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CONTENT OF COMPONENTS IN SOME GRASS SPECIES IRRIGATED WITH PURIFIED SEWAGE

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Abstract

Soil is a unique laboratory of transformations and energy flow, and in particular of biological sorption and synthesis of mineral components that can originate from various sources. The introduction of biomass or sewage into soil contributes to its nutrient enrichment. This can lead to periodical excess of these elements in soil and cause their migration from the soil system to underground waters, and eventually to open waters. Grass communities belong to a group of plants that make excellent use of nutrients present in soil and perform a very important role in additional purification of sewage after its mechanical purification. Grasses demonstrate resistance to the presence of large quantities of harmful compounds in sewage; they accumulate and neutralise them physiologically, thus preventing their dissemination.

The aim of this paper was to evaluate content of some macro- and microelements as well as heavy metals in chosen grass species irrigated with purified sewage. In 1997-2000, research was conducted near the Hajdów Sewage Works, using purified sewage for irrigation of grass communities. Three rates of irrigation (a – control without irrigation; b – irrigation in quantity 600 mm and c – irrigation in quantity 1200 mm) as well as two grass mixtures were tested. Content of basic macroelements (N, P, K, Ca, Mg), microelements (Cu, Zn, Mn) as well as heavy metals (Cd, Pb) in dominant grass species (*Alopecurus pratensis*, *Phalaris arundinacea*, *Festuca arundinacea*, *Festuca pratensis* and *Phleum pratense*) were determined. The content of the analyzed components in biomass was varied and depended on the grass species in the analyzing mixtures as well as on the applied rates of irrigation. *Festuca pratensis* and *Festuca arundinacea* were characterized by the largest capacity to take up calcium (Ca) and magnesium (Mg), *Phalaris arundinacea* – phosphorus (P) and zinc (Zn), while *Alopecurus pratensis* – cadmium (Cd) and lead (Pb). Biomass of *Alopecurus pratensis* was characterized by the lowest content of most of the ele-

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ments, especially nitrogen, phosphorus, calcium and magnesium. The applied irrigation, especially the 1200 mm rate significantly increased potassium content and decreased manganese content in biomass of the analyzed grass species. The most useful grass species used to establish meadows irrigated with sewage are *Phalaris arundinacea*, *Festuca arundinacea* and *Festuca pratensis*.

Keywords: macro- and microelements, heavy metals, irrigation, purified sewage.

ZAWARTOŚĆ SKŁADNIKÓW W WYBRANYCH GATUNKACH TRAW NAWADNIANYCH ŚCIEKAMI OCZYSZCZONYMI

Abstrakt

Gleba jest specyficznym laboratorium przemian i przepływu energii, zwłaszcza biologicznej sorpcji i syntezy składników mineralnych, które mogą pochodzić z różnych źródeł. Wprowadzenie do gleby biomasy lub ścieków powoduje jej wzbogacenie w składniki pokarmowe. Może to być przyczyną okresowego nadmiaru tych pierwiastków w glebie i powodować ich przemieszczanie poza układ glebowy – do wód gruntowych, a w końcowym etapie do wód otwartych. Do grupy roślin doskonale wykorzystujących składniki pokarmowe z gleby oraz spełniających ważną rolę w doczyszczaniu ścieków po mechanicznym ich oczyszczeniu należą zbiorowiska trawiaste. Trawy wykazują odporność na obecność w ściekach dużych ilości związków szkodliwych, kumulują je i neutralizują na drodze fizjologicznej, zapobiegając ich rozprzestrzenianiu.

Celem badań była ocena zawartości niektórych makro- i mikroskładników oraz metali ciężkich w wybranych gatunkach traw nawadnianych ściekami oczyszczonymi. W latach 1997-2000 prowadzono badania z wykorzystaniem wód pościekowych (ścieków po mechaniczno-biologicznym oczyszczeniu) z oczyszczalni ścieków miasta Lublina do nawadniania zbiorowisk trawiastych. W badaniach uwzględniono 3 dawki nawodnień (a – kontrola bez nawadniania; b – nawodnienie w ilości 600 mm, c – nawodnienie w ilości 1200 mm) oraz dwie mieszanki trawiaste. Dominujące gatunki w runi (*Alopecurus pratensis*, *Phalaris arundinacea*, *Festuca arundinacea*, *Festuca pratensis* i *Phleum pratense*) poddano analizom chemicznym na zawartość podstawowych makroelementów (N, P, K, Ca, Mg), mikroelementów (Cu, Zn, Mn) oraz metali ciężkich (Cd, Pb). Zawartość makro- i mikroelementów oraz metali ciężkich w biomasie była zróżnicowana w zależności od gatunków w analizowanych mieszankach oraz stosowanych nawodnień. Największą zdolność do pobierania wapnia i magnezu miały *Festuca pratensis* i *Festuca arundinacea*, fosforu i cynku – *Phalaris arundinacea*, a kadmu i ołowiu – *Alopecurus pratensis*. Najniższą zawartość większości oznaczonych pierwiastków, zwłaszcza azotu, fosforu, wapnia i magnezu, stwierdzono w biomasie *Alopecurus pratensis*. Stosowane nawadniania, głównie dawka 1200 mm, wpłynęły istotnie na wzrost zawartości potasu oraz obniżenie zawartości manganu w biomasie analizowanych gatunków. Gatunkami najbardziej przydatnymi do mieszanek łąkowych nawadnianych ściekami oczyszczonymi są *Phalaris arundinacea*, *Festuca arundinacea* i *Festuca pratensis*.

Słowa kluczowe: makro- i mikroelementy, metale ciężkie, nawadnianie, ścieki oczyszczone.

INTRODUCTION

Soil is a specific laboratory of mineral components, which comes from different sources, including sewage. Introduction of biomass or sewage into soil causes its enrichment in nutrients. This may be the cause of periodic excess of these elements in soil and cause their migration outside the soil system – to groundwater and eventually to open waters (BARYŁA 2005, KLASA et al. 2007). Therefore, it may be necessary to grow plants of high production potential combined with high demand for water and nutrients. Grass communities belong to a group of plants that make excellent use of nutrients present in soil and perform a very important role in additional purification of sewage following its mechanical purification. Grasses demonstrate resistance to the presence of large quantities of harmful compounds in sewage; they accumulate and neutralise them physiologically, thus preventing their dissemination. The most frequent grasses in plant communities irrigated with sewage are species from humid (*Phalaris arundinacea, Alopecurus pratensis*) and moderately humid habitats (*Phleum pratense Festuca pratensis, Festuca arundinacea, Poa pratensis*). Grass species sown on land irrigated with sewage should be selected in terms of their habitat requirements and the ability to use of nutrients.

The aim of this paper has been to evaluate content of some macro- and microelements as well as heavy metals in several grass species irrigated with purified sewage.

MATERIAL AND METHODS

In 1997-2000, a study was conducted in the Bystrzyca River valley, near the Hajdów Sewage Works, in which purified sewage from Lublin was used to irrigate grass communities. The study included three rates of irrigation (a – control without irrigation; b – irrigation with 600 mm and c – irrigation with 1200 mm) as well as two grass mixtures, which were sown in summer 1996. The experiment was carried out on mineral-muck soil of neutral reaction (pH 7.1-7.2) and low content of macronutrients. Water used for irrigation was characterized by the following content of components: N – 35.5, P – 7.44; K – 30.0; Ca – 77.5; Mg – 14,0; Na – 48.3 $g \cdot m^{-3}$ and Cd – 7.23; Pb – 19,8; Cu – 21,6; Zn – 118.0 $mg \cdot m^{-3}$. Meadow sward was mowed 3 times during the growing season. Species composition of the grass mixtures, especially in the irrigated area, changed systematically. However, *Alopecurus pratensis*, *Phalaris arundinacea* and *Festuca arundinacea* were dominant species in the sward of mixture A, whereas *Alopecurus pratensis*, *Festuca pratensis* and *Phleum pratense* prevailed in mixture B (BARYŁA 2005). The content of basic macroelements (N, P, K, Ca, Mg), microelements (Cu, Zn, Mn) as well as heavy metals (Cd, Pb) in the dominant species was determined. Chemical analysis of plant material performed in an accredited laboratory of the District Chemistry-Agriculture Station in Lublin, according to the Poland Norm or standard procedure. The results were put to statistical analysis of variance with Tukey's test.

RESULTS AND DISCUSSION

The analyzed species of grasses were characterized by diverse content of the elements. The actual amounts of the elements determined in grasses were shaped by the biological properties of particular species, irrigation rates as well as species composition of sown grass mixtures.

