applied to light soil caused worsening of Ca:P; Ca:Mg; K:Mg (narrowing) and K:Ca (widening) ratios in maize shoot biomass. Also Niemiec [11] who analyzed the effect of sediment with different shares in relation to soil (0–100 %) found generally worsening values of Ca:P and Ca:Mg relations.

Conclusions

1. Bottom sediment added to light soil had a positive effect on maize biomass yield.
2. Plant shoot biomass did not meet the criteria for fodder with respect to quality because of too small contents of most macroelements.
3. The analyzed bottom sediment, due to considerable proportions of clay and silt fractions in its composition, alkaline reaction and low content of heavy metals, may be used as a supplement to light and acid soils to improve their properties and productivity.
4. While using bottom sediment for plant cultivation one should apply supplementary mineral fertilization because of the sediment low concentrations of phosphorus and potassium.

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WPŁYW DODATKU OSADU DENNEGO DO GLEBY NA PLON I SKŁAD CHEMICZNY KUKURYDZY

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Abstrakt: Celem dwuletniego doświadczenia wazonowego była ocena wpływu osadu dennego stosowanego jako dodatek do gleby lekkiej na plon i zawartość makroelementów w kukurydzy. Osad denny dodano do gleby lekkiej w ilości 5 i 10 %. Materiał ten zakwalifikowano do grupy utworów pyłowych zwykłych i charakteryzował się on odczynem zasadowym, zawartością materii organicznej wynoszącą 25,8 $g \cdot kg^{-1}$, niską zawartością przyswajalnego fosforu i potasu oraz naturalną zawartością metali ciężkich. Po zakończeniu doświadczenia określono wielkość plonu suchej masy kukurydzy. Zawartość składników mineralnych w materiale roślinnym oznaczono po suchej mineralizacji i roztworzeniu popiołu w HNO_3 (1:3), techniką AAS (K, Mg, Ca, Na) oraz ICP-EAS (P). Zawartość N oznaczono metodą destylacyjną Kjeldahla.

Stwierdzono pozytywny wpływ osadu dennego dodanego do gleby lekkiej na plon biomasy kukurydzy. Największą biomasę rośliny uzyskano w obiekcie z dodatkiem osadu w ilości 5 %. Nadziemna biomasa roślinna nie spełniała jednak kryteriów dla paszy dobrej jakości, ze względu na zbyt małe zawartości większości makroelementów. Stwierdzono, że badany osad denny ze względu na duży udział frakcji pylastych i ilastych w swoim składzie, obojętny odczyn i małą zawartość metali ciężkich może być stasowany jako dodatek do gleb lekkich i kwaśnych w celu poprawy ich produkcyjności. W rolniczym wykorzystaniu osadu dennego należy jednak zastosować uzupełniające nawożenie mineralne z powodu niskiej zawartości pierwiastków nawozowych w osadzie oraz biomasie kukurydzy.

Słowa kluczowe: osad denny, gleba lekka, plon, makroelementy

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INFLUENCE OF HEAVY METALS IN SOIL UPON BROAD BEAN (*Vicia faba* L.) SEED INFECTION BY DISEASES AND PESTS

ODDZIAŁYWANIE SKAŻENIA GLEBY METALAMI CIĘŻKIMI NA PORAŻENIE NASION BOBU (*Vicia faba* L.) PRZEZ CHOROBY I SZKODNIKI

Abstract: The paper presents effect of the medium pollution of soil with single heavy metals upon the broad bean (*Vicia faba* L.) seed injuries by *Bruchus rufimanus* Boh. (*Col., Bruchidae*) and their infection by fungi *Botrytis fabae* and *Ascochyta fabae*.

Broad bean, White Windsor c.v. was cultivated on: soil with natural heavy metal concentrations (Control); soil with natural content of heavy metals receiving mineral fertilizers (Control + NPK); soil polluted with Cd (4 mg · kg^{-1} d.m.); soil polluted with a Pb (530 mg · kg^{-1} d.m.); soil contaminated with Cu (85 mg · kg^{-1} d.m.), soil polluted with Zn (1000 mg · kg^{-1} d.m.) and soil contaminated with Ni (110 mg · kg^{-1} d.m.). A harm from *Bruchus rufimanus* was assessed based on the number and weight of injured seeds per the total number and weight of seeds. The seed infection by *Botrytis fabae* and *Ascochyta fabae* was assessed under laboratory conditions. Soil contamination with zinc caused that broad bean plants did not form seeds. Contamination with nickel was fatal for number of delivered seeds, their weight, and number of pods. The contamination with either cadmium, copper or lead improved all indices and among them lead performed best. *Bruchus rufimanus* injured approximately ca 60–90 % seeds. The contamination with lead was the most critical in that respect. More intensive infection by *Botrytis fabae* (80–93%) was found among the seeds injured by *Bruchus rufimanus* whereas among non-injured seeds this count was between 40 and 67 %. *Ascochyta fabae* caused similar, 30 to 67 % infection of injured and healthy seeds. No marked differences were found between the kind of the soil contamination and degree of the seed infection by these diseases.

Keywords: heavy metals, soil pollution, *Bruchus rufimanus* Boh., *Botrytis fabae, Ascochyta fabae*

Broad bean (*Vicia faba* L.) seeds are known as a valuable source of protein, phosphorus and B vitamins. In recent years, its consumption and area of its cultivation area increase. Frequently, within the vegetation period the plants are damaged by

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insects and fungal pathogens. Fungal organisms on seeds decrease germinating ability of the plant and can disqualify the plant seeding material [1–3]. The soils contaminated with heavy metals may be suitable for seed crops. According to the IUNG classification [4], elevated and medium soil pollution with such elements as lead, cadmium or copper neither decreases the quantity of broad bean seed yield nor increases degree of their injuries by *Bruchus rufimanus* [5, 6].

In this study, the effect of the medium soil contamination with zinc, nickel, cadmium, copper and lead applied as a single heavy metal pollutant was checked against broad bean seed infection by *Botrytis fabae* and *Ascochyta fabae* and degree of their injuries by *Bruchus rufimanus* Boh.

Material and methods

Broad bean, White Windsor c.v. was cultivated on: soil with natural heavy metal concentrations (Control); soil with natural content of heavy metals receiving mineral fertilizers (Control + NPK); soil polluted with Cd (4 $mg \cdot kg^{-1}$ d.m.); soil polluted with Pb (530 $mg \cdot kg^{-1}$ d.m.); soil contaminated with Cu (85 $mg \cdot kg^{-1}$ d.m.), soil polluted with Zn (1000 $mg \cdot kg^{-1}$ d.m.) and soil contaminated with Ni (110 $mg \cdot kg^{-1}$ d.m.). The heavy metals were added to the soil as water solutions of the following salts: $3\ CdSO_4 \cdot 7H_2O$, $NiSO_4 \cdot 7\ H_2O$, $CuSO_4$, $ZnSO_4 \cdot 7\ H_2O$ and $Pb(NO)_{3.}$ The experiment was conducted in 2008 on degraded chernozem formed from loess with acid reaction (pH in 1 $mol \cdot dm^{-3}$ KCl solution was 5.3 and in water 6.1) and 1.13 % organic content. Detailed description of methods used for the heavy metal supplying into the soil was presented in the former paper [7]. A harm from *Bruchus rufimanus* was assessed based on the number and weight of injured seeds per the total number and weight of seeds, whereas broad bean healthiness was determined on 100 seeds randomly selected from each combination. The percentage of seeds with visible symptoms of *Botrytis fabae* and *Ascochyta fabae* was determined.

The obtained results were subjected to one way ANOVA using Statistica programme. The significance of differences was verified by means of the Duncan test on the significance level $p < 0.05$.

Results and discussion

The experiments demonstrated that in the soil contaminated with zinc broad bean plants set pods but did not form seeds, whereas soil contamination with nickel significantly limited both the number and weight of formed seeds (Table 1). The highest seed yield was obtained from broad bean plants grown in the lead polluted soil. Moreover, ANOVA did not reveal any apparent effect of soil contamination with cadmium or copper on the broad bean yielding (Table 1). *Bruchus rufimanus* injured from 60 % to 90 % seeds (Fig. 1). The highest number of injured seeds was found among those collected from the plants cultivated in the lead polluted soil – significantly exceeded the count for control plants. Moreover, among the seeds injured by *Bruchus rufimanus,* 80–93 % of them were infected by *Botrytis fabae*, whereas among the

Table 1

Characteristics of broad bean seeds from plants cultivated in natural soil and in heavy metal contaminated soil

Object	Average number of seeds per 1 plant [pcs]	Average weight of seeds per 1 plant [g]	Average number of pods per plant [pcs]	Average weight of single seed [g]
Cd	1.85 bc*	2.24 abc	0.84 b	1.09 a
Cu	2.05 bc	2.63 bc	0.97 bc	1.24 a
Ni	0.18 a	0.20 a	0.11 a	1.08 a
Pb	3.27 c	4.45 c	1.40 c	1.34 a
Control	1.38 ab	1.56 ab	0.49 ab	1.14 a
Control + NPK	2.21 bc	2.89 bc	0.97 bc	1.29 a

* Values for individual metals or control marked by different letters in columns are statistically different ($p < 0.05$).

non-injured seeds the number showing symptoms of *Botrytis fabae* was between 40–67 % (Fig. 2). Botrytis fungi are occasional plant parasites, but *B. fabae* can parasite one host [8]. Such fungal organisms provide better conditions for the development of mechanically damaged plant organs. Therefore, seeds already injured by *Bruchus rufimanus* were more strongly infected [9, 10]. On the other hand, non-injured broad bean seeds from the plots where the soil was polluted with copper and lead were almost twice more often infected by *Ascophyta fabae* than the seeds injured by *Bruchus rufimanus* (Fig. 3). No influence of the seed injuries on the occurrence of *Ascochyta fabae* was observed in the other combinations. The applied statistical analysis did not reveal any significant effect of the soil contamination on the occurrence of *Botrytis fabae* and *Ascophyta fabae* on the broad bean seeds. The lack of other studies on the influence of heavy metal soil pollution on the plant condition makes interpretation of the obtained results impossible. On the other hand, numerous investigations focus

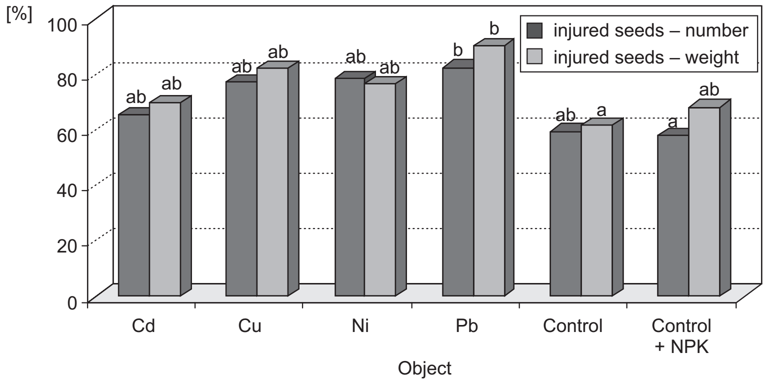

Fig. 1. Degree of injuries of broad bean seeds from plants cultivated in natural soil and in heavy metal contaminated soil by *Bruchus rufimanus* Boh. Values for individual metals or control and for individual features marked by different letters are statistically significantly different ($p < 0.05$)

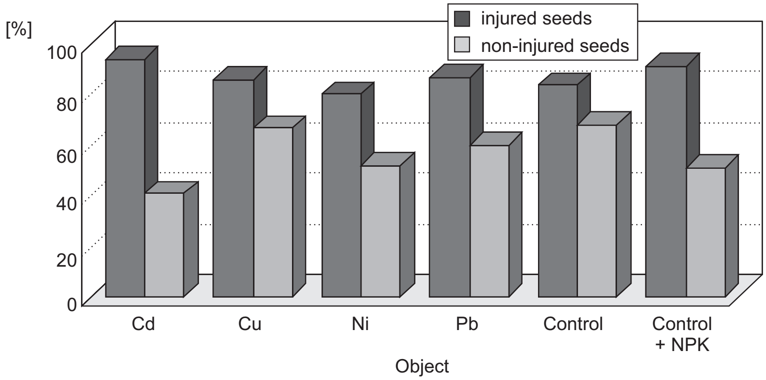

Fig. 2. Effect of soil contamination and broad bean injuries by *Bruchus rufimanus* Boh. on the occurrence of *Botrytis fabae* [%]

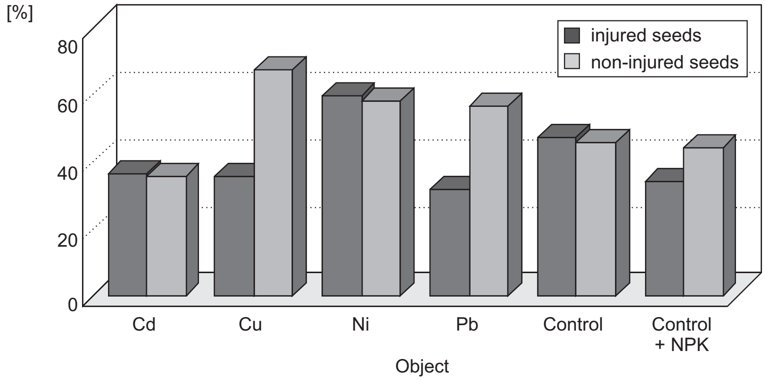

Fig. 3. Effect of soil contamination and broad bean seed injuries by *Bruchus rufimanus* Boh. on the occurrence of *Ascochyta fabae* [%]

on the healthiness of urban trees exposed to the soil and air pollution with heavy metals revealing that this factor does not affect the intensification of plant pathogen occurrence [11].

Conclusions

1. Broad bean, White Windsor c.v. grown in the soil contaminated with lead produced significantly higher yield than on the other objects. However, soil pollution with lead favoured seed injuries caused by *Bruchus rufimanus*.

2. Due to soil contamination with zinc, broad bean plants did not form seeds, whereas on the nickel contaminated soil a notable limiting of both the number and weight of formed seeds was registered. Soil contamination with cadmium and copper did not affect apparently the number of pods and seeds formed by broad bean plants.

3. Irrespectively of the kind of pollution *Bruchus rufimanus* injured on average between ca 60 % and 90 % of seeds. Moreover, broad bean seeds injured by *Bruchus rufimanus* were more often infected by *Botrytis fabae* (80–93 %) than the uninjured seeds (40–67 %). However, such dependence was not observed for seed infection by *Ascochyta fabae*.

4. The kind of soil contamination did not have any significant effect on the proportional share of seeds showing *Botrytis fabae* or *Ascochyta fabae* symptoms.

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ODDZIAŁYWANIE SKAŻENIA GLEBY METALAMI CIĘŻKIMI NA PORAŻENIE NASION BOBU (*Vicia faba* L.) PRZEZ CHOROBY I SZKODNIKI

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Abstrakt: Celem badań było określenie wpływu skażenia gleby pojedynczymi metalami ciężkimi na poziomie średniego zanieczyszczenia na stopień uszkodzenia nasion bobu (*Vicia faba* L.) przez strąkowca bobowego *Bruchus rufimanus* Boh. oraz porażenie ich przez czekoladową plamistość (*Botrytis fabae*) oraz askochytozę bobu (*Ascochyta fabae*).

Bób odmiany Windsor Biały uprawiany był w następujących obiektach: gleba o naturalnej zawartości metali ciężkich (Kontrola); gleba o naturalnej zawartości metali ciężkich nawożona mineralnie (Kontrola + NPK); gleba zanieczyszczona kadmem w dawce: 4 mg $\cdot$ kg^{-1} s.m., gleba zanieczyszczona ołowiem w dawce: 530 mg $\cdot$ kg^{-1} s.m., gleba zanieczyszczona miedzią w dawce: 85 mg $\cdot$ kg^{-1} s.m., gleba zanieczyszczona cynkiem w dawce: 1000 mg $\cdot$ kg^{-1} s.m., gleba zanieczyszczona niklem w dawce: 110 mg $\cdot$ kg^{-1} s.m. Ocenę szkodliwości strąkowca bobowego przeprowadzono na podstawie liczby i masy nasion uszkodzonych w stosunku do ogólnej liczby i masy nasion. W warunkach laboratoryjnych przeprowadzono ocenę porażenia nasion przez czekoladową plamistość oraz askochytozę bobu. Zastosowane skażenie gleby cynkiem sprawiło, że rośliny nie wytworzyły nasion. Skażenie gleby niklem ograniczyło istotnie zarówno liczbę, jak i masę wytworzonych nasion. Najwyższy plon nasion uzyskano z roślin bobu uprawianych w warunkach gleby zanieczyszczonej ołowiem. Skażenie gleby kadmem i miedzią nie wpłynęło istotnie na ilość wytworzonych strąków i nasion przez rośliny bobu. Strąkowiec bobowy uszkodził średnio od ok. 60 % do 90 % nasion. Najwięcej nasion z uszkodzeniami stwierdzono wśród tych zebranych z roślin uprawianych w warunkach gleby skażonej ołowiem – znacznie więcej niż w przypadku nasion z roślin kontrolnych. Wśród nasion uszkodzonych przez strąkowca bobowego stwierdzono większe porażenie przez *Botrytis fabae* (80–93 %) niż gdy analizie poddano nasiona nieuszkodzone (40–67 %). Natomiast porażenie nasion zarówno uszkodzonych, jak i nieuszkodzonych przez *Ascochyta fabae* było podobne (ok. 30–67 %). Nie stwierdzono istotnych różnic pomiędzy rodzajem skażenia gleby, a stopniem porażenia nasion przez ww. choroby.