Macroelements. The analyzed grass species considerably differed in their ability to accumulate most of the marked macroelements in the particular mixtures (Figure 1). *Alopecurus pratensis* had the smallest ability to take up components from soil, especially in communities with *Festuca arundinacea* and *Phalaris arundinacea*, which have a very strongly developed radicular system. In communities with these species, *A. pratensis* showed the significantly lowest content of macronutrients, with the exception of potassium. FALKOWSKI et al. (1991) report that the biomass of *A. pratensis* was characterized by low magnesium content. Moreover, these authors classify these species as nitrophilous grasses, an observation which is not confirmed by the present study. By contrast, in communities with *Festuca pratensis* and *Phleum pratense*, these species were only characterized by the significantly lowest content of calcium and significantly lower content of magnesium in relation to *F. pratensis*. It should be added that the significantly highest content of calcium and magnesium was found in the species of *Festuca* genus and that of phosphorus –in the biomass of *Phalaris arundinacea*. These results coincide with the data reported by WALCZYNA et al. (1975) and Falkowski et al. (1991), who classify *F. pratensis* and *F. arundinacea* as belonging to grasses with a high capacity for calcium accumulation. According to KOCHANOWSKA (1981), *Phleum pratense* is characterized by low magnesium content, which is confirmed by the present study. Biomass of *P. pratense* is also characterized by a low potassium content (WALCZYNA et al. 1975, BARYŁA 1992), which is not verified by the research does not conducted by FALKOWSKI et al. (1991).

The irrigation applied in our study also contributed to variations in the content of particular elements. Introduction of large quantities of macroelements with sewage waters to the soil environment resulted in increase or reduction of these ingredients in the biomass of the analyzed species. The irrigation caused a significant increase of potassium in all the grass species,

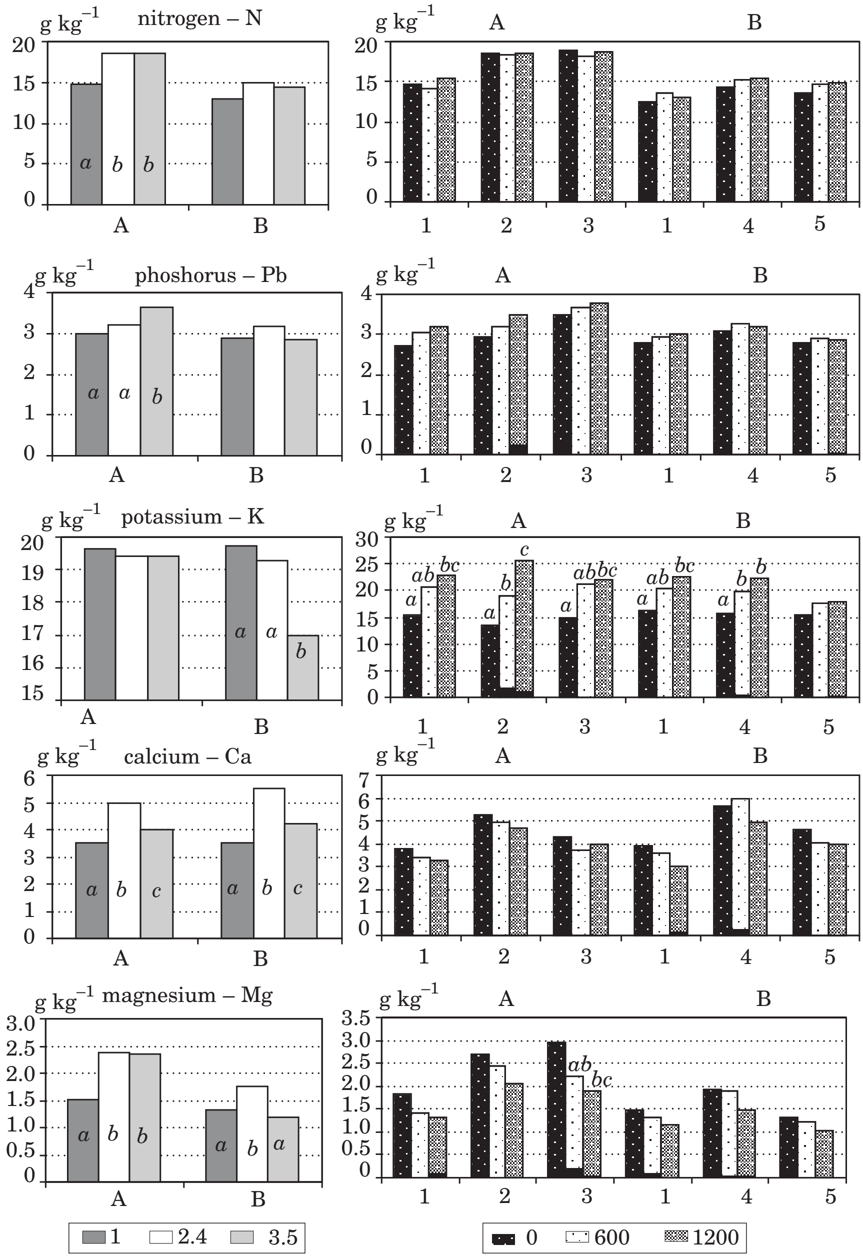

Fig. 1. Mean content of macroelements in some grass species depending on irrigation rate (mean of 4 years): A – mixture: 1 – *Alopecurus pratensis*, 2 – *Festuca arundinacea,* 3 – *Phalaris arundinacea*, B – mixture: 1 – *Alopecurus pratensis*, 4 – *Festuca pratensis*, 5 – *Phleum pratense*, irrigation rates: 0, 600 mm, 1200 mm

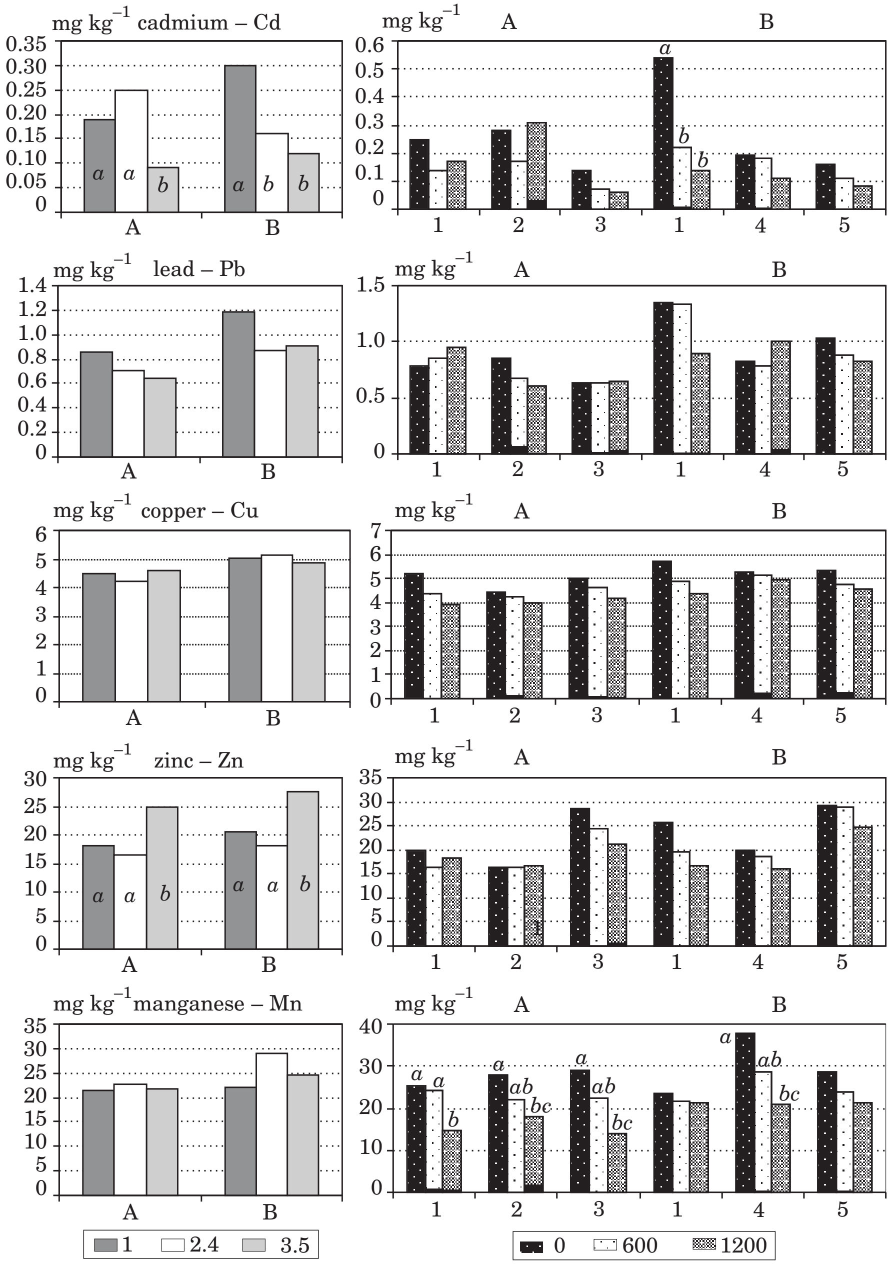

Fig. 2. Mean content of heavy metals and microelements in some grass species depending on irrigation rate (mean of 4 years). Explanations like in Fig. 1

with the exception of *Phleum pratense*. Similar correlation was observed for the content of nitrogen and phosphorus, but it was not statistically proven. In contrast, the irrigation resulted in a decrease of calcium and magnesium in the tested species, but significant differences were recorded only in the content of magnesium in the *Phalaris arundinacea* biomass. The higher irrigation rate (1200 mm) caused a significantly lower Mg content in the biomass of this species in relation to the control object (Figure 1).

Heavy metals and microelements. The biomass of the analyzed grass species was characterized by less diversity in the content of heavy metals and microelements. A relatively high content of heavy metals (cadmium and lead) was determined in *Alopecurus pratensis*. This species in the communities with *Festuca pratensis* and *Phleum pratense* had the significantly highest concentration of Cd. This is in accord with the results reported by BARYŁA and HARKOT (1997). However, our attention turned to the significantly lowest content of cadmium in *Phalaris arundinacea, F. pratensis* and *P. pratense* (Figure 2). The irrigation generally decreased the content of heavy metals in the biomass of the analyzed species, but it was only in the case of *A. pratensis* biomass in mixture B that the differences were proven statistically. According to STĘPNIEWSKA et al. (2001) irrigation with sewage waters leads to a lower concentration of heavy metals in the biomass and radicular system of grasses due to higher yields obtained under such conditions.

The content of microelements in the tested species was less variable, with the differences being statistically significant only for the content of zinc. The biomass of *Phalaris arundinacea* in mixture of A and *Phleum pratense* in mixture of B was characterized by the significantly highest content of this element (Figure 2). In a study by WALCZYNA et al. (1975), no significant modifications in the content of zinc were observed. However, the irrigation applied in our study generally decreased the content of microelements in the biomass of the analyzed species, although statistically proven modifications concerned only the content of manganese. The biomass of the analyzed grass species (with the exception of *Alopecurus pratensis* and *Phleum pratense* in mixture B) contained significantly less Mn, versus the control, when grasses were irrigated with the higher rate of sewage (1.200 mm) – Figure 2. In contrast, differences in the content of copper and zinc in the biomass of the grass species as correlated with the irrigation rates were within the limits of statistical error.

CONCLUSIONS

1. The content of macro- and microelements as well as heavy metals in the biomass was varied depending on the species and applied irrigation.

2. *Festuca pratensis* and *Festuca arundinacea* were characterized by the highest calcium and magnesium content, *Phalaris arundinacea* – by the highest phosphorus and zinc content, whereas *Alopecurus pratensis* – by the highest cadmium and lead content.

3. Biomass of *Alopecurus pratensis* had the lowest content of most of the analyzed elements, especially nitrogen, phosphorus, calcium and magnesium.

4. Adequate irrigation, mainly 1.200 mm, had a significant influence on the increase of potassium and decrease of manganese in the biomass of the tested grass species. It also caused decreased magnesium content in *Phalaris arundinacea* and cadmium content in *Alopecurus pratensis*.

5. *Phalaris arundinacea, Festuca arundinacea* and *Festuca pratensis* proved to be the most useful species in meadow mixtures sown on land irrigated with purified sewage.

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COPPER, ZINC, IRON AND MANGANESE CONTENT IN EDIBLE PARTS OF SOME FRESH VEGETABLES SOLD ON MARKETS IN POZNAŃ

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Abstract

Copper, zinc, iron and manganese contents were determined in edible parts of some fresh vegetables sold on markets in Poznań. The copper and zinc contents in vegetables obtained in the present study were compared to the ones reported from an analogous study carried out in the Department of Horticultural Plant Fertilization in Poznań fifteen years ago. Samples of vegetables were collected from six points distributed in the area of Poznań from March to July at monthly intervals. For the study, vegetables were divided into three groups according to edible parts: leaves (lettuce, cabbage, parsley, leek), roots (carrot, celeriac, parsley) and fruits (tomato, cucumber). The concentration of copper, zinc, iron and manganese was determined by the atomic flame absorption method using an AAS 3 Zeiss apparatus. The highest content of copper was found in roots of celeriac, while the smallest content was shown in cabbage leaves. The highest mean content of zinc was found in lettuce leaves and the lowest one in tomato fruit. The mean content of copper in all the vegetable species was lower in 2005 than in 1993. In 1993 more zinc was found in vegetables whose edible parts were fruits compared to the results of 2005. The vegetables whose leaves and roots are eaten were characterized by a higher zinc content in 2005. The highest content of iron was found in leaves of leek, while the lowest amounts were determined in tomato and cucumber fruits. The highest mean content of manganese was found in leaves of lettuce, while the smallest amount was in carrot roots. The iron content in the vegetables whose leaves and fruits are edible parts was lower in 2005 than in 1993, while the root vegetables were characterized by more iron in 2005. Higher content of manganese in all the vegetable species examined was found in 1993 than in 2005.

Key words: copper, zinc, iron, manganese, heavy metals, fresh market, vegetables.

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ZAWARTOŚĆ MIEDZI, CYNKU, ŻELAZA I MANGANU W CZĘŚCIACH JADALNYCH WARZYW SPRZEDAWANYCH NA RYNKACH MIASTA POZNANIA

Abstrakt

W częściach jadalnych warzyw sprzedawanych na terenie miasta Poznania oznaczono zawartość miedzi, cynku, żelaza, manganu oraz porównano te zawartości z zawartościami w warzywach, które uzyskano w analogicznych badaniach przeprowadzonych w Katedrze Nawożenia Roślin Ogrodniczych w Poznaniu 15 lat temu. Próby warzyw pobierano w okresie od marca do lipca, w odstępach miesięcznych, z 6 punktów rozmieszczonych na terenie miasta Poznania. Do badań wybrano warzywa, których częścią jadalną są liście (sałata, kapusta, pietruszka, por); korzenie (marchew, seler, pietruszka) i owoce (pomidor, ogórek). Stężenie miedzi, cynku, żelaza i manganu określono metodą płomieniowej absorpcji atomowej z użyciem aparatu Zeiss AAS 3. Największą zawartość miedzi stwierdzono w korzeniach selera, natomiast najmniejszą w liściach kapusty. Największą średnią zawartość cynku stwierdzono w liściach sałaty, natomiast najmniejszą w owocach pomidora. Średnia zawartość miedzi w badanych gatunkach warzyw była niższa w 2005 r. w porównaniu z zawartością w 1993 r. Większą zawartość cynku w 1993 r. stwierdzono w warzywach, których częścią jadalną są owoce, w stosunku do warzyw badanych w 2005 r. Warzywa, których częścią jadalną są liście i korzenie, zawierały więcej cynku w 2005 r. Największą zawartość żelaza stwierdzono w liściach pora, natomiast najmniejszą w owocach pomidora i ogórka. Największą średnią zawartość manganu stwierdzono w liściach sałaty, natomiast najmniejszą w korzeniach marchwi. Zawartość żelaza w warzywach, których częścią jadalną są liście i owoce, była niższa w 2005 r. w porównaniu z zawartością w 1993 r., natomiast warzywa korzeniowe zawierały więcej Fe w 2005 r. Większą zawartość manganu w badanych gatunkach warzyw stwierdzono w 1993 r. w porównaniu z zawartością tego pierwiastka w 2005 r.

Słowa kluczowe: miedź, cynk, żelazo, mangan, metale ciężkie, warzywa.

INTRODUCTION

There is a scarcity of papers discussing the problem of copper and zinc content in edible parts of vegetable plants. Copper and zinc are micronutrients necessary for proper plant development. In appropriate amounts, they are essential for plants, but their excessive quantities may cause some disturbances in development of plants and result in their depressed quality. Vegetables are an important source of micronutrients for humans and animals. In some regions of Poland, vegetables can be contaminated with these metals, but most vegetables are characterized by small amounts of copper and zinc. Many researchers undertake trials to assess the content of heavy metals in edible parts of vegetables. Iron deficit in humans and animals is a very urgent global problem. It is estimated that iron deficit affects about 65% of people, particularly in African and Asiatic countries (Brown 2004). Vegetables are a source of microelements in the human diet. They are also fed, fresh or processed, to animals (Grzyś 2004). Production of vegetables which are of suitable quality and consumption value is highly important for people and animals.

The objectives of the present study, carried out in the Department of Horticultural Plant Fertilization of the Poznań University of Life Sciences, were to:

– determine copper, zinc, iron and manganese content in edible parts of vegetables frequently consumed by residents of Poznań;
– compare the current copper, zinc, iron and manganese content in vegetables with results obtained in an analogous study carried out in the Department of Horticultural Plant Fertilization in Poznań fifteen years ago.