Słowa kluczowe: metale ciężkie, zanieczyszczenie gleby, *Bruchus rufimanus* Boh., *Botrytis fabae, Ascochyta fabae*

ECOLOGICAL CHEMISTRY AND ENGINEERING A

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ESTIMATION OF THE NUTRITIONAL VALUE OF HAY FROM SELECTED INDIVIDUAL FARMS IN THE REGION OF KRAKOW-CZESTOCHOWA JURA PART I. THE CONTENT OF ORGANIC COMPOUNDS AND NUTRITIONAL VALUE

OCENA JAKOŚCI I WARTOŚCI POKARMOWEJ SIANA Z WYBRANYCH GOSPODARSTW INDYWIDUALNYCH NA TERENIE JURY KRAKOWSKO-CZĘSTOCHOWSKIEJ CZ. I. ZAWARTOŚĆ SKŁADNIKÓW ORGANICZNYCH I WARTOŚĆ POKARMOWA

Abstract: This paper presents an estimation of the chemical composition and forage value of the hay derived from the 12 selected, individual farms specialized in milk production from the region of the Krakow-Czestochowa Jura. The content of the organic compounds was very variable, which can be the result of diversified allotments of grasses and dicotyledonous plants in analyzed hay samples. Only 42 % of all examined hay trials contained optimal dry matter content ie above 820 $g \cdot kg^{-1}$. When estimating nutritional value of the hay special attention must be paid to the crude protein and crude fiber content. The hay collected with 33 % of samples was characterized with protein content per dry matter below the level assumed as normative. 92 % of samples were characterized with crude fiber content above the optimal level. This fact can be the result of too late time of mowing, especially in the case of first mowing, as well as improper drying method. Among all analyzed components, the greatest diversification was noticed for raw fat content. The weighted mean of this component fluctuated in the range of 13.9–34.5 $g \cdot kg^{-1}$ d.m. The forage characteristics as regards energetic value were as follows: UFL – from 0.68 to 0.81 $g \cdot kg^{-1}$ d.m. and UFV – from 0.59 to 0.71 $g \cdot kg^{-1}$ d.m. The protein value was more diversified and ranged from 55.29 to 122.61 – PDIN and from 73.27 to 97.66 $g \cdot kg^{-1}$ d.m. – PDIE.

Keywords: meadow sward, the content of organic compounds, nutritional value

The preserved forages, including hay, constitute the basic food for cows during the winter period. The nutritional value of hay is in the highest degree affected by the

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floristic composition of the meadow sward, growth stage at which the plants are collected as well as drying and storage method [1–3]. The results of the investigations indicate that the losses resulted from inadequate drying can reach the value of 50 % [4]. Good quality hay provides many basic nutrients to animals as well as fiber essential for ruminants, which determines the proper function of digestive track [5]. Moreover, hay affects the fat content in milk, the higher the share of the bulky forages in the feeding dose, the higher fat concentration. The average daily hay dose for milk cows should amount to 3–4 kg, and the fiber contain should not exceed 25 %. Calves should be fed hay directly after birth because it accelerates the development of rumen and enhances the number of the rumination cycles [6]. The presence of bulky forages, including hay, in a feeding dose is essential, but they should be of the highest quality and feeding value.

Thus, the goal of the present study was to estimate the chemical composition and the forage value of the hay derived from the farms specialized in milk production located in the region of Krakow-Czestochowa Jura.

Materials and methods

The investigations were conducted in the years 2005–2007 under the production conditions in 12 farms specialized in milk production located in the region of Krakow-Czestochowa Jura. The experimental farms were located in the Pilica administrative district (Zawiercie county, Silesia province) 320 m above sea level. The grasslands were located on the brown, acid soils and podsolic soils classified from IVb to VI soil quantity class. The acidity expressed as pH_{KCl} ranged from 4.5 to 5.5 (acidic and very acidic reaction). The soils contained a medium level of assimilable forms of potassium and were poor in phosphorus and magnesium.

During the vegetation period (April–September) the total amounts of rainfall reached the value of 356.8 mm, 338.1 mm and 375.4 mm, respectively for the years 2005, 2006 and 2007. The respective mean temperatures were noticed for the following years: 14.8 ^{o}C, 15.2 ^{o}C and 14.3 ^{o}C.

The experimental hay was derived mostly from the first and second regrowth of grass flora and in a minor amount from the third regrowth. The material was collected at the turn of heading and flowering stages of grasses – the first regrowth and during the heading stage – the second and the third regrowths.

Before feeding the samples of hay were collected (4 from each farm) and subjected to chemical analysis, which comprised: the estimation of essential nutrients by the Weenden method [7]. The feeding value was estimated in the INRA system units using 1.6 Winwar software (DJG). The evaluation of hay was performed using the tabular coefficients of forage distribution in rumen and intestines.

The results in this paper were limited to the mean values for the following years. The obtained results were subjected to the analysis of variance and the significance of differences was estimated using the Duncan test at the significance level of $\alpha = 0.05$.

Table 1

The estimation of the hay feeding value [g · kg^{-1} d.m.]

Item	Examined farm											
	1	2	3	4	5	6	7	8	9	10	11	12
Dry matter	816.4b[*]	776.0a	808.4ab	833.9bc	768.2a	816.5b	872.2c	807.5ab	822.1bc	864.5c	776.5a	831.6bc
Organic mass	937.2b	907.0a	937.2b	933.1b	926.5ab	944.0bc	937.6b	934.9b	919.4ab	960.2d	956.3c	943.7bc
Crude protein	88.8a	145.7b	147.7b	104.9ab	177.4c	169.1c	174.8c	195.8d	196.9d	104.8ab	174.6c	112.0ab
Crude fiber	282.8ab	286.3ab	257.8a	269.1a	271.9a	309.5b	280.8ab	286.1ab	269.7a	305.6b	275.0a	339.2c
Raw fat	15.3a	24.4b	34.5c	24.0b	19.5ab	20.7ab	19.3ab	19.1ab	18.5ab	17.2a	27.3bc	13.9a
Nitrogen-free extract	550.2d	450.5ab	497.2bc	535.1c	457.6ab	444.7a	462.7ab	433.9a	434.3a	532.6c	479.5b	478.6b
UFL [kg^{-1} d.m.]	0.70a	0.68a	0.71a	0.69a	0.75b	0.81c	0.76b	0.76b	0.75b	0.70a	0.74a	0.69a
UVF [kg^{-1} d.m.]	0.62a	0.59a	0.62a	0.61 a	0.65b	0.71c	0.66b	0.66b	0.65b	0.62a	0.64a	0.60a
PDIN [g · kg^{-1} d.m.]	55.29a	90.74b	91.95b	65.33a	103.93bc	105.30bc	108.86bc	121.89c	122.61c	65.25a	108.72bc	69.70ab
PDIE [g · kg^{-1} d.m.]	73.27a	83.93b	85.18b	75.97a	87.37b	91.84c	92.93c	97.66c	97.09c	78.14ab	93.22c	79.15ab

[*] Means marked with the same letter are not statistically different following verification with the Duncan test ($p = 0.05$); UFL – *Feed Unit for Lactation* (1700 kcal EN), UVF – *Meat Production Unit* (1820 kcal EN), PDIE – *protein digested in the small intestine* supplied by rumen-undegraded dietary protein plus protein digested in the small intestine supplied by microbial protein *from rumen-fermented organic matter*, PDIN – protein digested in the small intestine supplied by rumen-undegraded dietary protein plus protein digested in the small intestine supplied by microbial protein *from rumen-degraded protein.*

Results and discussion

The dry matter content in the hay samples was diversified and fluctuated in the range of 768.2 to 872.2 g · kg^{-1} dry matter (Table 1). The data found in literature [7] suggest that hay should contain at least 820 g · kg^{-1} dry matter. Regarding this, it can be stated that only 42 % of the examined high samples met this requirement. When estimating the hay feeding value special attention needs to be paid on the crude protein and crude fiber content. Forage of good quality should contain 140–160 g protein · kg^{-1} d.m., and the optimal level of crude fiber is assumed to be 260 g · kg^{-1} d.m. [8, 9]. 33 % of hay samples were poorer in protein and the crude fiber content exceeded the optimal value in 92 % of the trials. Too high concentration of crude fiber is a worrisome fact, because it significantly decreases the hay feeding value. This phenomenon can be explained by simple negligence of too late time of harvesting, especially in the case of the first regrowth as well as by improper drying method [10]. Among all analyzed components the greatest diversification was found for raw fat content. The weighted mean of this component ranged from 13.9 to 34.5 g · kg^{-1} d.m. The level of nitrogen-free extract fluctuated in the range of 433.9 to 550.2 g · kg^{-1} d.m. The meadow hay of good quality contains on average 30.2 g of raw fat and 462.8 g · kg^{-1} d.m. of nitrogen-free extract [7]. The obtained results revealed that 8 % of the samples were characterized with the proper raw fat content and 58 % contained the required amount of nitrogen-free extract.

The energetic value of the plants collected from the investigated farms were as follows: expressed as Feed Unit for Lactation (UFL) – from 0.68 to 0.81 g · kg^{-1} d.m. and as Meet Production Unit (UFV) – from 0.59 to 0.71 g · kg^{-1} d.m. On the contrary, the study by Zurek et al [11] revealed that in the hay derived from the swamp flora the respective levels were lower and amounted to 0.62 and 0.52. In our investigations higher values for PDIE and PDIN were also observed, which resulted from a higher content of crude nitrogen.

Conclusions

1. Regarding 820 g · kg^{-1} d.m. as the optimal dry matter content it can be stated that only 42 % of hay samples met the feeding requirements. This fact indicates that the drying process was performed improperly in the examined farms.
2. High content of crude fiber in the examined hay indicates that farmers collect plants, especially from the first regrowth, too late.
3. According to the results of domestic investigations it can be stated that the concentration of nutrients in the examined hay samples was sufficient enough to cover the feeding requirements of animals.

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OCENA JAKOŚCI I WARTOŚCI POKARMOWEJ SIANA Z WYBRANYCH GOSPODARSTW INDYWIDUALNYCH NA TERENIE JURY KRAKOWSKO-CZĘSTOCHOWSKIEJ

CZ. I. ZAWARTOŚĆ SKŁADNIKÓW ORGANICZNYCH I WARTOŚĆ POKARMOWA

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Abstrakt: Praca prezentuje ocenę składu chemicznego i wartości paszowej siana pochodzącego z 12 wybranych gospodarstw indywidualnych, specjalizujących się w produkcji mleka. Gospodarstwa położone są na terenie Jury Krakowsko-Częstochowskiej. Zawartość składników organicznych wykazywała dużą zmienność, co może wynikać ze zróżnicowanego udziału traw i roślin dwuliściennych w badanych próbkach siana. Przyjmując optymalną zawartość suchej masy w sianie na poziomie powyżej 820 g $\cdot$ kg^{-1} s.m. stwierdzono, że tylko siano z 42 % próbek miało odpowiednią zawartość suchej masy. Przy ocenie wartości pokarmowej siana na podstawie analizy chemicznej, szczególną uwagę należy zwracać na zawartość białka ogólnego i włókna surowego. Siano pobrane z 33 % próbek zawierało mniej białka w absolutnie suchej masie niż przewidują normy, a zawartość włókna surowego przekroczyło zawartość optymalną w 92 % próbek. Zjawisko to można tłumaczyć opóźnionym terminem zbioru, zwłaszcza pierwszego pokosu oraz niewłaściwym sposobem suszenia. Spośród analizowanych składników największym zróżnicowaniem cechowała się zawartość tłuszczu surowego. Średnia ważona zawartość tego składnika wahała się w zakresie 13,9–34,5 g $\cdot$ kg^{-1} s.m. Pod względem wartości energetycznej badane pasze zawierały odpowiednio: JPM od 0,68 do 0,81 g $\cdot$ kg^{-1} s.m. i JPŻ od 0,59 do 0,71 g $\cdot$ kg^{-1} s.m. Natomiast wartość białkowa była znaczniej zróżnicowana i kształtowała się w zakresie 55,29–122,61 dla BTJN oraz 73,27–97,66 g $\cdot$ kg^{-1} s.m dla BTJE.

Słowa kluczowe: ruń łąkowa, składniki organiczne, wartość pokarmowa

ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 11 2011

Anna CHRZAN[1] and Maria MARKO-WORŁOWSKA[1]

CONTENT OF SELECTED TRAFFIC POLLUTION IN SOIL AND PEDOFAUNA NEAR BUSY TRAFFIC ROADS IN KRAKOW

ZAWARTOŚĆ WYBRANYCH ZANIECZYSZCZEŃ KOMUNIKACYJNYCH W GLEBIE I PEDOFAUNIE PRZY RUCHLIWYCH TRAKTACH KOMUNIKACYJNYCH W KRAKOWIE

Abstract: Two sites situated by busy roads in Krakow – by Dietla Road and by a motorway – were selected to assess the effect of heavy metals on the soil environment. At the studied sites, the soil was analysed for heavy metal content – Pb, Cd, Zn and Cu, its moisture content, pH, and the diversity and density of soil fauna. It was found that the content of the studied metals was significantly lower in the soil by the motorway than in the City Centre soil, namely, Pb – twice, Cu – fivefold, Cd – insignificantly. At this site, the density of pedofauna was considerably higher than in Dietla Road. The results of the studies also indicate that, besides heavy metal content, the moisture content, which was three times higher by the motorway, significantly affected the diversity and density of pedofauna. The content of heavy metals studied by busy transport routes did not show correlation with the content of these metals in the fauna inhabiting it.

Keywords: pedofauna, soil, heavy metals, density, diversity

Heavy metals are one of the most durable and toxic contamination of the soil environment. The content of heavy metals in the soil depends on environmental conditions and anthropogenic pollutions. Due to the intensification of anthropopressure related to communication, the contamination of the soil by heavy metals has increased [1–3].

As a result of consuming of fuels, rubbing of tyres and other vehicles parts Cd, Zn and Pb get into environment.

The danger of soils contaminations related to the use of motor vehicles depends mainly on traffic intensity, distance from the roads as well as lay and use of the land [2, 3]. Trace elements systematically brought into the soil accumulate in its top layer,

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because they are bonded by the soil sorption complex and only very slowly move into the depths of the soil profile. Since heavy metals migrate very slowly in the soil, they are counted among its most persistent pollutants. In the soil environment, heavy metals demonstrate diverse mobility. Lead is strongly bonded by organic matter of soil top layer and only slightly migrates into the depth of the profile, copper is a little more mobile, and zinc relatively easily moves into the depths of the soil [4, 5].

Soils located in the immediate vicinity of busy transport routes are exposed to various transport pollutants, including heavy metals. These metals may enter the food chain with humans being part of it. That is why it is important to monitor their concentration in soils located along busy roads in urban areas.

The aim of the studies was to assess the effect of heavy metals, lead, cadmium, zinc and copper, on the environmental state of soils by busy roads in Krakow.

Materials and methods

Soil studies were carried out at sampling sites located by busy transport routes in Krakow. One was situated in the City Centre at Dietla Road (Locality II), the second one by a motorway (Locality I). At the study sites, series of samples were taken by means of a Morris frame of 25 cm × 25 cm size in the autumn season 2008.

The soil frame was thrust into the soil on the depth of 10 cm. Each series consisted of 16 tests on the surface of around 1 m^2.

Mesofauna was scampered away by employing the dynamic method in the modified Tullgren apparatus. After marking the select mesofauna its density and diversity were analysed.

Soil moisture and its pH, its temperature as well as the content of Cd, Pb, Ni and Zn were determined by using FAAS method in the soil and in the pedofauna scampered away.

Dry samples of the soil and of the mesofauna were mineralized. For this purpose dry samples of the soil was poured over 3 cm^3 of 65 % $HNO_{3,}$ heated to the temperature of 120 ^{o}C and left for 4 hours. The filtered liquid was poured into measuring flasks and filled with distilled water to the volume of 25 cm^3. In solutions of the soil prepared in this way the content of heavy metals was determined by the *atomic absorption spectrometer* (AAS – Cole-Parmer, BUCK 200A).

The correlation coefficient R^2 of the soil fauna density and the heavy metal content was calculated using linear regression.

Contaminations by Pb, Zn, Cd and Cu were evaluated according to Kabata Pendias and others [5].

Results and discussion

The studied soils differed considerably in pH, moisture content and heavy metal content (Table 1).

At site I, located by the motorway, the soil showed acid reaction (5.75) and in the City Centre, it was alkaline. There were also considerable differences in the moisture content of the soils. At site I, moisture content was found to be almost three times higher than at site II (Table 1).

Table 1

Soil characteristics of the selected localities in Krakow

Selected parameters	Locality I	Locality II
Dampness of soil [%]	35.5 (31.9-41.5)	13.5 (12.5–15.2)
pH value of soil	5.75 (5.45–5.9)	7.21 (6.73–7.57)
Cd in the soil [mg/kg]	1.30 (1.08–1.63)	1.41 (1.01–1.95)
Pb in the soil [mg/kg]	43.96 (34.54–51.48)	105.71 (60.86–126.29)
Zn in the soil [mg/kg]	79.97 (73.80–85.92)	27.65 (7.61–62.29)
Cu in the soil [mg/kg]	11.55 (10.06–12.11)	45.011 (19.95–67.48)

Differences in Cd, Pb, Zn and Cu contents were observed at the studied sites. It was found that the total amount of cadmium, lead and copper in the City Centre soil was higher than by the motorway, whereas Zn content was more than twice lower here (Table 1 and Fig. 1).

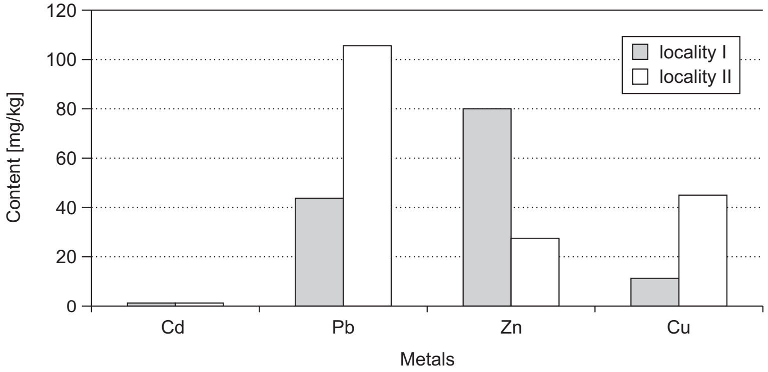

Fig. 1. Heavy metal content in the selected localities

The critical concentrations of the metals in the soils containing the anthropogenic contaminations, according to Kabata-Pendias and others [5] are: 70 mg Pb, 150 mg Zn and 1 mg Cd/kg. In the soil of the site II the exceeding of critical concentration of Pb and Cd was observed. The critical concentrations of Cd exceeded in the site I and II as well (Table 1).

An increased Cr, Ni and Cu contents in soils neighbouring busy road transport routes in urban and open areas were noticed in studies by Czarnowska et al [2] and Jarmul and Kamionek [6].

However, low concentrations of heavy metals in the vicinity of transport routes were found, among others, by Klimowicz and Melke [7] and Kolembasa et al [8].

Results concerning mesofauna and macrofauna indicate that the amount of the studied metals affects the density and diversity of pedofauna. Higher diversity and significantly higher density was found at the site by the motorway than in the City Centre of Krakow (Table 2).

Table 2

Comparison of pedofauna in the soils of the selected localities in Krakow

Selected parameters	Locality I	Locality II
Abundance of pedofauna [sp. no. per m^2]	32064	1008
Abundance withoute *Acarina i Collembola* [sp. no. per m^2]	2768	452
Diversity (number of taxonomic groups)	16	12

The results of the analysis indicate that the effect of the studied elements, Cd, Pb and Cu, in the soil on the density of pedofauna is significant.

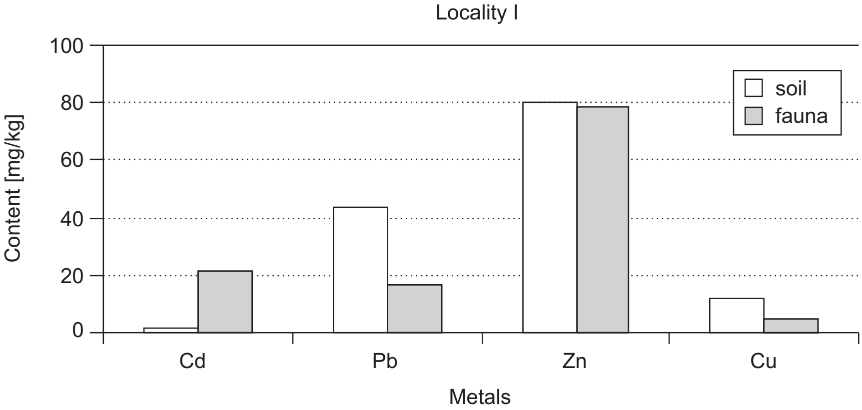

Fig. 2. Heavy metals content in the soil and in fauna by the motorway

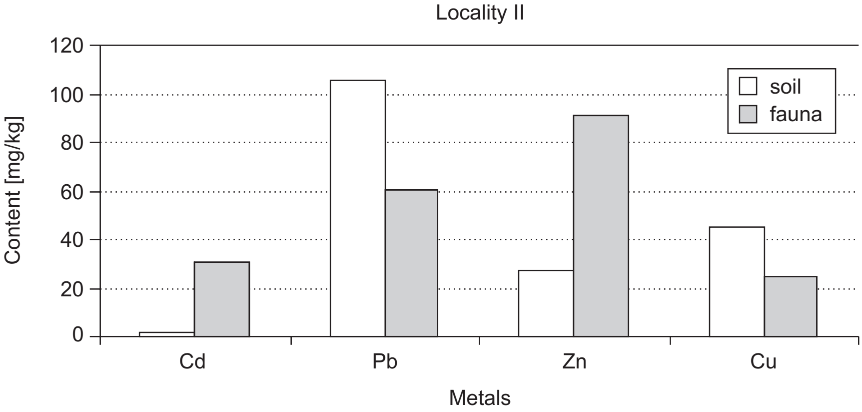

Fig. 3. Heavy metal content in the soil and in fauna in Dietla Road

The content of heavy metals studied by busy transport routes did not show correlation with the content of these metals in the fauna inhabiting it. At both sampling sites, the Cd content in the studied pedofauna was higher than in the soil, while the Pb and Cu amount was lower than in the soil (Fig. 2 and Fig. 3).

At the sampling site by the motorway, Zn content was equally high in the soil and fauna (Fig. 2).

Conclusions

1. In the studied soils located by the motorway, the contamination of the soil with Pb, Cd and Cu was found to be much lower than in the City Centre of Krakow.
2. The diversity and density of pedofauna is considerably affected by the concentration of heavy metals.
3. The density of soil fauna is also significantly affected by moisture content of the soil.
4. No direct correlation was found between Cd, Zn, Pb and Cu contents in the soil and the amount of these metals in the bodies of mesofauna inhabiting it.

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ZAWARTOŚĆ WYBRANYCH ZANIECZYSZCZEŃ KOMUNIKACYJNYCH W GLEBIE I PEDOFAUNIE PRZY RUCHLIWYCH TRAKTACH KOMUNIKACYJNYCH W KRAKOWIE

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Abstrakt: Do oceny wpływu metali ciężkich na środowisko glebowe wybrano dwa stanowiska usytuowane przy ruchliwych ulicach Krakowa – przy ulicy Dietla i przy autostradzie. Na badanych stanowiskach dokonano analizy gleby pod kątem zawartości metali ciężkich – Pb, Cd, Zn i Cu, jej wilgotności, odczynu oraz różnorodności i liczebności fauny glebowej. Stwierdzono, że w glebie przy autostradzie zawartość badanych metali ciężkich była znacznie mniejsza niż w glebie śródmiejskiej, Pb – dwukrotnie, Cu pięciokrotnie, Cd – nieznacznie. Na tym stanowisku zagęszczenie pedofauny było znacznie większe niż przy ulicy Dietla. Wyniki badań wskazują również, że na różnorodność i zagęszczenie pedofauny znaczący wpływ, oprócz koncentracji metali ciężkich, ma również wilgotność gleby, która była trzykrotnie wyższa przy autostradzie. Zawartość badanych metali ciężkich w glebie przy ruchliwych traktach komunikacyjnych nie wykazywała korelacji z ilością tych metali w faunie ją zamieszkującej.

Słowa kluczowe: fauna glebowa, gleba, metale ciężkie, zagęszczenie, różnorodność

ECOLOGICAL CHEMISTRY AND ENGINEERING A

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HEAVY METALS AVAILABILITY IN SOILS EXPOSED TO TRAFFIC POLLUTION

DOSTĘPNOŚĆ METALI CIĘŻKICH Z GLEB NARAŻONYCH NA EMISJE ZANIECZYSZCZEŃ KOMUNIKACYJNYCH

Abstract: Evaluation of a degree of soils pollution with heavy metals is usually conducted basing on total content of elements. This evaluation should be supplemented by analysis of content of heavy metals forms directly available for living organisms as well as forms which can be relatively easily mobilized. The aim of the research was to determine the content of selected fractions of copper, zinc and chromium in soils located near road No. 957 in the Zawoja passage. The research material consisted of soil samples taken from 13 points (in each point in the distance of 5 and 200 meters from the road edge). The soil samples underwent sequential chemical extraction using Zeien and Brümmer's method. Extracted were 3 fractions of heavy metals: easily soluble forms, exchangeable forms and bonds with manganese oxides.

In general, mean contents of the examined fractions of heavy metals were higher in case of the soils located in the distance of 5 m from the road edge than in the soils located in the distance of 200 m from the road. Copper occurred in soils generally as bound with manganese oxides, whereas zinc and chromium – as exchangeable forms.

Keywords: soil, traffic pollution, copper, zinc, chromium, sequential extraction

Evaluation of a degree of soils pollution with heavy metals is usually conducted basing on content of total forms of elements [1]. This evaluation should be supplemented by analysis of content of heavy metals forms directly available for living organisms as well as forms which can be transformed into available forms within short period of time. Soil is the first link of a "soil – plant – animal – human" food chain [2]. The higher the content of available heavy metals forms in soil, the higher the risk of accumulating these elements in plants, and eventually in following chain links. Human activity may lead to an increase in the content of available metals forms in soil directly

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through introducing metals to soil or indirectly as a result of influencing soil properties (reaction, sorption capacity) regulating elements availability.

The research aimed at determining the influence of traffic pollution on the content of the 3 fractions of heavy metals in soils. The content of easily soluble, exchangeable and bound with manganese oxides forms of copper, zinc and chromium in the soils located near road No. 957 in the Zawoja passage was analyzed.

Material and methods

The research material consisted of soil samples collected in 2008 from 13 points located along regional road No. 957 in Zawoja (the Malopolska province). The samples were collected from both sides of the 18.5 km long section of the road (the distance between the sampling points reached from 0.3 to 5.2 km). Road No. 957 is the only communication route to Zawoja, Skawica and the Babia Gora National Park (Babiogórski Park Narodowy). Within 24 hrs approximately 4827 road vehicles pass that road, including 367 heavy goods vehicles, 77 buses, about 20 motorcycles and 10 agricultural tractors [3]. In each point the material was collected from grass covered places (where tree vegetation did not occur) distant 5 and 200 m from the road edge. Soil samples were collected from the layer of 0–10 cm depth. The data concerning properties of the analyzed soils are shown in the paper by Filipek-Mazur and Tabak [4].

Analyses on air-dried material sifted through a sieve with 1 mm mesh were conducted. The content of the selected heavy metals fractions was assessed according to the method of sequential chemical extraction given by Zeien and Brümmer [5]. Extracted were 3 fractions of heavy metals:

- easily soluble metals forms (F_I),
- exchangeable metals forms (F_I),
- bonds of metals with manganese oxides (F_{III}).

The extraction conditions are shown in Table 1.

Table 1

Conditions of heavy metals extraction

Fraction	Extraction agent, time of extraction
F_I*	1 mol · dm^{-3} NH_4NO_3, 24 hrs
F_{II}	1 mol · dm^{-3} CH_3COONH_4, 24 hrs
F_{III}	1 mol · dm^{-3} $NH_2OH \cdot HCl$ + 1 mol · dm^{-3} CH_3COONH_4, 30 mins

* F_I – easily soluble metals forms; F_{II} – exchangeable metals forms; F_{III} – metals bound with manganese oxides.

A content approximate to the total content of heavy metals was assessed in separate aliquots of soils. For this purpose the samples were incinerated (8 hrs, 450 ^oC), evaporated with a mixture of nitric(V) and chloric(VII) acids, then the remainder was dissolved in hydrochloric acid [6]. The assessment of the heavy metals content was made using ICP-AES method on JY 238 Ultrace apparatus.

Results and discussion

As a rule, higher mean contents of the examined heavy metals fractions were noted in case of the soils located in the distance of 5 m from the road edge than in the soils located in the distance of 200 m from the road (Table 2).

Gondek et al [7] generally stated higher contents of heavy metals (extracted with 1 mol · dm^{-3} HCl) in soils distant 50 m from road than in soils located in a distance of 100 m. However, the authors did not state dependence between the distance of the soils from the road and the content of metals fraction extracted with 1 mol · dm^{-3} NH_4NO_3 [7]. Bieniek and Lachacz [8] obtained similar results to Gondek et al [7] in regard to mobile heavy metals forms (extracted using 1 mol · dm^{-3} HCl). The highest contents of mobile metals forms in surface horizons were marked in soils located closest to the road [8]. Moreover, these soils revealed an elevated content of some metals. A higher share of mobile heavy metals forms in the soils with an increased content of elements than in the soils with a natural content suggests their anthropogenic origin in the soils with the increased content [8]. Elements derived from natural sources (parent rock) would occur as silicate forms [8]. The soils analyzed in the Authors' own studies were generally characterized by a natural or elevated content of heavy metals (two samples weakly polluted with zinc were noted) [1, 4]. An elevated content and weak pollution were noted in the soils located in the distance of 5 m and 200 m from the road edge [1, 4].

The highest copper content was noted in the third fraction (bonds with manganese oxides), whereas zinc and chromium occurred mainly as an exchangeable form (Table 2). For the soils distant 5 m from the road edge the share of the sum of the three copper fractions in its total content ranged from 7.47 % to 32.84 % while for the soils in the distance of 200 m this share ranged from 5.10 % to 22.46 %. In the case of zinc the share amounted respectively from 0.23 % to 12.04 % (for the 5 m distance) and from 0.26 % to 11.94 % (for the 200 m distance). The chromium fractions constituted from 0.33 % to 4.50 % of the total element content in the soils located in the distance of 5 m from the road edge and from traces to 3.16 % in the soils located in the distance of 200 m.

According to other authors' researches, analyzed elements are present in soils mainly as hardly soluble or insoluble forms, which limits possibility of these elements uptake by plants. Copper occurs mainly as bonds with organic matter and as bonds with amorphous and crystalline iron oxides, a relatively high content of copper is also registered in residual fraction (in minerals) [9–11]. Zinc occurs as bonds with amorphous and crystalline iron oxides, in residual fraction and as bonds with organic matter [11–13]. Kalembasa et al [10] registered a high content of an exchangeable fraction of zinc. Chromium occurs as bonds with amorphous and crystalline iron oxides as well as in a residual fraction [10, 11, 14].

Table 2

Content of copper, zinc and chromium in soils [mg · kg^{-1} d.m.]

Distance from the road	Parameter	Approximate to total content of heavy metals			Content of heavy metals fractions								
		Cu	Zn	Cr	Cu			Zn			Cr		
					F_I*	F_{II}	F_{III}	F_I	F_{II}	F_{III}	F_I	F_{II}	F_{III}
5 m (n = 13)	arithmetic mean	14.61	109.81	31.98	0.29	0.59	1.09	0.55	3.27	2.31	0.16	0.33	0.10
	minimum	8.66	77.40	17.65	trace	trace	0.32	trace	trace	trace	trace	trace	trace
	maximum	31.63	166.65	39.69	1.35	2.44	2.14	4.01	10.48	7.76	0.50	0.82	0.49
	standard deviation	6.11	24.36	5.61	0.38	0.60	0.58	1.05	2.77	2.62	0.19	0.23	0.15
200 m (n = 13)	arithmetic mean	14.38	115.00	31.64	0.16	0.47	1.44	1.98	2.85	1.93	0.11	0.28	0.10
	minimum	8.71	80.15	26.54	trace	trace	0.30	trace	trace	trace	trace	trace	trace
	maximum	22.88	157.53	38.44	1.02	1.20	3.32	10.58	6.54	4.56	0.34	0.67	0.43
	standard deviation	3.71	22.20	3.85	0.29	0.43	0.97	2.86	2.05	1.68	0.11	0.25	0.15

* See Table 1.

Conclusions

1. In general, in the soils located in the distance of 5 m from the road edge higher mean contents of the examined fractions of heavy metals were noted than in the soils distant 200 m from the road. Only the contents of easily soluble zinc forms and bonds of copper with manganese oxides were higher in the distance of 200 m.

2. The highest copper content was noted in the fraction of bonds with manganese oxides, whereas zinc and chromium occurred mainly as exchangeable forms.