MATERIAL AND METHODS

Samples of fresh market vegetables were taken from six points distributed in Poznań, from March to July 2005 at monthly intervals. For the purpose of this study, vegetables were divided into three groups according to edible parts: *leaves* (lettuce, cabbage, parsley, leek – 120 samples), *roots* (carrot, celery, parsley – 90 samples) and *fruits* (tomato, cucumber – 60 samples). In total, 270 samples were taken from nine vegetable species. The material for studies was prepared in the same way as it is done for consumption, i.e., it was washed under running water and cleaned. Washed vegetables were fragmented and dried in an exhaust drier at 55°C. The dried material was ground in a laboratory mill. From each sample, 2.5 g of dry plant matter was weighed out and mineralised in a muffle furnace at 450°C. After complete mineralization, combusted samples were solved in 10% HCl and transferred to flasks of 50 cm^3 capacity. The concentration of copper, zinc, iron and manganese was determined by the atomic flame absorption method using an AAS 3 Zeiss apparatus.

The statistical processing of the results included analysis of variance for copper, zinc, iron and manganese content in edible parts of the vegetable species examined. Statistical analyses were carried out using Statobl programme, a univariate analysis of variance for factorial orthogonal experiments. Differences between mean values were determined at the significance level of $\alpha = 0.05$

RESULTS AND DISCUSSION

The content of copper in edible parts of the vegetables studied in 2005 ranged from 0.6 $mg \cdot kg^{-1}$ d.m. in cabbage up to 9.2 $mg \cdot kg^{-1}$ in lettuce (Table 1). While analyzing the mean content of copper in the particular vegetables, the highest amount of this metal was found in leek, while cabbage was characterized by the lowest Cu content. In a study carried out by TYKSIŃSKI

Table 1

Extreme values and average contents of copper (mg · kg^{-1} d.m.) in edible parts of vegetables

Species	1993*		2005	
	extreme values	mean	extreme values	mean
Vegetables whose edible parts are leaves				
Lettuce	3.2 - 8.2	5.3	2.0 - 9.2	4.6
Cabbage	1.0 - 3.7	2.7	0.6 - 4.3	2.1
Parsley (top leaves)	3.6 - 7.4	5.2	1.3 - 7.0	4.2
Leek	1.0 - 3.2	2.4	1.2 - 8.7	4.0
Vegetables whose edible parts are roots				
Carrot	2.3 - 6.8	4.2	1.5 - 6.4	4.2
Celeriac	2.1 - 8.3	4.8	2.1 - 8.9	5.4
Parsley	4.7 - 7.6	6.4	1.4 - 6.4	3.6
Vegetables whose edible parts are fruits				
Tomato	1.5 - 5.2	3.5	1.2 - 7.6	3.5
Cucumber	3.9 - 6.3	5.3	1.0 - 4.7	2.6
			$LSD_{0.05}$ = 0.7	

*Tyksiński et al. (1993)

et al. (1993), Cu content ranged from 1.0 mg·kg^{-1} d.m. in cabbage and in leak leaves to 8.3 mg·kg^{-1} d.m. in roots of celery (Table 1). These authors found the highest copper content in parsley roots, where it was 43.7% higher than the Cu content in this vegetable in 2005. On the other hand, the smallest copper content was found in leek, where it was 66.6% smaller than 2005. Small amounts of copper in vegetables are caused by rapid depletion of this metal from the soil (Czuba, Muszyńki 1993) and by lack of routine fertilization with microelements (Sienkiewicz-Cholewa, Wróbel 2004). As reported by Czuba (1996), in whole Poland there are as many as 39% of soils with a low content of copper available to plants

In our study, the content of zinc ranged from 4.9 mg·kg^{-1} d.m. in tomato to 118.8 m g·kg^{-1} d.m. in lettuce (Table 2). A study by Gambuś and Wieczorek (1995) also showed the highest amount of Zn in lettuce. The highest mean content of zinc was found in lettuce leaves, while the lowest content was found in tomato fruits. In the vegetables studied by Tyksiński et al. (1993), zinc content ranged from 10.3 mg·kg^{-1} d.m. in carrot roots to 104.6 mg·kg^{-1} in tomato fruits (Table 2). The same authors found the highest amount of zinc in tomato fruits, where it was 245.3% higher than the Zn content in tomato fruits in 2005. Tyksiński et al. (1993) found the smallest amount of zinc in carrot roots, where it was 14.4% smaller in comparison with the content found in 2005. Such significant differentiation of zinc content in edible parts of vegetables is connected with specific characteristic features (Room-Sinhk Sharama, Singh 1994), which strongly affect accumula-

Table 2

Extreme values and average contents of zinc (mg· kg^{-1} d.m.) in edible parts of vegetables

Species	1993*		2005	
	extreme values	mean	extreme values	mean
Vegetables whose edible parts are leaves				
Lettuce	36.2 - 67.7	50.7	17.7 - 118.8	65.1
Cabbage	17.2 - 47.1	30.9	9.4 - 48.9	23.8
Parsley (top leaves)	18.4 - 74.4	40.4	13.8 - 52.7	31.6
Leek	16.8 - 23.9	19.7	9.5 - 38.4	26.1
Vegetables whose edible parts are roots				
Carrot	10.3 - 26.0	19.5	13.8 - 33.5	22.3
Celeriac	24.2 - 34.5	29.1	12.9 - 64.6	32.2
Parsley	16.2 - 28.3	21.5	11.4 - 44.8	21.8
Vegetables whose edible parts are fruits				
Tomato	11.7 - 104.6	51.8	4.9 - 31.9	15.0
Cucumber	25.1 - 32.7	28.7	14.6 - 58.9	28.0
			$LSD_{0.05}$ = 6.8	

*Tyksiński et al. (1993)

tion of Zn in yields of consumable plants (Hryńczuk et al. 1996). Deficit of zinc is the most important deficiency of micronutrients, limiting the world production of food (Takkar, Walker 1993).At present, adhering to admissible contents of copper and zinc in vegetables is no longer obligatory. In spite of that, determination of such metals as copper and zinc in edible parts of vegetables is necessary for constant monitoring of vegetable food products. Bosiacki and Golcz (2004) undertook investigations aimed at determination of the content of zinc and copper in vegetables grown in production farms in Środa Wielkopolska. The authors did not find any cases of excessive copper content in edible parts of plants, but excessive amounts of zinc were detected in two vegetable species: red cabbage and red beet.

The comparison of our results with the results obtained in an analogous study by Tyksiński et al. in 1993, both carried out in the area of Poznań, revealed that the mean content of copper in the vegetable species examined was lower in 2005 than in 1993 (Table 3).

The analysis of changes in the copper content in edible parts of the particular species showed that in 2005 only two vegetables, leek and parsley, contained more copper in edible parts than in 1993 (Table 1). In carrot roots and tomato fruits, the mean copper content remained unchanged between the two years, and in the other vegetable species more copper was determined in 1993.

In 1993, higher zinc content versus the determinations of 2005 was found in vegetables whose edible parts are fruits. Vegetables with edible

Table 3

The comparison of average contents the copper and zinc (mg· kg^{-1} d.m.) in individual groups of vegetables in 1993 and 2005

Group of vegetables	Cu		Zn	
	1993*	2005	1993*	2005
Vegetables whose edible part are leaves	3.9	3.7	35.4	36.7
Vegetables whose edible part are roots	5.1	4.4	23.4	25.5
Vegetables whose edible part are fruits	4.4	3.4	40.3	21.4
Mean	4.5	3.8	33.0	27.9

*Tyksiński et al. (1993)

leaves and roots were characterized by higher zinc content in 2005. The mean Zn content in all the analyzed vegetables was 29.2 mg·kg^{-1} d.m. More zinc content in edible parts of vegetables (33.0 mg·kg^{-1} d.m.) was found by Tyksiński et al. in 1993. The analysis of changes in the zinc content in edible parts of the particular species revealed an increase of this element in 2005, in lettuce and leek leaves as well as in carrot, celeriac and parsley roots, as compared with the results of 1993 (Table 2). The remaining vegetable species were characterized by higher Zn concentrations in 1993.

The iron content determined in edible parts of the vegetables ranged from 14.8 mg·kg^{-1} d.m. in cucumber fruits to 228.5 mg·kg^{-1} d.m. in leek. Analyzing the mean content of this metal in edible parts of the particular vegetables, we found out that the highest amount of iron occurred in leek. On the other hand, tomato fruits were characterized by the smallest amount of iron. Smaller amounts of Fe were reported by Golcz and Dłubak (1998). Tyksiński et al., who studied vegetables in 1993, found that the Fe content ranged from 14.4 mg·kg^{-1} d.m. in roots of celeriac to 326.9 mg·kg^{-1} d.m. in parsley leaves (Table 4). These authors found that the highest mean content of iron was in lettuce leaves, where it was 120.4% higher than the iron content in lettuce determined in 2005. The lowest amount of Fe found by Tyksiński et al. (1993) appeared in celery, where it was 126.9% lower than the quantity found in 2005. The lowest content of manganese in lettuce leaves was 2.5 mg·kg^{-1} d.m. (Table 5). The highest mean content of manganese was found in lettuce leaves, while the smallest amount was in carrot roots. In the 1993 study, the content of manganese ranged from 4.4 mg·kg^{-1} d.m. in carrot roots to 45.2 mg·kg^{-1} d.m. in cabbage leaves (Table 5). In 1993, the highest mean content of manganese was found in lettuce leaves, where it was 13.5% smaller than the manganese content in lettuce leaves analyzed in 2005. The smallest mean amount of Mn in 1993 was found in carrot roots, where it was 96.1% higher than the content determined in carrot roots in 2005. At present, adhering to the admissible iron and manga-

Table 4

Extreme values and average contents of iron ($mg \cdot kg^{-1}$ d.m.) in edible parts of vegetables

Species	1993*		2005	
	extreme values	mean	extreme values	mean
Vegetables whose edible parts are leaves				
Lettuce	132.3 - 301.7	197.5	34.5 - 205.2	89.6
Cabbage	24.1 - 93.0	37.7	16.2 - 132.0	57.0
Parsley (top leaves)	99.9 - 326.9	191.2	28.0 - 191.1	87.8
Leek	52.8 - 89.0	76.5	17.0 - 228.5	98.8
Vegetables whose edible parts are roots				
Carrot	15.7 - 53.5	35.0	16.2 - 141.7	54.4
Celeriac	14.4 - 52.7	26.0	19.0 - 105.3	59.0
Parsley	40.7 - 64.4	54.7	21.1 - 224.4	59.0
Vegetables whose edible parts are fruits				
Tomato	16.1 - 132.3	49.4	12.9 - 55.4	28.0
Cucumber	26.5 - 48.1	45.7	14.8 - 58.4	31.9
			$LSD_{0.05}$ = 15.0	

*Tyksiński et al. (1993)

Table 5

Extreme values and average contents of manganese ($mg \cdot kg^{-1}$ d.m.) in edible parts of vegetables

Species	1993*		2005	
	extreme values	mean	extreme values	mean
Vegetables whose edible parts are leaves				
Lettuce	17.7 - 43.1	28.8	2.0 - 9.2	32.7
Cabbage	11.9 - 45.2	28.4	0.6 - 4.3	18.2
Parsley (top leaves)	15.3 - 35.0	24.3	1.3 - 7.0	16.7
Leek	8.9 - 26.9	17.3	1.2 - 8.7	14.1
Vegetables whose edible parts are roots				
Carrot	4.4 - 26.5	10.0	1.5 - 6.4	5.1
Celeriac	10.2 - 31.1	21.1	2.1 - 8.9	12.9
Parsley	11.3 - 40.9	24.6	1.4 - 64	9.1
Vegetables whose edible parts are fruits				
Tomato	6.5 - 21.7	10.7	1.2 - 7.6	7.1
Cucumber	10.1 - 13.7	11.5	1.0 - 4.7	11.2
			$LSD_{0.05}$ = 3.4	

*Tyksiński et al. (1993)

nese levels in vegetables is no longer obligatory. However, determination of the content of such metals as iron and manganese in edible parts of vegetables is necessary in order to monitor these food products.

Comparing the results of our study with an analogous study carried out by TYKSIŃSKII et al. in 1993, it was found that the iron content in vegetables whose leaves and fruits are the edible parts was lower in 2005 than in 1993. On the other hand, root vegetables were characterized by a higher content of Fe in 2005 (Table 6). The mean content of Fe in all the vegetables analyzed was 56.9 mg·kg^{-1} d.m. Higher mean Fe content (69.2 mg·kg^{-1}d.m.) was found by TYKSIŃSKI et al. in 1993. In 1993, more manganese was found in all the vegetables compared to the results obtained in 2005.

Table 6

The comparison of average contents the iron and manganese (mg· kg^{-1} d.m.) in individual groups of vegetables in 1993 and 2005

Group of vegetables	Cu		Zn	
	1993*	2005	1993*	2005
Vegetables whose edible part are leaves	125.7	83.3	24.7	20.4
Vegetables whose edible part are roots	38.6	57.5	18.6	9.0
Vegetables whose edible part are fruits	43.3	30.0	11.1	9.1
Mean	69.2	56.9	18.1	12.9

*TYKSIŃSKI et al. (1993)

CONCLUSIONS

1. The highest content of copper was found in roots of celeriac, while the smallest content of this micronutrient was shown by cabbage leaves.

2. The highest mean content of zinc was found in lettuce leaves. The lowest mean content of zinc was detected in tomato fruits.

3. In 1993, more zinc was found in vegetables whose fruits are the edible parts, when compared with the study performed in 2005. Vegetables whose leaves and roots are the edible parts were characterized by a higher zinc content in 2005.

4. The highest content of iron was found in leaves of leek, while the lowest concentration appeared in tomato and cucumber fruits.

5. The highest mean content of manganese was found in leaves of lettuce, while the smallest amount was in carrot roots.

6. The iron content in vegetables whose leaves and fruits are the edible parts was lower in 2005 in comparison with 1993, while the root vegetables were characterized by a greater amount of iron in 2005.

7. More manganese and cooper in al the vegetable species examined was found in 1993 than in 2005.

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CONTENT AND REMOVAL OF Cu AND Zn WITH HARVESTED CROPS GROWN ON SOIL FERTILIZED WITH COMPOSTED MUNICIPAL SEWAGE SLUDGE

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Abstract

The purpose of the study has been to determine the direct and residual effect of farmyard manure and composts made from sewage sludge on the content and uptake of copper and zinc by crops growing in a four-field crop rotation system. In 2004-2007, a field experiment was established on proper grey-brown podzolic soil, originating from light boulder clay, rich in P, moderately abundant in K and low in Mg, whose reaction was pH = 5.04. The experiment involved a four-field crop rotation cycle with the following crops: potato, spring barley, winter oilseed rape and winter wheat. The design of the experiment, set up according to the random block method, consisted of 8 object (2 x 4): 1) FYM, 2) composted sewage sludge, 3) compost (sewage sludge + straw), 4) dried and granulated sewage sludge. The composts and farmyard manure were applied once in the rotation system (under potato) at a rate of 10 t d.m. ha^{-1} or twice, each time 5 t d.m. ha^{-1} (under potato and under winter oilseed rape). In the objects fertilized with organic fertilizers and manure, nitrogen was balanced to 150 $kg \cdot ha^{-1}$ (under potato) and to 120 $kg \cdot ha^{-1}$ (under oilseed rape) depending on their total content of nitrogen. Spring barley and winter wheat received only mineral fertilizers. Before the experiment was set up, samples of soil, manure and composts had been collected for determination of Cu and Zn in 1 mol HCl dm^{-3} by atomic absorption spectrophotometry.

The content of zinc and copper in the crops was modified by the form of sewage sludge and sewage sludge composts to a greater extent than by the way these fertilizers were applied in the crop rotation system. Soil fertilization with dried and granulated sewage sludge or composted sludge increased the content of copper and its removal with harvested potato and winter rape, but the analogous values were higher when the cereals were grown on FYM fertilized soil. The strongest influence on the content and removal of zinc

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was exerted by soil fertilization with dried and granulated sewage sludge. The index of copper and zinc uptake was to a greater degree conditioned by the species of a crop than by the type of fertilizers or their application method. Municipal sewage sludge and sewage sludge composts can be used as a substitute of manure in farms which do not keep farm animals.

Key words: copper, zinc, crops, sewage sludge, composted municipal sewage sludge.