3. The content of zinc in soil samples showed that content to be elevated (1st and 2nd level of pollution).

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DOSTĘPNOŚĆ METALI CIĘŻKICH Z GLEB NARAŻONYCH NA EMISJE ZANIECZYSZCZEŃ KOMUNIKACYJNYCH

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Abstrakt: Ocena stopnia zanieczyszczenia gleb metalami ciężkimi przeprowadzana jest zazwyczaj na podstawie całkowitej zawartości pierwiastków. Uzupełnieniem tej oceny powinna być analiza zawartości bezpośrednio dostępnych dla organizmów żywych form metali ciężkich oraz form, które stosunkowo łatwo mogą ulec uruchomieniu. Celem niniejszych badań było określenie zawartości wybranych frakcji miedzi, cynku i chromu w glebach położonych w pobliżu drogi nr 957 na odcinku Zawoi. Materiał badawczy stanowiły próbki gleb pobrane z 13 punktów (w każdym punkcie z miejsc oddalonych o 5 i 200 m od brzegu jezdni). Próbki gleb poddano sekwencyjnej ekstrakcji chemicznej według metody Zeiena i Brümmera. Wyekstrahowano 3 frakcje metali ciężkich: formy łatwo rozpuszczalne, formy wymienne oraz połączenia z tlenkami manganu.

Z reguły większe średnie zawartości badanych frakcji metali ciężkich stwierdzono w odniesieniu do gleb położonych w odległości 5 m od brzegu jezdni niż gleb w odległości 200 m od jezdni. Miedź występowała głównie w formie połączeń z tlenkami manganu, natomiast cynk i chrom – jako formy wymienne.

Słowa kluczowe: gleba, zanieczyszczenia komunikacyjne, miedź, cynk, chrom, ekstrakcja sekwencyjna

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Piotr KACORZYK[1]

EFFECT OF THE WAY OF UTILIZATION AND THE LEVEL OF FERTILIZATION ON THE QUALITY OF LEACHATE WATER PART II. THE LOADS OF COMPONENTS CARRIED WITH LEACHATE WATER*

WPŁYW SPOSOBU UŻYTKOWANIA I POZIOMU NAWOŻENIA NA JAKOŚĆ WÓD ODCIEKOWYCH CZ. II. ŁADUNKI SKŁADNIKÓW WYNIESIONYCH Z WODAMI ODCIEKOWYMI

Abstract: The location of the experiment, kind of soil as well as variants and the way of their utilization were reported in the part I entitled: "Concentration of mineral components in leachate water". The amount of mineral components in leachate water was calculated by multiplying the amount of water outlet from 1 ha by the concentration in [dm^3] of these components. Among all examined components calcium was washed out in the highest degree. Significantly higher washing out of nitrate nitrogen, potassium, calcium and magnesium from the arable land and forest in comparison with the other variants resulted from the following reasons: arable land was cultivated for a short period of time, which determined a limited uptake of the above-mentioned components by the plants, on the other hand the roots of forest trees were not able to penetrate deep and assimilate nutrients from the lysimeters which constituted a closed area. The surface of the lysimeters was not covered with living plants but with the duff layer. Additionally, a high amount of organic matter in the forest (11 %) and fast mineralization of the arable land caused by aeration, plough cultivation of the soil, resulted in an increased supply of these components.

Keywords: fertilization, plant coverage of the soil, macroelements, load provided

The protection of water reservoirs is a significant factor of multifunctional and balanced development of the mountain areas. The proper management of the mineral components provided to the soil with fertilizers is also of great importance. The balanced management of these components is important from a productive, ecological and economic point of view and is a basic criterion for the operation of a farm [1].

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* Part I was published in Ecol. Chem. Eng. A 2011, **18**(8), 1033–1039 ([3]).

Circulation of the components in the environment should proceed by balanced rules, which are fulfilled when natural fertilizers supplemented with mineral fertilizers are applied rationally and under conscious utilization of self-control mechanisms proceeding in an ecosystem. In the mountain area the landscape, high amount of rainfalls, shorter vegetation period, longitude of snow-cover, low level of soil thickness, which is additionally strongly acidified, makes the rural management very difficult and non-profitable for many cultivations. Therefore, the production of forages under such conditions should be done mainly on grasslands, which provides cheap and good quality forage and has a positive influence on the natural environment [2].

The aim of the study was to compare the losses of nutrients from the soil as affected by the kind of plant cultivation.

Materials and methods

The location of the experiment, kind of soil as well as variants of the study and the manner of their utilization were presented in [3]. The amount of mineral components in leachate water was calculated by multiplying the amount of water outlet from 1 ha by the concentration of these components in dm^3.

The results of investigations

Table 1 presents the amount of macroelements in kg derived with the leachate water in the years 2007 and 2008. The lowest losses (0.37 $kg \cdot ha^{-1}$ per year) of ammonium nitrogen ($N\text{-}NH_4$) were observed on the meadow which was not utilized, whereas on the utilized meadows they were 20 % higher. On the arable land the losses reached the value of 0.53 $kg \cdot ha^{-1}$ and were 0.04 kg lower then those measured for the forest. During the winter and spring periods the levels of ammonium nitrogen losses were the lowest. In 2007 the losses of $N\text{-}NH_4$ were greater than during the following year.

In the analyses of the amount of nitrate nitrogen ($N\text{-}NO_3$) in leachate water, great differences between the results were observed. The lowest concentration of this component was found for the leachates of the non-fertilized meadow, 4.05 $kg \cdot ha^{-1}$, in contrast the concentration for the leachate water of the fertilized meadow was higher, 6.00 $kg \cdot ha^{-1}$. The losses of this nitrogen form from the arable land and forest amounted to 34.63 and 52.40 $kg \cdot ha^{-1}$, respectively. During the spring period the losses of this component for both meadows were several times lower, and for the rest of objects even up to a dozen times lower, when compared with the respective values determined during the summer, autumn and winter.

The phosphorus losses with leachate water on the non-utilized meadow amounted to 0.4 $kg \cdot ha^{-1}$ and were 25 % higher than the respective losses stated for the other objects. The amounts of potassium washed out from both meadows were usually equal and amounted to 3 $kg \cdot ha^{-1}$, twice higher losses were found for the arable land and 6 times higher for the forest object. During spring and autumn the losses of this element reached levels ranging between 0.03 $kg \cdot ha^{-1}$ for the non-fertilized meadow and 3.65 $kg \cdot ha^{-1}$ for the forest.

Table 1

The amounts of components derived from the leachate water [kg · ha^{-1}]

Variant	Lear/season	[kg · ha^{-1}]													
		N-NH$_4$		N-NO$_3$		P		K		Ca		Mg		Na	
	Year	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
Non-utilized meadow	Spring	0.08	0.01	0.26	0.05	0.09	0.00	0.52	0.03	4.84	4.60	0.63	0.17	0.24	0.08
	Summer	0.29	0.22	2.34	2.30	0.19	0.06	1.55	1.15	27.87	127.48	2.85	4.54	1.34	1.95
	Autumn	0.09	0.04	0.69	0.08	0.31	0.01	1.22	0.15	69.17	42.3	3.40	0.96	1.28	0.45
	Winter	0.00	0.00	1.85	0.52	0.08	0.06	1.37	0.55	34.97	124.12	6.24	4.76	3.12	2.06
	Total	0.46	0.27	5.14	2.96	0.67	0.13	4.67	1.89	136.85	298.43	13.12	10.43	5.98	4.53
	Mean for 2007–2008	0.37^a		4.05^a		0.40^b		3.28^a		217.64^c		11.78^b		5.26^a	
Fertilized meadow	Spring	0.02	0.01	0.07	0.05	0.08	0.00	0.43	0.01	1.74	0.54	0.19	0.06	0.12	0.04
	Summer	0.23	0.16	1.98	2.10	0.09	0.05	1.10	0.37	16.46	14.70	1.86	2.01	1.65	1.03
	Autumn	0.16	0.12	0.79	1.27	0.12	0.01	0.56	0.11	11.18	5.76	1.21	0.96	0.95	0.54
	Winter	0.00	0.23	4.50	1.25	0.16	0.06	2.27	1.54	32.01	24.13	4.22	3.16	2.92	1.65
	Total	0.41	0.51	7.33	4.66	0.45	0.12	4.37	2.04	61.39	45.13	7.48	6.20	5.65	3.26
	Mean for 2007–2008	0.46^a		6.00^a		0.29^a		3.20^a		53.26^a		6.84^a		4.45^a	
Arable land	Spring	0.07	0.02	0.53	0.06	0.04	0.00	0.24	0.04	5.81	1.15	0.55	0.14	0.19	0.07
	Summer	0.34	0.28	14.96	11.54	0.14	0.11	2.91	1.49	91.92	36.77	9.43	6.43	4.20	4.69
	Autumn	0.18	0.17	8.73	12.96	0.09	0.02	1.56	1.06	69.46	16.72	6.99	5.34	3.00	5.50
	Winter	0.00	0.00	18.52	1.97	0.12	0.06	3.75	1.22	130.83	30.16	11.47	6.79	7.42	2.96
	Total	0.58	0.48	42.73	26.52	0.39	0.20	8.45	3.81	298.01	84.79	28.43	18.70	14.81	13.21
	Mean for 2007–2008	0.53^b		34.63^b		0.29^a		6.13^b		191.40^b		23.57^c		14.01^c	

Table 1 contd.

Variant	Lear/season	[kg · ha^{-1}]													
		$N-NH_4$		$N-NO_3$		P		K		Ca		Mg		Na	
	Year	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008	2007	2008
Forest	Spring	0.12	0.02	7.09	1.44	0.06	0.00	2.58	0.54	25.19	5.12	2.41	0.48	1.30	0.21
	Summer	0.16	0.25	17.83	15.73	0.07	0.06	5.39	5.75	51.05	54.74	4.48	3.88	2.21	2.13
	Autumn	0.40	0.11	18.65	11.60	0.09	0.01	3.65	1.48	84.99	17.11	7.60	1.16	3.37	0.59
	Winter	0.00	0.09	14.11	18.35	0.23	0.09	10.73	7.77	160.02	79.34	11.83	9.51	7.73	4.52
	Total	0.67	0.47	57.68	47.12	0.46	0.16	22.35	15.54	321.26	156.31	26.32	15.03	14.61	7.46
	Mean for 2007–2008	0.57^b		52.40^c		0.31^a		18.94^c		238.79^{cd}		20.67^c		11.03^b	

** Homogeneous groups according to LSD test, $\alpha < 0.05$, s.i. – statistically insignificant.

The load of calcium derived with the leachates from the fertilized meadow was the lowest and equal to 53 kg · ha^{-1}, the arable land was characterized with a 138 kg higher level for this parameter. The losses observed for the non-utilized meadow amounted to 218 kg · ha^{-1}, in the forest object the amount of Ca washed out was 4.5 times higher than in the fertilized meadow. The lowest level of Ca in leachates was observed in the spring.

The losses of magnesium for the fertilized meadow amounted to 6.8 kg · ha^{-1} and were the lowest among all the objects. The non-fertilized meadow was characterized with a 72 % higher level for this parameter. The amount of magnesium washed out from the forest was equal to 20.7 kg · ha^{-1}, whereas for the arable land the measured magnesium losses were the highest with a value of 23.6 kg · ha^{-1}. The highest Mg level was found in leachates during the winter period.

The amounts of sodium washed out from both meadows were similar and amounted to 4.5 kg · ha^{-1} for the fertilized and 5.3 kg · ha^{-1} for the non-utilized meadow, whereas the forest object was characterized with an almost 2 times higher value. The highest amount of sodium (14 kg · ha^{-1}) was washed out from the arable land. When the effect of the season of the year is taken into consideration, it can be stated that the highest amount of this element were found in leachates during the winter and the lowest in the spring.

Discussion

The plant coverage of the soil has no significant effect on the level of ammonium nitrogen and phosphorus retained in the soil, because both components were washed out from all objects only in small quantities. These results are in agreement with the findings of Sapek [4]. On the fertilized meadow the losses of nitrate nitrogen were 28.6 kg · ha^{-1} lower than the respective losses found for the arable land. Kasperczyk et al [5] reported that on the mountain meadow which was fertilized in a similar way, 1 kg · ha^{-1} of nitrogen gives a 30.4 kg (d.m.) increase in yield. The calculations indicate that the yield losses from the arable land amounted to 876 kg · ha^{-1} d.m., which constitutes 10 % of a large yield under such conditions. The losses of potassium were affected to a higher degree by the season of the year than by the kind of plant coverage and reached the highest level during the winter, due to the fact that this element is released from the crystal network as a result of the freeze-thaw processes proceeding in the soil [6]. The amounts of losses of the other elements: calcium, magnesium and sodium were affected by the plant coverage of the soil and its ability to retain water as well as by the amount of rainfall. The large losses of nutrients derived from the forest resulted from the fact that the roots of the trees were not able to penetrate deep into the soil profile and assimilate nutrients from the lysimeters which constituted a closed area. The surface of the lysimeters was not covered with trees (due to technical circumstances) or with other living plants but with a layer of duff. Additionally, the soil contained a high level of organic matter (11 %) which was mineralized.

Conclusions

1. The fertilized and mown meadow limits the losses of the biogenic components to the highest degree.

2. The lowest losses of the nutrients were observed in the spring, ie, the most intensive period for plant development.

3. On the arable land the short-term plant coverage as well as fast mineralization caused by aeration, plough cultivation of the soil affected the increased washout of the nutrients from the soil.

4. The plant coverage of the soil has no significant effect on the losses of ammonium nitrogen and phosphorus.

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WPŁYW SPOSOBU UŻYTKOWANIA I POZIOMU NAWOŻENIA NA JAKOŚĆ WÓD ODCIEKOWYCH

CZ. II. ŁADUNKI SKŁADNIKÓW WYNIESIONYCH Z WODAMI ODCIEKOWYMI

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Abstrakt: Wapń był wymywany spośród wszystkich badanych składników w największych ilościach. Zdecydowanie większe wymywanie azotu azotanowego, potasu, wapnia i magnezu z gruntu ornego oraz lasu w porównaniu do innych wariantów wynikało z następujących przyczyn: na gruncie ornym roślinność była uprawiana przez krótki okres, w związku z tym pobieranie wyżej wymienionych składników przez rośliny zostało ograniczone, a na obiekcie las korzenie drzew nie mogły wnikać i pobierać składników pokarmowych z lizymetrów, ponieważ te stanowiły zamkniętą przestrzeń. Na powierzchni lizymetrów również brakowało żywych roślin, zalegała natomiast ściółka leśna. Dodatkowo duża ilość materii organicznej w lesie (11 %), a na gruncie ornym szybka mineralizacja spowodowana napowietrzaniem, uprawą płużną gleby, powodowały zwiększoną podaż tych składników.

Słowa kluczowe: nawożenie, okrywa roślinna gleby, woda, makro składniki, ładunek wyniesiony

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BIOACCUMULATION OF ALUMINIUM IN THE AQUATIC ENVIRONMENT OF THE DOBRA RIVER IN WROCLAW

BIOAKUMULACJA GLINU W ŚRODOWISKU WODNYM RZEKI DOBREJ WE WROCŁAWIU

Abstract: Laboratory tests were carried out regarding the aquatic environment of the Dobra River within the borders of the city of Wroclaw. The study material was constituted by the river water and aquatic plants. The concentration of aluminium in the water oscillated between 0.0517 mgAl $\cdot$ dm^{-3} and 0.2130 mgAl $\cdot$ dm^{-3}. The maximum concentration of aluminium in the aquatic plants amounted to 7.178.65 mgAl $\cdot$ kg^{-1} and the minimum to 118.75 mgAl $\cdot$ kg^{-1}. The tests indicated that the Dobra River waters should be classified as water of medium pollution. Aluminium concentrations in the plants were also found to be moderate.

Keywords: bioaccumulation, aluminium, aquatic plants, water, rivers

Aluminium is the third most common building material of the earth's crust, after oxygen and silicon. It is found in water in the form of hydrogen and oxygen compounds, sulfate, fluoride or aluminium fluoride complexes. Aluminium concentration in soil ranges from 150 mgAl $\cdot$ kg^{-1} to 600 mgAl $\cdot$ kg^{-1}, in the air – amounts up to 1.00 μgAl $\cdot$ m^{-3}, and in water depends on its pH value. Aluminium is characterized by high solubility in acidic environments. Its solubility in soil is proportional to soil acidity. The process occurs most effectively in an environment of pH = 4.00–4.50. When pH is 5.50 aluminium concentration can reach 100.00 mgAl $\cdot$ dm^{-3} [1–6]. The element is easily absorbed by bottom deposits in water reservoirs and is quickly activated when water acidity increases. Aluminium is also carried into rivers by water flowing from cultivated land. The process is seasonal in nature, occurs principally from the direct catchment area during heavy rainfalls or the melting of snow, and depends on

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the type of cultivation and fertilizers used, the sowing cycle and the cultivation schedule [5, 7–13].

Because of high aluminium concentrations in surface waters, a decision was made to determine aluminium concentrations in the water and aquatic plants as well as its accumulation in the aquatic plants in the Dobra River in Wroclaw.

Material and methods

The study material was made up by water and aquatic plants collected in the year 2007 (spring, summer, autumn). The following aquatic plant species were sampled:

– Common reed (Spermatophyta, Monocotyledoneae, Lilidae, Graminales, Gramineae: *Phragmites australis* (Cav.) Trin. ex Steud;

– Acorus calamus (Spermatophyta, Monocotyledoneae, Arecidae, Arales, Araceae: *Acorus calamus* L.)

– Reed canarygrass (Spermatophyta, Monocotyledoneae, Lilidae, Graminales, Gramineae: Phalaris arundinacea L.);

– Canadian pondweed (Spermatophyta, Monocotyledoneae, Alismatidae, Hydrocharitales, Hydrocharitaceae: *Elodea canadensis* L.);

– Great pond-sedge (Spermatophyta, Monocotyledoneae, Lilidae, Cyperales, Cyperaceae: *Carex riparia* Curtis).

Sampling sites:

– above Pawlowski Bridge;

– below Pawlowski Bridge;

– above Klokoczycki Bridge;

– below Klokoczycki Bridge.

The plants were dried in room temperature until air-dry. Whole plants were pre-ground by crushing and then homogenized. Mineralization was performed with concentrated nitric and perchloric acids at a ratio of 1 to 3 in a Mars 5 microwave oven. Aluminium concentrations were determined using atomic absorption spectrophotometry by means of a Varian Spectr AA-110/220 unit.

The aluminium accumulation rate (k) in the plants was computed by dividing the metal concentration in the plants by its concentration in the water.

Results and discussion

The aluminium concentration in the water of the Dobra River ranged between 0.0517 mgAl $\cdot$ dm^{-3} and 0.2130 mgAl $\cdot$ dm^{-3} (Tables 1–3). The maximum concentration was recorded in the autumn, at the site above Pawlowicki Bridge and the minimum – in the summer, at the site below the same bridge (0.0517 mgAl $\cdot$ dm^{-3}). At all of the sites the highest concentrations were found in the autumn and the lowest in the summer. Over the entire section of the river covered by the sampling sites, aluminium concentrations in the water were falling slightly downstream, irrespective of the season.

Aluminium concentrations in water as determined in the research in question were very similar to those found in the waters of the Dobra and the Strzegomka Rivers as

Table 1

Aluminium in water and aquatic plants – spring 2007 (mean values)

Site	Plant species	Al plants [mg · kg^{-1}]	Al water [mg · dm^{-3}]	Accumulation rates (*k*)
Above Pawlowski Bridge	*Phragmites australis*	449.18	0.0940	4778.51
	Acorus calamus	4285.88		45594.50
Below Pawlowski Bridge	*Phalaris arundinacea*	7178.65	0.0788	91099.60
Above Klokoczycki Bridge	*Phragmites australis*	902.76	0.0836	10798.60
	Elodea canadensis	1209.51		14467.80
	Acorus calamus	367.17		4391.98
Below Klokoczycki Bridge	*Phragmites australis*	1563.83	0.0615	25428.10
	Acorus calamus	1040.99		16926.70

Table 2

Aluminium in water and aquatic plants – summer 2007 (mean values)

Site	Plant species	Al plants [mg · kg^{-1}]	Al water [mg · dm^{-3}]	Accumulation rates (*k*)
Above Pawlowski Bridge	*Phragmites australis*	118.75	0.0570	2083.33
	Acorus calamus	696.34		12216.50
Below Pawlowski Bridge	*Phragmites australis*	791.33	0.0517	15306.20
	Acorus calamus	955.41		17479.90
Above Klokoczycki Bridge	*Phragmites australis*	1150.20	0.0702	16384.60
	Elodea canadensis	293.21		4176.78
	Acorus calamus	1173.25		16713.00
Below Klokoczycki Bridge	*Phragmites australis*	1735.91	0.0546	31793.20
	Acorus calamus	1843.65		33766.50

Table 3

Aluminium in water and aquatic plants – autumn 2007 (mean values)

Site	Plant species	Al plants [mg · kg^{-1}]	Al water [mg · dm^{-3}]	Accumulation rates (*k*)
Above Pawlowski Bridge	*Acorus calamus*	882.03	0.2130	4140.98
Below Pawlowski Bridge	*Phragmites australis*	3943.81	0.0946	41689.30
	Carex riparia	846.08		8943.76
	Acorus calamus	386.27		4083.19
Above Klokoczycki Bridge	*Phragmites australis*	2384.87	0.1046	22799.90
	Acorus calamus	4098.07		39178.50
Below Klokoczycki Bridge	*Phragmites australis*	1563.83	0.0699	22372.40
	Carex riparia	1040.99		14892.60

well as in the flowing waters near the city of Zielona Gora [14, 15]. The values recorded for the Dobra River in 2007 were higher than those quoted for the rivers in western

Poland (0.009–0.035 mgAl · dm^{-3}) [16]. However, they were not higher than the concentrations established for the water flowing from the landfill site into the Topór River (a tributary of the Dobra River), which ranged from 0.5900 to 0.8100 mgAl · dm^{-3} [17] or the Biala Przemsza River, which flows through Upper Silesia [18].

Aluminium concentrations in the aquatic plants from the Dobra River oscillated between 118.75 mgAl · kg^{-1} in common reed at the site above Pawlowicki Bridge in the summer and 7,178.65 mgAl · kg^{-1} in reed canary grass below Pawlowicki Bridge in the spring (Tables 1–3). The minimum and maximum accumulation rates for the above sites amounted to 2.083 and 91.099 respectively. The highest average aluminium concentration in aquatic plants was found in the spring (2.124.75 mgAl · kg^{-1}) and the lowest, at 973.12 mgAl · kg^{-1}, in the summer.

Similar aluminium concentrations in aquatic plants were observed in the rivers of western Poland – from 935 mgAl · kg^{-1} to 3.124 mgAl · kg^{-1} [16]. Aluminium concentrations in macrophytes in the reservoirs located in urbanized areas were similar to those found for the Dobra River [14, 18]. Analysis of plant samples from water reservoirs in Germany and France indicates that aluminium concentrations there are similar to those determined for the Dobra River, with the maximum at 6.800 mgAl · kg^{-1} [19, 20].

Recapitulation

The tests indicated that the Dobra River water should be classified as water of medium pollution with aluminium. The highest aluminium concentrations in the water for all of the four sampling sites were found in the autumn, and the lowest in the summer. Most probably this is a result of surface flows from the soils after the autumn rainfalls, which happens every year.

Aluminium bioaccumulation in the biotic components of the aquatic environment – aquatic plants – occurs similarly to that in areas with a moderate pollution of the aquatic environment.

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BIOAKUMULACJA GLINU W ŚRODOWISKU WODNYM RZEKI DOBREJ WE WROCŁAWIU

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Abstrakt: Przeprowadzono badania środowiska wodnego rzeki Dobrej na terenie Wrocławia. Materiałem badawczym były woda rzeczna i rośliny wodne. Poziom glinu w wodzie zawierał się między 0,0517 mgAl $\cdot$ dm^{-3} a 0,2130 mgAl $\cdot$ dm^{-3}. W roślinach wodnych maksimum zawartości glinu wyniosło 7178,65 mgAl $\cdot$ kg^{-1}, a minimum 118,75 mgAl $\cdot$ kg^{-1}. Wody rzeki Dobrej można zaliczyć do wód o średnim stopniu zanieczyszczenia. Obecność glinu w badanych roślinach utrzymuje się również na umiarkowanym poziomie.

Słowa kluczowe: bioakumulacja, aluminium, rośliny wodne, woda, rzeki

ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 11 2011

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OCCURRENCE OF *PHYTOPHTHORA* SPECIES IN RIVERS, CANALS AND WATER RESERVOIRS IN RELATION TO ITS LOCATION, SEASONAL ANALYSIS AND FUNGICIDE RESIDUES

WYSTĘPOWANIE GATUNKÓW *PHYTOPHTHORA* W RZEKACH, KANAŁACH I ZBIORNIKACH WODNYCH W ZALEŻNOŚCI OD ICH LOKALIZACJI, OKRESU DETEKCJI I POZOSTAŁOŚCI FUNGICYDÓW

Abstract: *Phytophthora* spp. were detected from 3 rivers, 2 nursery canals and 2 reservoirs during all year. Number of *Phytophthora* necrotic spots on rhododendron leaves, used as baits, in March, July and October indicated on the lack of significant differences in that group of pathogens in relation to water sources, their location as well as during observation period. Only in one water reservoir *Phytophthora* density was about 2–3 times higher than in 6 other sources. *In vitro* trials showed different reaction of *P. cinnamomi*, *P. citricola* and *P. citrophthora*, often detected in water, on fenamidon and metalaxyl. *P. cinnamomi* was the most sensitive whereas *P. citrophthora* the most resistant. Amendment of river water contaminated with *P. cinnamomi* with metalaxyl at dose 1.6 μg/cm^3 reduced at least twice pathogen density in water. In case of fenamidon such effect was obtained when water was amendment with 8 μg of that compound /cm^3.

Keywords: *Phytophthora* spp. rhododendron baits, detection, fenamidon, metalaxyl, inhibition

Most of *Phytophthora* species, classified by European *Phytophthora* Group as *Algae* like *Oomycetes* (kingdom *Chromista*, class *Oomycetes*, family *Pythiacae*), are the most dangerous soil-borne pathogens of many plants, including hardy nursery stocks. Polish production of ornamental plants, including bushes, trees and perennials, increased every year about 15 %. Most of plants are grown outdoors in containers stands. The surplus water used for plant irrigation or sprinkling and rain run off through drains or open canals to local streams or rivers but is also stored in reservoirs situated in the lowest part of nurseries. About 35 % of such water run back to nursery ponds and is used again for

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plant irrigation [1]. Parts of substratum, rest of fertilizers and plant protection products including metalaxyl, dimetomorph, fenamidon, mancozeb and others often occur in surplus water and they can influence on plant pathogens. Hong and Moorman [2] reported, that some pathogenic bacteria, fungi and viruses can be spread with water. The authors concluded that contaminated water is a primary, if not the sole, source of inoculum for *Phytophthora* diseases of numerous nursery, fruit, and vegetable crops. *Phytophthora* species are one of the most imported plant pathogens [1] causing root and/or stem rot and twig blight of many plants [3–5]. Number of *Phytophthora* propagules in water depending on many factors. The objective of this study was to determine (1) the occurrence of *Phytophthora* spp. in relation to source of water, (2) the seasonal occurrence and frequency of that group of pathogens (3) influence of some protection products on *Phytophthora cinnamomi* Rands detection from river water.

Material and methods

Running water and reservoirs. Three rivers, one swims through forests, and 2 other through horticultural area, 2 canals in 2 hardy ornamental nursery stocks and 2 water reservoirs situated in the same nurseries were chosen for detection of *Phytophthora* spp. and estimation of their population densities in relation to water source and period of baiting.

Detection of *Phytophthora* spp. Top parts of rhododendron leaves cv. Nova Zembla were used according to procedure described by Orlikowski et al [6]. Leaves were held in water about 2 m from the banks from April till October at month intervals. After 5 days baits were put into plastic bags and transported to laboratory. After washing of leaves under tap water and drying number of necrotic spots on each leaf were counted. After desinfection over the burner flame about 5 mm necrotic parts of inocula were put on PDA medium in 90 mm Petri dishes [7]. Within 48 hrs of plates incubation at 25 ^{o}C number of colonies growing around inocula were counted and some of them were transferred into PDA slants. After segregation representative cultures were clean and identified to species on the base of their morphological features [6].

Influence of some fungicides on detection of *Phytophthora cinnamomi* from water contaminated with fungicide residues. Linear growth of *P. cinnamomi*, *P. citricola*, *P. citrophthora* on PDA amended with fenamidon and metalaxyl at concentrations 8 and 40 μg of a.i./cm^3 was evaluated after 5-day-incubation at 25 ^{o}C. Relationship between chemicals applied, their concentrations and changes in the population density of *P. cinnamomi* was evaluated in river water contaminated with the pathogen using rhododendron leaf baits [7].

Results and discussion

Detection of *Phytophthora* spp. in water. *Phytophthora* species including *P. cinnamomi* Rands*, P. citricola* Sawada*, P. citrophthora* (R.E Smith and E.H Smith) Leonian and *P. cryptogea* Pethybr. and Laff., were detected from all tested sources of water during all year. Using rhododendron leaves as the bait *Phytophthora* spp. was recovered at almost the same level from rivers, canals and reservoirs (Table 1). Themann et al [1] concluded that even at low winter temperature reservoirs and sediments did not freeze and enable the survival and development of *Phytophthora* species. In addition, the organic materials in sediments and the anaerobic conditions at the base of reservoirs are known to favour survival and development of *Oomycetes* [8, 9]. In the last 2 years checked rivers and reservoirs were froze on the depth about 10–15 cm during the winter time only for a few days so such condition did not significantly effect on *Phytophthora* population. Lack of sudden increase or decrease of *Phytophthora* spots on leaf baits was probably connected with the lack or very low contamination of water by metalaxyl and dimethomorph which may strongly suppressed *Phytophthora* development.Water pH which fluctuated only slightly had no any influence on *Phytophthora* level.

Table 1

Relationship between source of water, detection time and number of *Phytophthora* necrotic spot on rhododendron leaf baits

Source of water	Observation time		
	March	July	October
Korabiewka river	7.8 ab	5.3 a	18.0 cd
Kurowka river	12.3 a–c	8.5 ab	10.0 a–c
Ner river	12.5 a–c	12.8 a–c	9.5 ab
Canal I	13.3 a–c	9.3 ab	13.5 bc
Canal II	11.0 a–c	5.8 ab	12.5 a–c
Pond I	10.8 a–c	11.3 a–c	11.5 a–c
Pond II	6.3 ab	24.0 d	11.0 a–c

Note: Means followed by the same letter do not differ with 5 % of significance; Duncan's multiple range test.

Relationship between fungicides, their concentration and development of *Phytophthora* spp. Amendment of PDA medium with fungicides resulted in different reaction of *Phytophthora* species on active ingredients (Table 2).

Table 2

Relationship between *Phytophtora* species, different fungicides and inhibition [%] of linear growth on potato-dextrose agar amended with chemical at dose 8 (a) and 40 (b) [μg/cm^3]

Phytophtora species	Fenamidon		Metalaksyl	
	a	b	a	b
P. cinnamomi	100 c	100 b	95 b	95 b
P. citricola	57 b	74 a	83 b	87 ab
P. citrophthora	34 a	64 a	61 a	77 a

Note: see Table 1.

Fenamidon at dose 8 μg of a.i./cm^3 completely inhibited the growth of. *P. cinnamomi* whereas the other 2 species for about 40 %. Increase of fenamidon concentration resulted in the inhibition of *P. citricola* and *P. citrophthora* growth for about 70 %. Metalaxyl already at concentration 8 μg/cm^3 reduced the growth of *P. cinnamomi* in 95 % whereas *P. citrophthora* only 61 % (Table 2). Increase the fungicide concentration 5 times only slightly reduced the growth of *P. citricola* and *P. citrophthora.* Amendment of river water with fenamidon with 1.6 μg of fenamidon/cm^3 did not influence population density of *P. cinnamomi* (Table 3).

Table 3

Relationship between 2 fungicides, their concentrations and occurrence of *Phytophtora cinnamomi* in river water; number of spots/leaf bait

Concentration [μg/cm^3]	Fenamidon	Metalaksyl
0.0	23 c	23 c
1.6	22 c	9.5 b
8.0	9.5 b	5.3 a

Note: see Table 1.

Increase of the fungicide level to 8 μg/cm^3 resulted in the decrease of propagule numbers at least twice. Activity of metalaxyl at 8 μg/cm^3 was about twice higher than fenamidon (Table 3). Results obtained indicated on lack or minimal amount of fenamidon and metalaxyl in analysed water sources and lack of influence on *Phytophthora* spp. (Table 1).

Themann et al [1] reported a dramatic increase in *Phytophthora* isolates in recycled nursery irrigation water from autumn to spring because of reservoirs are refill very rare so there are no dilution of water as well as application of fungicide specific to *Oomycetes* during that period. Studies of Oudemans [10] indicated that application of 2 kg of metalaxyl/ha to manage *Phytophthora* root rot of cranberry, caused by *P. cinnamomi,* had no significant, long-term effect on the recovery of that species from drainage canals.

Conclusions

1. Our study showed the occurrence of *Phytophthora* spp. in rivers, nursery canals and reservoirs

2. Location of water source, implements of surrounding of rivers and detection period had no significant differences on the number of *Phytophthora* necrotic spots on rhododendron leaf baits

3. Fenamidon and metalaxyl, specific fungicides against *Oomycytes,* already at concentration of 8 μg/cm^3 almost completely inhibited the development of *P. cinnamomi* whereas *P. citrophthora* slightly reacted on that compounds

4. Amendment of river water with metalaxyl at dose 1.6 μg/cm^3 decreased *P. cinnamomi* density at least twice. Such effect was also observed when fenamidon was added to water at concentration 8 μg/cm^3.

5. Results obtained indicated on lack or minimal amount of tested fungicides in water sources because of only slightly differences in *Phytophthora* levels during analysed periods.