ZAWARTOŚĆ I WYNOS Cu I Zn Z PLONEM ROŚLIN UPRAWIANYCH NA GLEBIE UŻYŹNIANEJ KOMPOSTAMI Z KOMUNALNYCH OSADÓW ŚCIEKOWYCH

Abstrakt

Celem badań było określenie bezpośredniego i następczego wpływu obornika oraz kompostów z osadów ściekowych na zawartość oraz pobranie miedzi i cynku przez rośliny uprawiane w czteropolowym zmianowaniu. W latach 2004-2007 na glebie płowej typowej, wytworzonej z gliny lekkiej zwałowej, o wysokiej zawartości przyswajalnego P, średniej K, niskiej Mg i pH=5,04, przeprowadzono doświadczenie z czteropolowym płodozmianem: ziemniak, jęczmień jary, rzepak ozimy, pszenica ozima. Schemat doświadczenia założonego metodą losowanych bloków obejmował 8 obiektów (2x4): 1) obornik, 2) osad ściekowy kompostowany, 3) kompost (osad ściekowy+słoma), 4) osad ściekowy suszony i granulowany. Komposty i obornik zastosowano 1 raz w zmianowaniu (pod ziemniak) w dawce 10 t s.m.$\cdot$ha^{-1} lub 2 razy po 5 t s.m.$\cdot$ha^{-1} (pod ziemniak i rzepak ozimy). Na obiektach z nawozami organicznymi i obornikiem azot został zbilansowany do 150 kg$\cdot$ha^{-1} (pod ziemniak) i do 120 kg$\cdot$ha^{-1} (pod rzepak), w zależności od zawartości w nich N-ogółem. Pod jęczmień jary i pszenicę ozimą stosowano tylko nawożenie mineralne. Przed założeniem doświadczenia pobrano do analizy próbki gleby, obornika i kompostów, i oznaczono w nich zawartość Cu, Zn w 1 mol HCl$\cdot$dm^{-3} metodą ASA.

Zawartość cynku i miedzi w roślinach uprawnych była w większym stopniu modyfikowana formą osadów ściekowych i kompostów produkowanych z ich udziałem, niż sposobem stosowania w zmianowaniu. Użyźnianie gleby osadem ściekowym suszonym i granulowanym lub tylko kompostowanym zwiększało zawartość i wynos miedzi z plonem ziemniaka i rzepaku ozimego, a wartości te były wyższe, gdy rośliny zbożowe uprawiano na obiektach nawożonych obornikiem. Największy wpływ na zawartość i wynos cynku z plonem roślin miało nawożenie gleby osadem ściekowym suszonym i granulowanym. Indeks zbioru miedzi i cynku w większym stopniu zależał od gatunku rośliny niż od rodzaju i sposobu użyźniania gleby. Komunalne osady ściekowe, zwłaszcza komposty z ich udziałem, mogą być stosowane jako substytut obornika w gospodarstwach bezinwentarzowych.

Słowa kluczowe: miedź, cynk, rośliny uprawne, osady ściekowe, kompostowane komunalne osady ściekowe.

INTRODUCTION

The current conditions in agriculture stimulate the importance of micronutrients, which can be easily depleted due to the dramatically lower FYM fertilization, especially at farms which do not keep farm animals. A possible alternative to farmyard manure is the application of sewage sludge, which consists mostly of organic substance, which in turn lends itself readily to composting (Klasa et al. 2007, Mazur 1996, Siuta 1996). Good quality compost can be applied in crop production at rates and frequencies analogous to those of FYM fertilization (Andruszczak et al. 1988, Hryńczuk et al. 2000, Kaczor et al. 2006).

The objective of this study has been to determine the direct and residual effect of FYM and sewage sludge composts on the content of copper and zinc as well as their uptake by crops grown in a four-field crop rotation system.

MATERIAL AND METHODS

A field experiment was conducted at the Experimental Station in Bałcyny near Ostróda from 2004 to 2007. The experiment was established on proper grey-brown podzolic soil, originating from light boulder clay, which was highly abundant in available P, moderately abundant in K and poor in Mg. The soil reaction was pH 5.04 in 1 mol KCl dm^{-3}. The experimental crops were grown in the following four-field crop rotation system: potato, cv. Jssia, spring barley, cv. Justyna, winter oilseed rape, cv. Californium and winter wheat, cv. Zyta. The experiment was set up according to a random block design and comprised eight objects (2 x 4): 1) farmyard manure (FYM), 2) composted sewage sludge, 3) compost (sewage sludge + straw at a ratio of 1:0.5), 4) dried and granulated sewage sludge. The sewage sludge for the tests came from two wastewater treatment plants: one in Ostróda (object 2) and the other one in Iława (objects 3 and 4). The composts and FYM were applied once in the whole crop rotation system (under potato) at a rate of 10 t d.m. ha^{-1} or twice (under potato and winter rape) at a rate of 5 t d.m. ha^{-1} each time. In the objects fertilized with organic fertilizers or manure, nitrogen was balanced to 150 $kg \cdot ha^{-1}$ (under potato in 2004) and to 120 $kg \cdot ha^{-1}$ (under winter oilseed rape in 2005), depending on the total content of nitrogen. Spring barley (N– 90, P– 26 and K– 100 $kg \cdot ha^{-1}$) as well as winter wheat (N– 120, P– 26 and K 100 $kg \cdot ha^{-1}$) received only mineral fertilization. The concentration of micronutrients in the composts was presented in another paper (Bowszys et al. 2009).

Before the experiment was established, samples of soil, manure and composts had been taken to determine the content of Cu and Zn in 1 mol HCl dm^{-3} using atomic absorption spectrometry with an aid of an AA-6800 Shimadzu device (Table 1).

The plant material, sampled during the technological maturity phase, was first mineralized in a mixture of nitrogen (V) and chloric (VII) acids and then assayed for the content of Cu and Zn. The determination of the elements was conducted on an AA-Schimadzu apparatus by atomic absorption spectrophotometry.

The results (from replications) underwent analysis of variance, testing the significance of differences at p=0.05.

RESULTS AND DISCUSSION

Some authors claim that the uptake of copper and zinc by plants from sewage sludge as well as the distribution and accumulation of these elements in particular plant organs can be conditioned by certain differences between botanic families and species of plants (Borkowska et al. 1996, Bavacqua et al. 1993, Mishra et al. 1995). The response of the four crops to the organic fertilizers tested in this experiment was to a greater extent dependent on the species and organs of plants as well as on the type of a fertilizer applied than on the actual fertilization method (Tables 2, 3).

The highest content of copper (5.04 mg kg^{-1} d.m.) was found in potato tubers grown in soil fertilized with dried and granulated sewage sludge (Table 2). Potato plants cultivated on the other objects were characterised by similar levels of copper (on average 4.60 mg·kg^{-1} d.m.). By adding a second rate of sewage sludge under winter oilseed rape (the series 2 × 5 t d.m. ha^{-1}), elevated concentration of copper in rape seeds was obtained. The average increase, depending on the form of sewage sludge used, was around 7%. In turn, the content of copper in rape straw collected from all the objects was approximately the same, reaching on average 1.47 mg·kg^{-1} d.m.

No significant residual effect of the tested organic fertilizers (sewage sludge) has been found on the content of copper in the cereal plants tested. The grain of spring barley and winter wheat fertilized with FYM appeared to be richer in copper (5.52 and 3.72 mg·kg^{-1} d.m., respectively). The straw of these two cereal plants sampled from any of the objects had a similar concentration of this micronutrient, on average 1.72 and 1.20 mg·kg^{-1} d.m., respectively.

The direct influence of the bio-waste fertilizers on the content of zinc in potato tubers was significantly varied mainly due to the rate of a fertilizer applied (Table 3). In the objects which received 10 t d.m. ha^{-1} in a single dose, the concentration of zinc in potato tubers was on average 13% higher than in the objects which received two doses of fertilizers, 5 t d.m. ha^{-1} each. Moreover, Maćkowiak et al. (1999) demonstrated that tubers of potato fertilized with sewage sludge composts accumulated less zinc than the ones receiving mineral fertilizers.

The way the manure and composts were introduced to soil in the crop rotation system did not play a significant role in the accumulation of zinc in oilseed rape seeds, with an average level of this element being 39.49 (the series 10 t d.m. ha^{-1}) and 40.63 mg Zn ka^{-1} d.m. (the series 2 x 5 t d.m. ha^{-1}). Fertilization of soil with dried sewage sludge or composted sludge alone raised the content of zinc in spring barley grain by 7% and in winter wheat grain by 27%, as compared to the objects treated with FYM.

Wołoszyk et al. (2004) found out that the direct effect of composts consisted of increasing the content of copper and zinc in oilseed rape seeds, whereas the residual effect of these fertilizers modified the content of zinc more profoundly than that of copper in wheat grain and straw. Also Hruńczuk et al. (2000) noticed more Cu and Zn in grain of wheat fertilized with sewage sludge than that nourished with farmyard manure, although the differences were not statistically proven.

The removal of copper and zinc with harvested crops depended mainly on the type of a fertilizer applied (Figures 1, 2). The highest copper removal with potato (on average 61.5 $g \cdot ha^{-1}$) and oilseed rape (on average 31.6 $g \cdot ha^{-1}$) yields occurred when dried or composted sewage sludge had been applied in a single dose of 10 t d.m. ha^{-1}. The cereal crops, in contrast, took up most of copper in the objects fertilized with FYM, irrespective of the way it had been introduced to soil (single or split dose). The respective values were 56.9 and 39.6 $g \cdot ha^{-1}$. Potato as well as the cereals took up most zinc from the soil which had received 10 t d.m. ha^{-1} of dried and granulated sewage sludge, whereas oilseed rape accumulated most zinc when fertilized with an analogous dose of composted sewage sludge. Studies reported by other researchers seem to confirm that sewage sludge stimulates the uptake of copper and zinc by plants (Kaczor et al. 2006, Haneklaus et al. 1999).