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WYSTĘPOWANIE *PHYTOPHTHORA* SPP. W RZEKACH, KANAŁACH I ZBIORNIKACH WODNYCH W ZALEŻNOŚCI OD ICH LOKALIZACJI, OKRESU DETEKCJI I POZOSTAŁOŚCI PESTYCYDÓW

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Abstrakt: Stosując wierzchołkowe liście różanecznika odm. Nova Zembla, wykrywano *Phytophthora* spp. przez cały rok w 3 rzekach, 2 kanałach i 2 zbiornikach wodnych. Liczba nekrotycznych plam, stwierdzanych na liściach pułapkowych w marcu, lipcu i październiku wykazała brak znaczących różnic w liczebności tej grupy patogenów w badanych źródłach wody niezależnie od miejsca ich usytuowania, zagospodarowania oraz czasu detekcji. Tylko w jednym zbiorniku wodnym w szkółce liczebność *Phytophthora* spp. była około 3-krotnie wyższa aniżeli w pozostałych 6 źródłach wody. Doświadczenie *in vitro* wykazało zróżnicowaną reakcję *P. cinnamomi, P. citricola* i *P. citrophthora* na fenamidon i metalaksyl. Gatunek *P. cinnamomi* okazał się najwrażliwszy na te środki, podczas gdy najodporniejszym. okazał się *P. citrophthora.* Wprowadzenie metalaksylu w stężeniu 1,6 μg/cm^3 do wody rzecznej, skażonej przez *P. cinnamomi*, spowodowało redukcję liczebności patogenu na liściach pułapkowych co najmniej dwukrotnie. W przypadku fenamidonu taki efekt uzyskano, gdy środek dodano do wody w stężeniu 8 μg/cm^3.

Słowa kluczowe: *Phytophthora* spp., pułapki różanecznikowe, wykrywanie, fenamidon, metalaksyl, hamowanie

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INFLUENCE OF DIMILIN 25 WP ON CHARACTERISTICS OF EARTHWORM *Eisenia fetida* Sav., VERMICOMPOSTING ORGANIC WASTE

WPŁYW DIMILINU 25 WP NA CECHY POPULACJI DŻDŻOWNIC *Eisenia fetida* Sav., WERMIKOMPOSTUJĄCYCH ODPADY ORGANICZNE

Abstract: Vermicomposting of organic kitchen residues at a place where waste is produced can be conducted in small containers – an earthworm ecology box. The serious problem for the user can be the presence of *Diptera*. In laboratory experiment, the influence of the insecticide Dimilin 25 WP was tested on *Eisenia fetida* Sav. population characteristics, in addition to its influence on the rate of kitchen residues vermicomposting.

The experiment showed that Dimilin limited the number of *Dipteran* larvae, when it was applied to ecological boxes ($p < 0.001$). After four months, the mean number of the *E. fetida* population in boxes with insecticide was only 1 % lower than in boxes without Dimilin, and the population biomasses did not differ statistically ($p < 0.05$). When no differences were present in number and biomass of mature and immature specimens, differences between laid cocoons were noticed, depending on Dimilin treatment ($p < 0.001$).

Keywords: earthworm ecology box, kitchen organic waste, *E. fetida, Diptera,* Dimilin 25 WP

The household-scale vermiculture, run in ecology boxes enables a bio-transformation of organic waste at the spot of their generation, which is significant both ecologically and economically. Apart from difficulties with sustaining earthworm number and their reproductive capacity in small containers [1–3], the serious problem for the user of ecological box is the presence of *Diptera*.

In order to remove the trouble with these insects, we can introduce an insecticide to the mixture of vermicomposted residues. How will that influence the earthworm population and the speed of kitchen residues vermicomposting?

In this laboratory experiment, the influence of the insecticide Dimilin 25 WP – popular in Polish mushroom-growing cellars, was tested on *Eisenia fetida* (Sav.)

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population characteristics, in addition to its influence on the rate of kitchen residues vermicomposting.

Material and methods

Fifty *E. fetida* specimens (all clitelled, with biomass equalized in each of the pots) were bred in the laboratory, in each of ten pots with dimension of (15 × 22 × 9) cm^3 – width, length and depth. All of the pots were filled with two litre of universal garden soil protecting plant growth, prepared from peat and sand: humidity 70 %, pH = 6.5; salinity 1 g NaCl · dm^{-3}.

Pots 1–5 were treated as control, pots 6–10 also contained the insecticide Dimilin 25 WP (in concentrations of 4 g · m^{-2} – conformable to instruction of the producer), what was giving 0.13 g per pot). During four month lasting experiment, every earthworm population was then fed regularly once a month, the same amount of organic kitchen waste (900 cm^3 of boiled macaroni and potatoes, soaked bread and apple peelings, mixed with soaked cartoon cellulose in proportion 1:1:1:1:2 – to try to overcome declining earthworm populations [2]). All pots were regularly watered, to keep the 70 % of bed moisture (to limit the evaporation all pots were covered).

Earthworms and their cocoons were regularly counted and weighed, by manual sorting of the media. At the same time the amount of not transformed residues and the number of *Diptera* larvae found in both types of media (in each eight, 0.1 dm^3, random samples taken, analysed by wet funnel method), were checked. The data obtained were subjected to analysis using a two-factor ANOVA, as well as Tukey's test at the significance level of 0.05.

Results and discussion

The experiment showed that Dimilin limited the number of *Dipteran* larvae, when it was applied to ecological boxes (to a mean of (1.0 ± 3.1) dm^{-3} in comparison to (168.4 ± 178.5) dm^{-3} in boxes without Dimilin).

The average number of whole *E. fetida* populations in pots with insecticide (128 ± 29 ind./pot) and the average number in controlled pots (130 ± 37 ind.) were similar ($p > 0.05$) (Fig. 1).

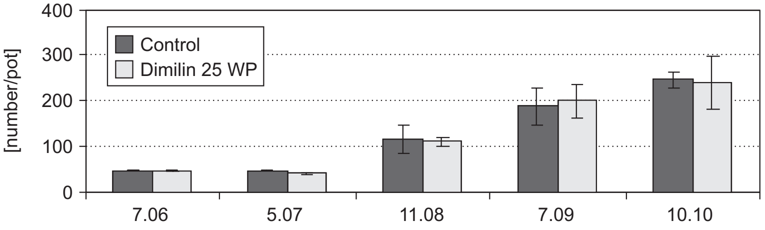

Fig. 1. Influence of Dimilin 25 WP on the dynamics of average number of *E. fetida* [number/pot]

The average sum of *E. fetida* populations biomass in pots with and without insecticide did not differ statistically ($p > 0.05$) (Fig. 2).

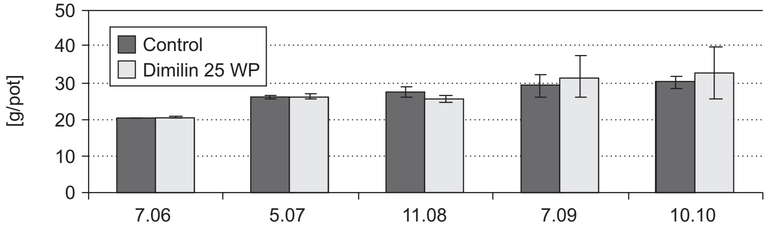

Fig. 2. Influence of Dimiln 25 WP on average sum of biomass of *E. fetida* [g/pot]

It was noticed that the insecticide did not affect mature and immature specimens ($p > 0.05$) (Table 1). Dimilin 25 WP did affect the average number and sum of biomass of cocoons laid. Pots with insecticide included smaller number of cocoons, and the difference (mean 38 ± 8 and 60 ± 10 ind./pot) was statistically important ($p < 0.001$). Populations also differed considerably as far as sum of cocoon's biomass were concerned ((0.658 ± 0.109) g/pot and (0.976 ± 0.182) g/pot) ($p < 0.01$) (Table 1).

It was proven that populations also differed considerably as far as mean biomass of immature individuals and cocoons were concerned (Table 2).

The amount of kitchen waste that was not processed, was fluctuating in particular months and was dependent on the temperature (Table 3). In July, when the temperature was the highest all waste in both types of pots disappeared. Gradual decreasing of average temperature in August, September and October caused increasing of unprocessed waste amount (equally in both types of containers ($p > 0.05$)).

The negative influence of dumping sites to environment is a result, among the other, of organic waste's presence. Food wastes make up even to 40 % of all municipal waste mass [4, 5]. One of the ways of rendering organic waste, is its selection and vermicomposting in earthworm ecological boxes. Thus produced vermicompost may be used to feed plants, vegetables and flowers up in houses and gardens. The vermicomposting rate depends on number and form of earthworms, that are dependent on soil humidity and aeration, pH, and providing with waste mixed with cellulose [2]. There may happen that *Diptera* multiply excessively near the box, which may not be pleasant, however, there is a way of handling this problem, shown in the experiment. It was proved that using Dimilin 25 WP (at the level of $4\ \text{g} \cdot \text{m}^{-2}$) had been efficacious in decreasing the number of *Diptera* larvae. It was also proved that the presence of insecticide had not affected the effectiveness of earthworm ecological box. In July all wastes were vermicomposted in both type of the pots. In August and September, when temperature was lower, the waste's disappearing decreased. Rate of vermicomposting decreased most in lowest temperature – in October.

The average sum of earthworm number in controlled pots was only about 1 % higher than in pots with insecticide, and the average sum of both type of population biomass did not differ. This fact had probably had crucial influence on examined waste

Table 1

Mean number [ind./pot] and mean sum of biomass [g/pot] of *E. fetida* as dependent on Dimilin 25 WP presence

Pots	VI	VII	VIII	IX	X	Mean
Matured (clitelled and possessing *tuberculae pubertatis*)						
Control [ind./pot]	50	41 ± 1	32 ± 7	24 ± 5	23 ± 6	34 ± 3^{a}
Dimilin	50	42 ± 1	36 ± 2	21 ± 5	27 ± 5	35 ± 2^{a}
Control [g/pot]	25.986 ± 0.393	25.458 ± 1.700	16.441 ± 4.000	10.043 ± 2.333	9.114 ± 2.249	17.360 ± 1.878^{b}
Dimilin	25.914 ± 0.574	25.388 ± 0.929	18.000 ± 1.700	8.951 ± 2.333	10.886 ± 1.348	18.060 ± 1.378^{b}
Immature						
Control [ind./pot]	—	7 ± 2	84 ± 32	165 ± 40	223 ± 21	96 ± 18^{a}
Dimilin	—	0.8 ± 0.8	75 ± 8	180 ± 32	212 ± 58	94 ± 16^{a}
Control [g/pot]	—	2.058 ± 0.519	8.789 ± 3.368	19.292 ± 2.777	26.886 ± 6.426	11.240 ± 1.604^{b}
Dimilin	—	0.174 ± 0.050	9.662 ± 0.680	22.540 ± 4.153	21.210 ± 2.628	10.854 ± 1.686^{b}
Cocoons						
Control [ind./pot]	—	34 ± 6	54 ± 23	112 ± 44	98 ± 39	60± 10^{a}
Dimilin	—	34 ± 6	36 ± 6	60 ± 17	56 ± 20	38 ± 8^{b}
Control [g/pot]	—	0.539 ± 0.100	0.930 ± 0.427	1.734 ± 0.683	1.678 ± 1.153	0.976 ± 0.182^{a}
Dimilin	—	0.560 ± 0.084	0.613 ± 0.086	0.963 ± 0.315	0.702 ± 0.458	0.658 ± 0.109^{b}

— – lack of immatured or cocoons; a, b – describe significant difference ($p < 0.001$).

Table 2

Mean biomass [g] of matured, immatured and cocoons, as dependent on Dimilin 25 WP presence

Individuals	Pots	VI	VII	VIII	IX	X	Mean
Matured	Control	0.519 ± 0.132	0.621 ± 0.126	0.507 ± 0.120	0.429 ± 0.081	0.393 ± 0,089	0.494 ± 0.088^{a}
	Dimilin	0.519 ± 0.138	0.593 ± 0.125	0.502 ± 0.116	0.438 ± 0.087	0.409 ± 0.091	0.492 ± 0.072^{a}
Immatured	Control	—	0.286 ± 0.043	0.104 ± 0.087	0.117 ± 0.084	0.095 ± 0.073	0.120 ± 0.073^{a}
	Dimilin	—	0.145 ± 0.115	0.129 ± 0.085	0.125 ± 0.087	0.126 ± 0.079	0.105 ± 0.059^{b}
Cocoons (weighed by 10 pieces)	Control	—	0.159 ± 0.008	0.172 ± 0.012	0.155 ± 0.020	0.171 ± 0.034	0.131 ± 0.073^{a}
	Dimilin	—	0.165 ± 0.021	0.170 ± 0.011	0.159 ± 0.013	0.206 ± 0.036	0.140 ± 0.080^{b}

a, b – describe significant difference ($p < 0.05$).

Table 3

The kitchen waste vermicomposting (unprocessed waste in cm^3)

Period of experiment	July of 2006	August	September	October of 2006	
	Mean month temperature [^{o}C]				
	31.1 ± 1.9	26.1 ± 1.7	18.2 ± 2.1	16.4 ± 0.9	
Type of pot	Unprocessed waste [cm^3]				Mean
Control	—	83 ± 10	47 ± 9	330 ± 103	156 ± 41^{a}
Dimilin	—	67 ± 15	57 ± 10	320 ± 76	145 ± 30^{a}

— – lack of unprocessed waste; a – lack of significant difference ($p = 0.05$).

vermicomposting, though one cannot rule out the same influence of other detritivores accompanying earthworms in ecological boxes [1, 2, 6], but this problem was not investigated in this experiment.

It has been proven, that according to the producer's indications in order to limit the occurrence of *Sciaridae* larva, the inhibitor of chitin biosynthesis under the name of Dimilin 25 WP, has no influence on the average number and biomass of the earthworm *E. fetida* Sav., vermicomposting domestic organic waste in the earthworm ecology box. It has been also found that the dose indicated by the producer was efficient with limitation of the occurrence of *Sciaridae* larva also in the conditions of the earthworm ecology box. Its presence in the bedding of the box did not influence the average rate of vermicomposting of tested kitchen wastes.

Dimilin 25 WP has not changed the number and the sum of biomass of mature specimens, as well as these individuals has not differ in average biomass. In the reach of the class of immatures, Dimilin has not influenced their number and the sum of biomass but the negative influence of this insecticide on an average mass of immature individuals ($p < 0.05$) was noticed. It should be also stressed that the insecticide Dimilin 25 WP, used in the dose indicated by the producer, influenced the breeding of earthworms. It caused the decrease in average quantity and average sum of biomass ($p < 0.001$) of the cocoons being laid. It also differentiated ($p < 0.05$) average biomass of laid cocoons (in the pot with Dimilin the living strategy of earthworms was carried out by laying heavier cocoons – but it did not suffice, to overcome the negative effects on sum of their biomass).

The case considered in the publication proves, as other authors [7, 8], that chemicals used for protection of plants, even according to the rules of protection on environment, are not indifferent for other living organisms.

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WPŁYW DIMILINU 25 WP NA CECHY POPULACJI DŻDŻOWNIC *Eisenia fetida* Sav., WERMIKOMPOSTUJĄCYCH ODPADY ORGANICZNE

Zakład Biologicznych Podstaw Rolnictwa i Edukacji Środowiskowej
Uniwersytet Rzeszowski

Abstrakt: Wermikompostowanie kuchennych odpadów organicznych na miejscu ich powstawania można prowadzić w małych pojemnikach – dżdżownicowych skrzynkach ekologicznych. Ponieważ problem dla ich użytkownika może stanowić obecność muchówek *Diptera,* dlatego w badaniach laboratoryjnych testowano wpływ ograniczającego je insektycydu Dimilin 25 WP na cechy populacji *Eisenia fetida* Sav. Badano również jego wpływ na tempo wermikompostowania wybranych odpadów organicznych.

Wykazano, że zastosowanie Dimilinu 25 WP ograniczyło liczebność larw muchówek w skrzynkach ekologicznych ($p < 0,001$), nie zmieniając tempa wermikompostowania odpadów. Po czterech miesiącach średnia liczebność populacji *E. fetida* w skrzynkach z insektycydem była tylko o 1 % mniejsza niż w skrzynkach kontrolnych i biomasy populacji nie różniły się statystycznie ($p < 0,05$). Podczas gdy nie stwierdzono wpływu Dimilinu 25 WP na liczebność i biomasę osobników dojrzałych, wykazano różnice w obrębie składanych kokonów. Insektycyd redukował liczebność ($p < 0,001$) i sumę biomasy ($p < 0,01$) kokonów, różnicował także ($p < 0,05$) ich średnie masy (w pojemnikach z Dimilinem strategia życiowa dżdżownic była realizowana przez składanie kokonów cięższych).

Słowa kluczowe: dżdżownicowa skrzynka ekologiczna, kuchenne odpady organiczne, *E. fetida*, *Diptera,* Dimilin 25 WP

ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 11 2011

Janina GOSPODAREK[1]

RESIDUAL EFFECT OF SOIL CONTAMINATION WITH HEAVY METALS ON *Sitona* sp. BEETLES FEEDING ON BROAD BEAN (*Vicia faba* L.)

NASTĘPCZY WPŁYW SKAŻENIA GLEBY METALAMI CIĘŻKIMI NA ŻEROWANIE CHRZĄSZCZY OPRZĘDZIKÓW (*Sitona* sp.) NA BOBIE (*Vicia faba* L.)

Abstract: The research aimed at an assessment of heavy metal soil contamination effect on the intensity of *Sitona* beetles feeding on broad beans cultivated in the soil three years after the moment of pollution, from the perspective of possibly enhanced attractiveness of this host plant as food. Broad bean (*Vicia faba* L.), White Windsor c.v. was cultivated in two series differing by the date of the soil contamination with heavy metals. The soil was contaminated in 2002 (III) and 2005 (0). In each series the plants were cultivated in the following objects: unpolluted soil – with natural content of heavy metals (Control); unpolluted soil with natural content of heavy metals and fertilized minerally (NPK); soil polluted with a dose of 4 mg $\cdot$ kg^{-1} d.m. of cadmium; soil polluted with a dose of 530 mg $\cdot$ kg^{-1} d.m. of lead; soil polluted with a dose of 85 mg $\cdot$ kg^{-1} d.m. of copper; soil contaminated with zinc dosed 1000 mg $\cdot$ kg^{-1} d.m. and soil polluted with a dose of 110 mg $\cdot$ kg^{-1} d.m. of nickel. The harmfulness of *Sitona* sp. beetles was assessed by measuring the leaf surface losses caused by their feeding, the consumed area and by counting the percentage of injured leaves. After 3 years from the soil contamination with nickel, zinc, copper, lead and cadmium no increase of attractiveness of the plants for *Sitona* sp. beetles was observed.

Keywords: heavy metals, soil pollution, *Sitona* sp.

Soil contamination with lead, cadmium, copper and nickel either on the I or III level of pollution in the IUNG classification does not cause any significant seasonal changes in the degree of plant injuries caused by the beetles from *Sitona* species [1]. However, a reduced feeding of *Sitona* beetles was observed on the plants growing in the soil contaminated with zinc on a higher level. Significant differences were noted also in the course of *Sitona* feeding dynamics on broad bean growing in the soil contaminated with various heavy metals [2]. The research conducted to assess the degree of *Sitona* harmfulness for broad bean cultivated in heavy metal polluted soil in the year of the

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analysis, a year before and two years before, revealed that at the early development stage, plants growing in the soil contaminated with zinc and nickel (in the same year as the analysis) proved the least attractive for *Sitona* beetles. For the object where the soil was contaminated with nickel and copper, the tendency was observed also at the later stage of the pest feeding [3].

The present research aimed at an assessment of heavy metal soil contamination effect on the intensity of *Sitona* beetles feeding on broad beans cultivated in the soil three years after the moment of pollution, from the perspective of possibly enhanced attractiveness of this host plant as food.

Material and methods

The experiment was conducted in 2005 under field conditions. The experimental soil was a degraded chernozem formed from loess with acid pH and 1.13 % organic carbon content. Broad bean (*Vicia faba* L.), White Windsor c.v. was cultivated in two series differing by the date of the soil contamination with heavy metals. The soil was contaminated in 2002 (III) and 2005 (0). In each series the plants were cultivated in the following objects: unpolluted soil – with natural content of heavy metals (Control); unpolluted soil with natural content of heavy metals and fertilized minerally (NPK); soil polluted with a dose of 4 $mg \cdot kg^{-1}$ d.m. of cadmium; soil polluted with a dose of 350 $mg \cdot kg^{-1}$ d.m. of lead; soil contaminated with zinc dosed 1000 $mg \cdot kg^{-1}$ d.m. and soil polluted with a dose of 110 $mg \cdot kg^{-1}$ d.m. of nickel. The plants were grown in plastic pots with 9.8 kg of soil d.m. The heavy metals were added to the soil as water solutions of the following salts: $3CdSO_4 \cdot 7H_2O$, $NiSO_4 \cdot 7H_2O$, $CuSO_4$, $ZnSO_4 \cdot 7H_2O$, $Pb(NO)_3$. Because on the object receiving $Pb(NO_3)_2$ some amount of nitrogen was already supplied into the soil, its dose was adequately diminished in the applied basic fertilization. Basic fertilization, the same on all objects (except the unfertilized control), dosed 0.7 g N (as NH_4NO_3); 0.8 g P_2O_5 (as KH_2PO_4) and 1.2 g K_2O (as KCl) per pot of 9.8 kg d.m. of soil, was applied in the first year of the investigations.

The data on the methods applied for soil chemical analyses were presented in other papers [4–5].

The harmfulness of *Sitona* sp. beetles was assessed by measuring the leaf surface losses caused by their feeding, the consumed area and by counting the percentage of injured leaves. The analysis of injuries was conducted at the early stage of plant development (several leaves stage – 21.05.2005) and two weeks later (2.06.2005).The significance of differences between the means was tested by a one-way ANOVA. The means were differentiated using the Duncan test on the significance level $p < 0.05$.

Results and discussion

On the first of the analyzed dates *Sitona* sp. beetles injured ca 23 % of leaves (depending on the object). The greatest number of leaves with consumed area were observed in the year when the research was conducted on the plants growing in nickel contaminated soil. At that time no leaf injuries were spotted yet in the object where the soil was contaminated with zinc 3 years prior to the observations (Fig. 1A). No statistically significant differences were found either in the total consumed area caused by the beetles between the analyzed objects at that time. When the observations were carried out 2 weeks later the percentage of injured leaves was between 27 and 77 % (depending on the object) (Fig. 1B). In the case of cadmium contaminated soil, no significant differences in the degree of injuries due to *Sitona* sp. beetles were assessed between the objects contaminated on various dates (Fig. 1B and 2B). The analysis of heavy metal contents in broad bean plants revealed that with time elapsing from the soil cadmium contamination moment, its concentrations in broad bean shoots remained on a similar level or even slightly increased [6].

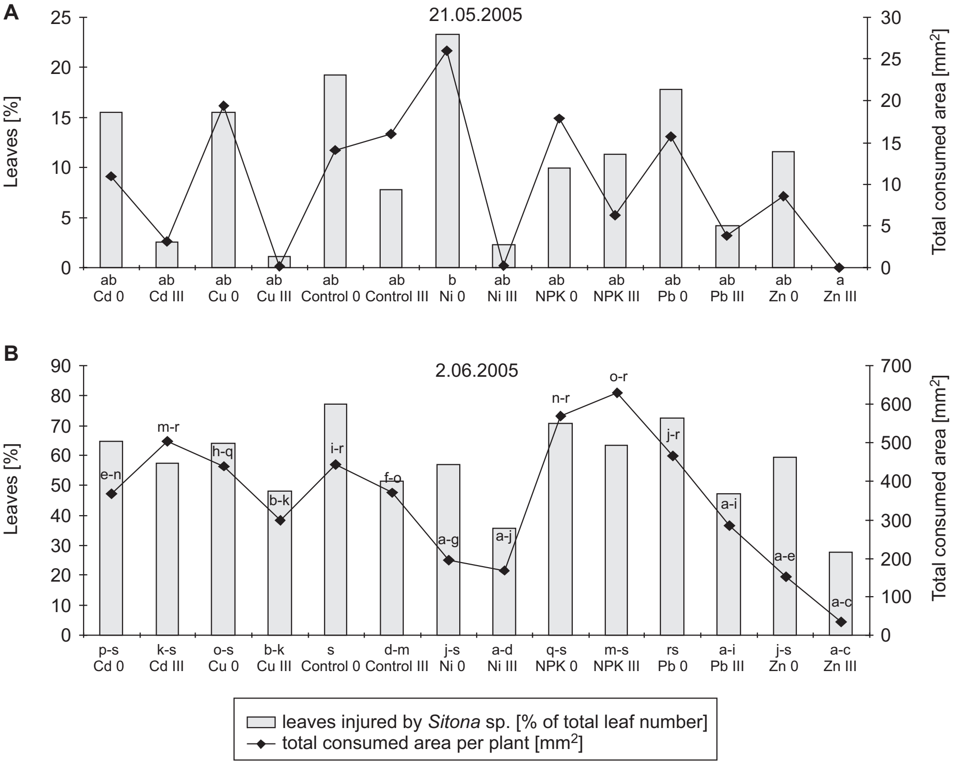

Fig. 1. Injuries of broad bean growing in natural soil (Control, NPK) and in soil contaminated with individual metals (III – soil contaminated three years earlier, 0 – soil contaminated in the year of the observations) caused by *Sitona* beetles. Values for individual metals or control and for individual features marked by different letters are statistically significantly different ($p < 0.05$). Assessments were presented only if there was statistical differentiation between objects. In other cases differences were statistically insignificant

Under conditions of the soil polluted with copper 3 years before the observation date a smaller number of leaves injured by *Sitona* sp. beetles was observed, as well as smaller consumed area than on broad bean growing under conditions of the soil contaminated in the year of the experiment (Fig. 1B). In former investigations, increased attractiveness of broad bean plants as feed for *Sitona* was observed one or two years after the pollution moment [3]. A significant decrease in copper content in broad bean shoots was registered as time elapsed from the moment of the soil contamination with this metal. This metal concentrations in the plants cultivated in the soil contaminated 3 years earlier were only about 1.5 times higher than in the control plants, whereas the concentrations in the plants growing in the soil contaminated in the year of the analysis were almost 4 times higher than in the plants growing in the unpolluted soil [6].

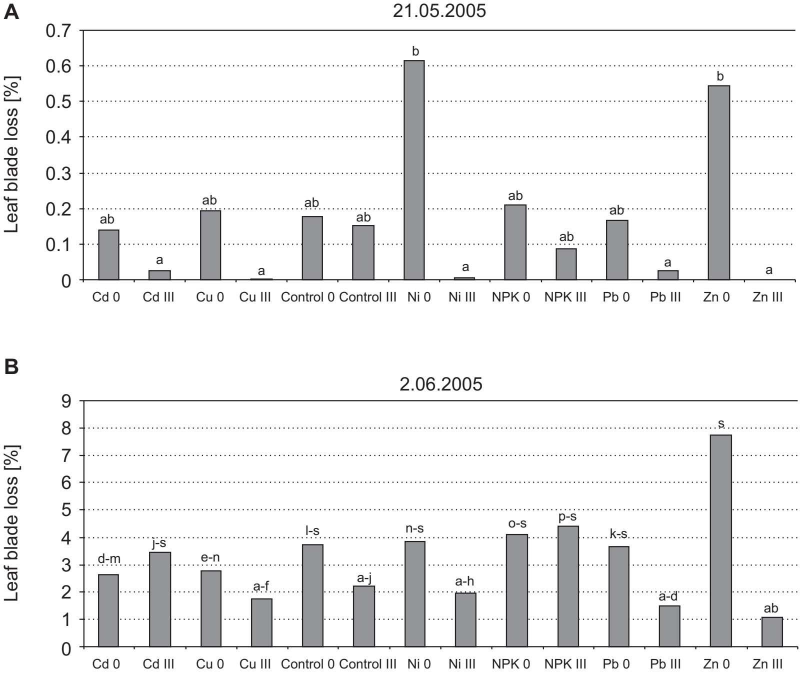

Fig. 2. Leaf blade loss as a result of *Sitona* beetles feeding (per cent of total leaf area) on broad bean growing in natural soil (Control, NPK) and in soil contaminated with individual metals (III – soil contaminated three years earlier, 0 – soil contaminated in the year of the observations). Values for individual metals or control and for individual features marked by different letters are statistically significantly different ($p < 0.05$). Assessments were presented only if there was statistical differentiation between objects. In other cases differences were statistically insignificant

Former research registered an increase in the degree of broad bean plant injuries with the lapse of time (one or two years) from the soil contamination with lead [3]. In the presented research, a decreased harmfulness of *Sitona* beetles was already noticed under conditions of soil contaminated 3 years before. The analysis of lead content in broad beans revealed that 3 years after the soil contamination, this metal content in broad bean shoots was about 4 times lower than in the plants growing in the soil contaminated in the year when the analysis was conducted. Similarly to in the former investigations, the smallest consumed area was observed under conditions of soils contaminated with nickel and zinc. The percentage of injured broad bean leaves growing in the soil polluted with nickel and zinc 3 years earlier was significantly lower than in the case of soil contaminated with these metals in the year of the experiment. Also leaf blade loss was lower. The value of the latter parameter might have resulted from improved condition of plants growing in the soil polluted with heavy metals earlier in comparison with the plants cultivated in the "freshly contaminated soil". Nickel concentrations in broad bean shoots cultivated in the soil 3 years from the contamination moment were over twice lower than under conditions of soil contaminated in the year of the experiment, zinc content decreased by about 20 %. Changes in plant attractiveness for phytophages feeding on them might result not only from changes in heavy metal content in plants as such, but also changes in other biochemical and physiological plant parameters, which are modified by the presence of these pollutants [7, 8].

Conclusions

After 3 years from the soil contamination with nickel, zinc, copper, lead and cadmium no increase of attractiveness of the plants for *Sitona* sp. beetles was observed.

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NASTĘPCZY WPŁYW SKAŻENIA GLEBY METALAMI CIĘŻKIMI NA ŻEROWANIE CHRZĄSZCZY OPRZĘDZIKÓW (*Sitona* sp.) NA BOBIE (*Vicia faba* L.)

Wydział Rolniczo-Ekonomiczny
Uniwersytet Rolniczy im. Hugona Kołłątaja w Krakowie

Abstrakt: Celem podjętych badań była ocena wpływu skażenia gleby metalami ciężkimi na intensywność żerowania chrząszczy oprzędzików *Sitona* sp. na bobie uprawianym w glebie po upływie 3 lat od momentu skażenia, pod kątem możliwości wzrostu atrakcyjności tej rośliny żywicielskiej jako pokarmu. Bób (*Vicia faba* L.) odm. Windsor Biały uprawiany był w 2 seriach, różniących się datą skażenia gleby metalami ciężkimi. Glebę skażano w latach: 2002 i 2005. W każdej serii rośliny uprawiano w następujących obiektach: gleba niezanieczyszczona – o naturalnej zawartości metali ciężkich (Kontrola); gleba niezanieczyszczona – o naturalnej zawartości metali ciężkich nawożona mineralnie (NPK); gleba zanieczyszczona kadmem w dawce: 4 mg $\cdot$ kg^{-1} s.m., gleba zanieczyszczona ołowiem w dawce: 530 mg $\cdot$ kg^{-1} s.m., gleba zanieczyszczona miedzią w dawce: 85 mg $\cdot$ kg^{-1} s.m., gleba zanieczyszczona cynkiem w dawce: 1000 mg $\cdot$ kg^{-1} s.m., gleba zanieczyszczona niklem w dawce: 110 mg $\cdot$ kg^{-1} s.m. Szkodliwość chrząszczy oprzędzików (*Sitona* sp.) oceniono, mierząc ubytek powierzchni liści na skutek ich żerowania, powierzchnię wyżerek oraz licząc odsetek uszkodzonych liści. Po upływie 3 lat od momentu zanieczyszczenia gleby niklem, cynkiem, miedzią, ołowiem lub kadmem nie obserwuje się wzrostu atrakcyjności roślin bobu dla chrząszczy *Sitona* sp.

Słowa kluczowe: metale ciężkie, zanieczyszczenie gleby, *Sitona* sp.

ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 11 2011

Joanna JARMUŁ-PIETRASZCZYK[1], Marta KAMIONEK[1]
and Ines KANIA[2]

OCCURRENCE OF ENTOMOPATHOGENIC FUNGI IN SELECTED PARKS AND URBAN FORESTS OF THE WARSAW DISTRICT URSYNOW

WYSTĘPOWANIE GRZYBÓW ENTOMOPATOGENNYCH W WYBRANYCH PARKACH I LASACH MIEJSKICH WARSZAWSKIEJ GMINY URSYNÓW

Abstract: The present study concerns choice composition, as well as intensification of occurrence entomopathogenic fungi on chosen terrains of the park and municipal forests of the Ursynow district in Warsaw. The following entomopathogenic fungi were isolated: *Peacilomyces fumosoroseus, Bauveria bassiana* and *Metharisium anisopliae*. Position did not influence the occurrence of entomopathogenic fungi. However, different seasons of the year had an influence on the occurrence of the fungi. *P. fumosoroseus* turned out to be predominant in spring, summer, while *B. bassiana* in autumn.

Keywords: entomopathogenic fungi, soil, season of year

There are c. 200 species of entomopathogenic fungi in Poland. Most of them infect insects rarely or occasionally [1]. Their presence and activity in the environment depend on abiotic and biotic conditions. Under favourable conditions such as appropriate temperature, moisture and host availability, these fungi may largely reduce the number of insects at various stages of their growth. Apart from typical environmental factors, the number of fungi is controlled by human activity – plant protection chemicals and heavy metals introduced to soils [2, 3].

Warsaw – a modern city – is a complex socio-economic, technical and also biological system. Natural greenery and artificial green complexes play an important role in the functioning of this urban agglomeration. There are many insect species, which are the food base for entomopathogenic fungi in urban green areas. These fungi most often attack soil-dwelling insects. Individuals dead due to mycosis are a source of

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spreading the disease and often become hotbeds of epizootic diseases [4, 5]. Now entomopathogenic fungi are used in plant protection in greenhouses and field crops. Their increasing importance for pest control, particularly in monocultures, raised the interest in domestic species and their occurrence in various ecosystems [6–8].

The aim of this study was to estimate species composition of entomopathogenic fungi in urban greens of the Ursynow district in Warsaw during various seasons.