The index of copper uptake depended on a plant species (81-82% for cereals and *ca* 64% for oilseed rape) and, to some extent, on the type of a fertilizer used (Figure 1). For spring barley and winter wheat, the index was higher when FYM had been used (*ca* 83%). The sewage sludge composts slightly depressed the contribution of grain to the total accumulation of copper. As regards winter oilseed rape, the highest Cu uptake index was obtained when composted sewage sludge (with or without straw) had been introduce to soil, especially in the series consisting of two doses of 5 t d.m. fertilizer per ha.

The grain of the two cereal plants accumulated on average from 79% (wheat) to 88% (barley) of zinc, whereas rape seed gathered about 75% of this element (Figure 2). As for the cereals, the sewage sludge composts only slightly increased the contribution of grain to retaining zinc, while for oilseed rape the highest value of the uptake index was attained when dried and granulated sewage sludge had been used.

The total removal of copper and zinc in the four-field crop rotation system is shown in Figure 3. The crops growing on the objects fertilized with FYM or dried and granulated sewage sludge took up, respectively, 161 and 164 g $Cu \cdot ha^{-1}$. Soil fertilization with composted sewage sludge (with or without straw) made it possible to keep the uptake of this micronutrient at an average level of 153-155 $g \cdot ha^{-1}$. When the composts were applied twice dur-

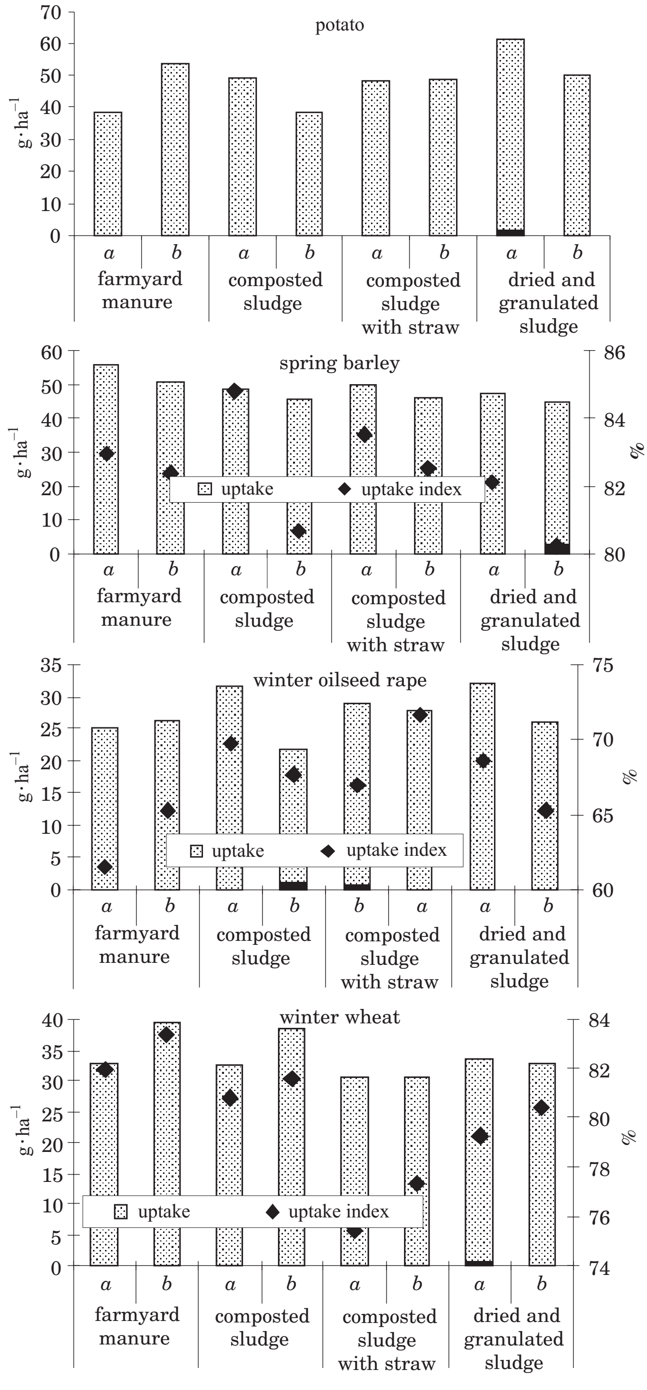

Fig. 1. Copper removal and uptake index (*a*, *b* – explained under Table 2)

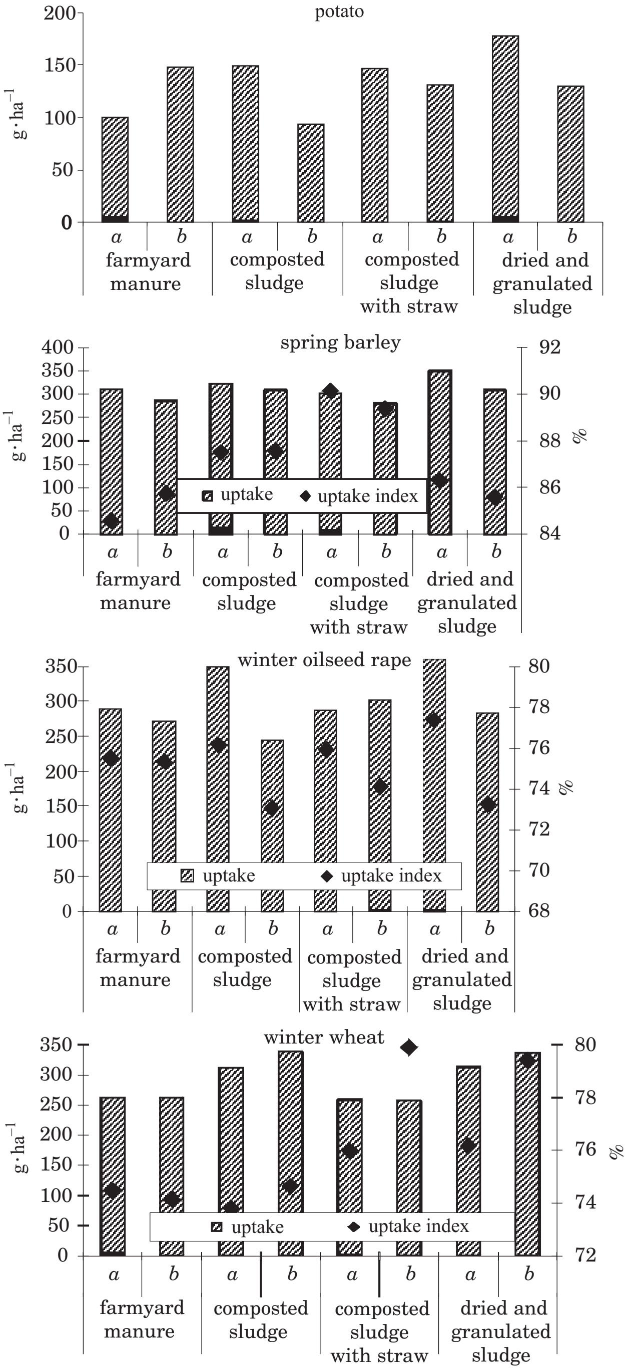

Fig. 2. Zinc removal and uptake index (*a, b* – explained under Table 2)

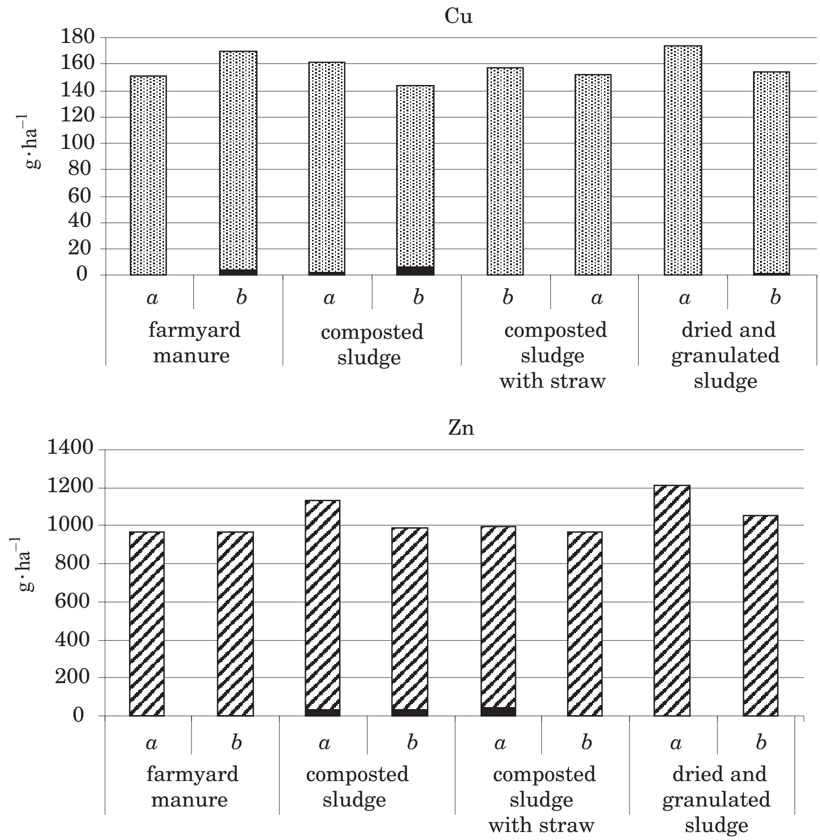

Fig. 3. Total removal of copper and zinc in the crop rotation cycle
(*a, b* – explained under Table 2)