Material and methods

Soil samples collected in 2007 from five selected sites in the Ursynow district were used in the experiment. Soil was collected from: the park of the Warsaw University of Life Sciences – Ursynow Escarp (soil pH 4.7–6.8), Park of Culture in Powsin (pH 4.7–6.6), Roman Kozlowski's Park (pH 4.7–6.8) and from two city forests – Kabaty (soil pH 3.2–4.9) and Natolin (pH 3.2–4.9). Mixed samples were taken in triplicate during various phenologic seasons with the soil cane to the depth of 20 cm.

Fungi were isolated from soil samples with the method of Zimmermann (1986) [9] using trap insects. Caterpillars of *G. mellonella* from the own culture of the Department of Zoology WULS were the trap animals. Experiments were carried out at 25 ^{o}C for 25 days for each soil sample. First control was performed 5 days after set up of the experiment and then the samples were controlled every 2–3 days. Dead insects were removed from samples and replaced by live ones. Dead insects were transferred to Petri dishes to estimate the cause of their death and to complete the growth of mycelium on the skin surface. The obtained results were statistically processed with the Statgraphics Plus 4.1 programme.

Results and discussion

Three species of entomopathogenic fungi (*Peacilomyces fumosoroseus, Bauveria bassiana, Metharizium anisopliae*) were isolated from soils of the greens in the Ursynow district of Warsaw. The studied sites did not differ significantly in species composition of entomopathogenic fungi. *P. fumosoroseus* was the dominating species in analysed soil samples. Depending on site it infected from 45 % to 73 % of insects. The second frequent species was *B. bassiana* which infected 25 % to 39 % of insects. *M. anisopliae* was isolated sporadically and only in spring (Table 1).

Apart from typical infections caused by entomopathogenic fungi the trap insects were also infected by saprophages and by entomopathogenic nematodes (Table 1). In samples collected in spring the trap insects were infected by nematodes more than by fungi in other seasons.

Changes in the density of particular species of isolated fungi were related to a phenologic season (Table 2). Season exerted a significant effect on *M. anisopliae*. This fungus was most numerous in early spring; only few mycelia were noted in summer. The species was not found in soils from forest areas.

Table 1

The occurrence of entomopathogenic fungi in the greens of the Ursynow district of Warsaw

		SGGW – Ursynow Escarp	Park of Culture in Powsin	Roman Kozłowski's Park	Forest Natolin	Forest Kabaty
Entomopathogenic fungi	*B. bassiana*	5.3*	6	7.7	8.3	6.7
	P. fumosoroseus	15.3	8.7	11	13	16.3
	M. anisopliae	0.3	4.7*	2.7*	0	0
Saprofic fungi		0.7	0.7	2	0	0.3
Entomopathogenic Nematode		4.7	7	5	7.3	5
Other biotic factor		3.7	3	1.7	1.3	1.7

* $p > 0.05$ denotes a statistically significant difference.

Table 2

The effect of season on isolated species of entomopathogenic fungi

Season	*B. bassiana*	*P. fumosoroseus*	*M. anisopliae*	Saprofic fungi
Spring	4.7	21.7*	4.3	0.7
Summer	4.0	25.3*	3.3	1.7
Autumn	25.3*	17.3	0	1.3

* $p < 0.001$ denotes a statistically significant difference.

P. fumosoroseus dominated in studied ecosystems in spring and summer. In spring it was found in 71 % of trap insects. In summer it infected 78 % of insects. In autumn the dominant species was *B. bassiana* which infected 59 % of isolated trap insects.

The obtained results confirm observations made by other authors on the common occurrence of the three species of fungi in various ecosystems [4, 9, 10]. They found another species – *P. farinosus* – which was not present in the soils analysed within this study. Studies carried out by other authors [11, 12] in Poland indicate that entomopathogenic fungi are most frequent in forest ecosystems which have naturally richer flora and fauna. This finding was confirmed in this study since most entomopathogenic fungi were isolated from soils collected in Kabaty Forest.

Common occurrence of the three species of entomopathogenic fungi was confirmed by other authors [4], They demonstrated that *P. fumosoroseus* was the dominating species in contrast to other European countries where it occurs less frequently [13].

The Ursynow district, despite strong human impact, is very attractive to insects because of the presence of green areas in its territory. That is why insects as potential hosts of entomopathogenic fungi are affected by mycoses there contributing thus to species diversity of pathogens [14].

Conclusions

1. Three most frequent species of entomopathogenic fungi: *P. fumosoroseus, B. bassiana* and *M. anisopliae* were isolated from soils in the city greens and forests of the Ursynow district.

2. *P. fumosoroseus* was the dominating species in studied soils and *M. anisopliae* was found rarely.
3. Season affected the occurrence of particular species of entomopathogenic fungi.

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WYSTĘPOWANIE GRZYBÓW ENTOMOPATOGENNYCH W WYBRANYCH PARKACH I LASACH MIEJSKICH WARSZAWSKIEJ GMINY URSYNÓW

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Abstrakt: W pracy przedstawiono skład oraz nasilenie występowania grzybów entomopatogennych w wybranych parkach i lasach miejskich gminy Ursynów w Warszawie. W pracy zwrócono uwagę także na różnicę w wysterowaniu w zależności od miejsca bytowania i okresu fenologicznego. Na badanych terenach wyizolowano następujące gatunki grzybów: *P. fumosoroseus, B. bassiana* oraz *M. anisopliae*. Stwierdzono, że siedlisko nie miało wpływu na występowanie grzybów entomopatogennych, natomiast wpływ miał okres fenologiczny. Dominującym gatunkiem okazał się *P. fumosoroseus* (wiosna, lato), a na jesieni dominowała *B. bassiana*.

Słowa kluczowe: grzyby entomopatogenne, gleba, sezon fenologiczny

ECOLOGICAL CHEMISTRY AND ENGINEERING A

Vol. 18, No. 11 2011

Joanna MATUSKA-ŁYŻWA[1] and Marta KAMIONEK[2]

MORPHOMETRIC CHANGES IN *Heterorhabditis megidis* (POINAR, JACKSON AND KLEIN 1987) AFTER DIFFERENT CONTACT WITH LEAD(II) IONS

ZMIANY MORFOMETRYCZNE *Heterorhabditis megidis* (POINAR, JACKSON I KLEIN 1987) PO RÓŻNYM CZASIE KONTAKTU Z JONAMI OŁOWIU(II)

Abstract: Nematodes of the families *Steinernematidae* and *Heterorhabditidae* are a natural factor controlling population density of insects and for many years have been used in biological plant protection. When using entomopathogenic nematodes as biological pest control it was found that heavy metal ions might negatively affect their pathogenic properties.

In laboratory experiments invasive larvae of *H. megidis* were kept for 24 and 120 hours in Petri dishes containing water solutions of lead nitrate(V) at a concentration of 500 ppm Pb(II). Nematodes that survived the contact with lead ions were transferred to pots with soil and test insects (*Galleria mellonella* L.). Nematodes kept in distilled water served as a control. Half of dead insects was dissected two days after their death. Individuals of the first nematode generation were isolated from dead insects and selected body dimensions (body length, body width, length of the pharynx and tail) were measured. Second half of dead insects was intended for reproduction. Larvae obtained from this reproduction were used for further tests aimed at analysing the effect of long term passaging of nematodes through the host. Five passages were made in total. The time of the contact of nematodes with lead ions was found to affect their body dimensions.

Keywords: entomopathogenic nematodes, *Heterorhabditis megidis*, *Galleria mellonella,* lead ions

Environmental pollution is not the only effect of the common use of heavy metals. Sometimes even small amounts of these metals may cause many diseases in man [1], farm animals [2] and free living animals like eg entomopathogenic nematodes [3–9]. Lead is one of the most toxic metals for living organisms. Lead ions in soil habitat

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negatively affect survival, pathogenic properties and reproduction of entomopathogenic nematodes [3–9].

This study was performed to assess the effect of the time of contact of nematodes with lead ions on selected body dimensions of the first generation of *Heterorhabditis megidis*.

Material and methods

Invasive larvae of *H. megidis* and larvae of the last growth stage of *Galleria mellonella* L. (mean body mass 163 mg) were used in experiments. Both entomopathogenic nematodes and insects were taken from the culture of the Department of Zoology, Warsaw Agricultural University.

Invasive larvae of nematodes were kept in Petri dishes for 24 h (sample B) and for 120 h (sample C) in water solutions of lead nitrate(V) at a concentration of 500 ppm Pb(II). Larvae that survived the contact with lead ions were used to infect test insects. Control (sample A) consisted of larvae kept in distilled water. Insects were infected individually: one insect larva and 500 larvae of invasive nematodes were placed in a pot filled with wet sand. Half of dead insects was dissected two days after their death. Mature individuals of the first nematode generation (hermaphroditic individuals) were isolated and measured (body length and width, length of the pharynx and tail) under light microscope. Second half of dead insects was transferred onto individual migration sponges (modified traps for collecting nematode larvae migrating from insects' bodies). So obtained invasive larvae were used to infect next test insects to check the effect of long term passaging of nematodes dealt with lead ions through the same host. Five passages were made in total. Body length and width, length of the pharynx and tail were measured in hermaphroditic individuals whose larvae were subjected to lead ions for different time period.

Experiments were carried out at 25 ^{o}C – an optimum temperature for *H. megidis* at which the species shows the greatest invasiveness [10]. UNIANOVA was used to compare obtained results.

Results and discussion

Results show that adult individuals whose larvae contacted lead ions had smaller body dimensions than those in the control sample A. A slight decrease of body size was noted during consecutive passages.

Individuals isolated from the first passage had larger body dimensions than those isolated during the next four passages. Therefore, results from the first passage were compared with the mean from the next four passages (2–5). This relationship was not observed in one sample (B) and one morphometric feature – body length of nematodes whose larvae had shorter (24 h) contact with lead ions. After the first passage they were markedly shorter (2.52 mm) than individuals which being in the larval stage had longer

(120 h) contact with lead ions (4.64 mm) and than the control individuals (4.8 mm) (Table 1).

Table 1

Body size [mm] of hermaphroditic individuals of *H. megidis*

Samples / Body size [mm]	Sample A (passage 1)	Sample A (mean of passages 2–5)	Sample B (passage1)	Sample B (mean of passages 2–5)	Sample C (passage 1)	Sample C (mean of passages 2–5)
Body length	4.80	4.75	2.52	4.59	4.64	4.51
Body width	0.26	0.25	0.21	0.20	0.23	0.22
Length of the pharynx	0.24	0.23	0.22	0.21	0.23	0.22
Tail length	0.122	0.121	0.103	0.100	0.118	0.115

In consecutive passages the differences diminished ie body size of individuals, which when being in the larval stage contacted lead ions approached those of individuals from samples A and C. Changes in the body dimensions of *H. megidis* in relation to the contact time and passage are presented in Tables 2–5.

Table 2

Body length [mm] of hermaphroditic individuals of *H. megidis*

Samples / Body length [mm]	Sample A	Sample B	Sample C
Passage 1	4.80	2.52	4.64
Passage 2	4.74	4.48	4.55
Passage 3	4.77	4.69	4.49
Passage 4	4.69	4.62	4.47
Passage 5	4.81	4.58	4.53
Mean of passages 2–5	4.75	4.59	4.51

Table 3

Body width [mm] of hermaphroditic individuals of *H. megidis*

Samples / Body width [mm]	Sample A	Sample B	Sample C
Passage 1	0.26	0.21	0.23
Passage 2	0.24	0.21	0.23
Passage 3	0.25	0.20	0.21
Passage 4	0.23	0.19	0.22
Passage 5	0.26	0.21	0.23
Mean of passages 2–5	0.25	0.20	0.22

Table 4

Length of the pharynx [mm] in hermaphroditic individuals of *H. megidis*

Samples / Length of the pharynx [mm]	Sample A	Sample B	Sample C
Passage 1	0.24	0.22	0.23
Passage 2	0.22	0.20	0.23
Passage 3	0.23	0.21	0.19
Passage 4	0.22	0.20	0.24
Passage 5	0.25	0.22	0.22
Mean of passages 2–5	0.23	0.21	0.22

Table 5

Tail length [mm] in hermaphroditic individuals of *H. megidis*

Samples / Tail length [mm]	Sample A	Sample B	Sample C
Passage 1	0.122	0.103	0.118
Passage 2	0.121	0.099	0.117
Passage 3	0.123	0.101	0.104
Passage 4	0.119	0.100	0.118
Passage 5	0.122	0.099	0.122
Mean of passages 2–5	0.121	0.100	0.115

Described above small body length of nematodes from the first generation (after the first passage) which when being in the larval stage had 24 h contact with lead ions was observed in every next experimental repetition.

One factor ANOVA performed for selected body dimensions showed significant differences between studied groups (Table 6). Highly significant differences during the first passage were noted in all body dimensions between control group and nematodes whose former larval generation was kept for 24 h in the solution of lead ions at a concentration of 500 ppm Pb(II). Multiple comparison of the first passage between the control group and the nematodes whose former generation was affected by lead ions showed significant differences in body length and highly significant differences in body width. Comparison of body size of nematodes that survived short contact with lead ions with those that contacted these ions for a longer period revealed no significant differences in the length of pharynx. Other body dimensions between these two groups were highly significant.

Obtained results indicate that body length of hermaphroditic individuals of *H. megidis* was more influenced by shorter (24 h) than longer (120 h) contact period of invasive larvae of the previous generation with lead ions. It seems that the longer contact with lead ions eliminated biologically weaker nematodes from experiment. It was also found that the time of contact with lead ions did not affect internal morphometric feature – length of the pharynx – in studied nematodes.

Table 6

ANOVA for selected body dimensions in nematodes

Body dimensions	Groups	SS	df	MS	F	p
Body length	Between groups	64.827	5	12.965	246.464	.000
	Within groups	11.521	219	.053		
	Total	76.348	224			
Body width	Between groups	.072	5	.014	35.747	.000
	Within groups	.089	219	.000		
	Total	.161	224			
Length of the pharynx	Between groups	.020	5	.004	9.244	.000
	Within groups	.093	219	.000		
	Total	.113	224			
Tail length	Between groups	.018	5	.004	51.449	.000
	Within groups	.015	219	.000		
	Total	.033	224			

The effect of lead ions on nematodes was the topic of many papers. Unfavourable effect of lead(II) ions on the pathogenic properties of entomopathogenic nematodes was demonstrated eg by Jarmuł and Kamionek and by Jaworska et al [5, 6, 8].

When studying biological activity of entomopathogenic nematodes in soil one should pay attention to other factors that might limit or change their population. In urban areas species composition of micro- and mesofauna may vary largely thus affecting animal biodiversity. Environmental contamination by heavy metals might be one of the causative factors in such cases.

Conclusion

Performed studies allow for the conclusion that time of the contact of nematode invasive larvae with lead(II) ions affects morphometric features of the first generation of adult individuals of *H. megidis*. Repetitive passage of nematodes results also in small morphometric changes.

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ZMIANY MORFOMETRYCZNE *Heterorhabditis megidis* (POINAR, JACKSON I KLEIN 1987) PO RÓŻNYM CZASIE KONTAKTU Z JONAMI OŁOWIU(II)

Zakład Zoologii, Instytut Biologii, Wydział Matematyczno-Przyrodniczy
Uniwersytet Jana Kochanowskiego w Kielcach

Abstrakt: Nicienie z rodziny *Steinernematidae* i *Heterorhabditidae* stanowią naturalny czynnik redukujący liczebność populacji owadów i od wielu lat są wykorzystywane w biologicznej ochronie roślin. W momencie wykorzystania nicieni entomopatogennych jako biologicznego środka w zwalczaniu szkodników upraw, stwierdzono, że jony metali ciężkich mogą w znacznym stopniu niekorzystnie wpłynąć na patogenność nicieni owadobójczych.

W doświadczeniach larwy inwazyjne *H. megidis* przetrzymywano przez 24 godziny i 120 godzin w roztworach wodnych azotanu(V) ołowiu o stężeniu 500 ppm Pb(II) w szalkach Petriego. Nicienie, które przeżyły kontakt z jonami ołowiu, wprowadzano do pojemników z glebą, w których znajdowały się owady testowe (*Galleria mellonella* L.). Kontrolę stanowiły nicienie przetrzymywane w wodzie destylowanej. Połowę martwych owadów poddawano sekcji po dwóch dniach od ich śmierci. Izolowano z nich osobniki pierwszego pokolenia nicieni i oznaczano ich wybrane wymiary ciała (długość ciała, szerokość ciała, długość gardzieli i długość ogona). Drugą połowę martwych owadów przeznaczano na reprodukcję. Otrzymane z reprodukcji larwy wykorzystano do dalszych testów mających na celu analizę wpływu długotrwałego pasażowania nicieni przez jednego żywiciela. Wykonano 5 pasaży. Zaobserwowano, że czas kontaktu nicieni z jonami ołowiu(II) wpływa na wymiary ciała.

Słowa kluczowe: nicienie entomopatogenne, *Heterorhabditis megidis*, *Galleria mellonella*, jony ołowiu

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[3] Bruns I., Sutter K., Neumann D. and Krauss G.-J.: *Glutathione accumulation – a specific response of mosses to heavy metal stress*, [in:] Sulfur Nutrition and Sulfur Assimilation in Higher Plants, P. Haupt (ed.), Bern, Switzerland 2000, 389–391.

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