ing the crop rotation cycle (series 2 × 5 t d.m. ha^{-1}), the uptake of Cu was raised only slightly. The highest total uptake of zinc was found following the application of sewage sludge fertilizers – dried and composted sewage sludge (respectively, 1135 and 1060 $g \cdot ha^{-1}$). Plants growing on the objects fertilized with sewage sludge composted with straw took up similar amounts of zinc as those fertilized with FYM.

CONCLUSIONS

1. The content of copper and zinc in crops was more strongly modified by the form of sewage sludge and sewage sludge composts than by the way these fertilizers were introduced to soil.

2. Fertilization of soil with dried and granulated sewage sludge or composted sewage sludge alone increased the content and uptake of copper by potato and winter oilseed rape yields; as for the cereal crops, the analogous values were higher when the plants were fertilized with farmyard manure.

3. The content of zinc and its uptake by the crops was most strongly affected by fertilization with dried and granulated sewage sludge.

4. The index of copper and zinc removal depended on the species of a plant rather than the type of a fertilizer and the application method.

5. Municipal sewage sludge, and sewage sludge composts in particular, can be used as a substitute of FYM in farms which do not keep farm animals.

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MODIFICATIONS IN THE CONTENT OF AVAILABLE ZINC AND COPPER IN SOIL FERTILIZED WITH BIO-WASTE COMPOSTS

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Abstract

The aim of this study has been to determine the indirect and direct effects of farmyard manure and sewage sludge composts, produced in the north-eastern part of Poland, on the content of 1 mol $HCl \cdot dm^{-3}$ soluble forms of zinc and copper in soil.

In 2004-2007, a field experiment was carried out at the Experimental Station in Bałcyny near Ostróda. The experiment was established on proper grey-brown podzolic soil originating from light boulder clay, which was rich in P, moderately abundant in K and low in Mg. It comprised a four-field crop rotation system (potato, spring barley, winter oilseed rape and winter wheat. The design of the experiment, set up according to the random block method, involved 8 objects (2 x 4): 1) farmyard manure, 2) compost (sewage sludge + straw), 3) dried and granulated sewage sludge, 4) composted sewage sludge. The composts and FYM were introduced to soil once (in 2004) at a rate of 10 t d.m.$\cdot ha^{-1}$ or 2×5 d.m.$\cdot ha^{-1}$ (under potato and winter oilseed rape). In 2004, nitrogen in the soil enriched with natural fertilizers was balanced to 150 $kg \cdot ha^{-1}$ according to the N-total content. In 2005, soil cropped with spring barley received only mineral fertilization, whereas winter oilseed rape received the second rate of organic fertilizers (in the series consisting of 2×5 d.m.$\cdot ha^{-1}$) and nitrogen was balanced to 120 $kg \cdot ha^{-1}$. In 2006, soil under winter wheat received only mineral fertilization.

Prior to the establishment of the experiment, soil, manure and compost samples were taken. Having been averaged, the samples were subjected to determination of their content of Cu and Zn in 1 mol HCl dm^{-3}. The soil, whose reaction was 5.04 in 1 mol HCl dm^{-3}, was moderately abundant in available zinc and low in copper. After four years of the trials, the levels of available forms of copper and zinc in the soil fertilized with sewage sludge

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composts, compared to the soil enriched with FYM, were higher. In the first and fourth year of the experiment, the content of both elements was found to increase significantly in the objects fertilized with dry, granulated and composted sludge. Sludge composted with straw significantly raised the content of Zn and Cu in the second and third year of the experiment. However, fertilization of grey-brown podzolic soil with sewage sludge did not change its classification according to the abundance of available forms of copper and zinc.

Key words: sewage sludge, zinc, copper, soil.

ZMIANY ZAWARTOŚCI PRZYSWAJANYCH FORM CYNKU I MIEDZI W GLEBIE UŻYŹNIANEJ KOMPOSTAMI Z BIOODPADÓW

Abstrakt

Celem badań było określenie bezpośredniego i następczego wpływu obornika i kompostów z osadów ściekowych, pochodzących z Polski północno-wschodniej, na zawartość w glebie form cynku i miedzi rozpuszczalnych w 1 mol $HCl \cdot dm^{-3}$.

W latach 2004-2007, w Zakładzie Produkcyjno-Doświadczalnym Bałcyny k. Ostródy, na glebie płowej typowej wytworzonej z gliny lekkiej zwałowej, o wysokiej zawartości P, średniej K i niskiej Mg, przeprowadzono doświadczenie z 4-polowym płodozmianem (ziemniak, jęczmień jary, rzepak ozimy, pszenica ozima). Schemat doświadczenia, założonego metodą losowanych bloków, obejmował 8 obiektów (2x4): 1) obornik, 2) kompost (osad ściekowy+słoma), 3) osad ściekowy suszony i granulowany, 4) osad ściekowy kompostowany. Komposty i obornik zastosowano jednorazowo (2004 r.) w dawce 10 t s.m.$\cdot ha^{-1}$ lub 2×5 t s.m.$\cdot ha^{-1}$ (pod ziemniak i rzepak ozimy). W 2004 r. na obiektach z nawozami organicznymi i obornikiem azot został zbilansowany do 150 $kg \cdot ha^{-1}$, w zależności od zawartości w nich N-ogółem. W 2005 r. pod jęczmień jary zastosowano tylko nawożenie mineralne, a pod rzepak ozimy – drugą dawkę nawozów organicznych (w serii 2×5 t s.m.$\cdot ha^{-1}$) i zbilansowano azot do 120 $kg \cdot ha^{-1}$. W 2006 r. pod pszenicę ozimą stosowano tylko nawożenie mineralne.

Przed założeniem doświadczenia pobrano próbki gleby, obornika i kompostów. W próbkach, po uśrednieniu, oznaczono zawartość Cu, Zn w 1 mol $HCl \cdot dm^{-3}$. Gleba o pH=5,04 w 1 mol $HCl \cdot dm^{-3}$ charakteryzowała się średnią zasobnością w przyswajalny cynk i niską w miedź. Po czterech latach badań wzrosła zawartość przyswajalnych form miedzi i cynku w glebie użyźnianej kompostami z osadów ściekowych, w porównaniu z glebą nawożoną obornikiem. W pierwszym i czwartym roku istotny wzrost zawartości tych pierwiastków stwierdzono na obiektach z osadem suszonym i granulowanym oraz kompostowanym. Osad kompostowany z dodatkiem słomy istotnie zwiększał zawartość Zn i Cu w drugim oraz trzecim roku badań. Użyźnianie gleby płowej osadami ściekowymi nie zmieniało jednak klasy zasobności w przyswajalne formy miedzi i cynku.

Słowa kluczowe: osad ściekowy, cynk, miedź, gleba.

INTRODUCTION

Under the current conditions in agriculture, the importance of micronutrients is constantly growing. The negative balance of these elements in soil used for farming is largely conditioned by a dramatic decrease in FYM fertilization levels. A possible replacement for FYM can be seen in application of sewage sludge, especially from wastewater treatment plants in small towns. Such sludge is typically better as a fertilizer and safer to use in natural environment than sludge obtained in cities, particularly in industrialized areas. Good quality compost produced from sewage sludge as one of its components improves the balance of humus compounds in soil as well as the content of macro- and micronutrients (KLASA et al. 2007, HANEKLAUS et al. 1998, SIUTA 1996, PIGNALOSA et al. 1994, KRZYWY et al. 2002).

The objective of this study has been to determine the direct and indirect effects of FYM and sewage sludge composts, produced in the north-eastern part of Poland, on the content of 1 mol HCl dm^{-3} soluble forms of copper and zinc.

MATERIAL AND METHODS

A field trials was conducted at the experimental Station in Bałcyny near Ostróda from 2004 to 2007. The experiment was established on proper grey-brown podzolic soil originating from light boulder clay, which was rich in available P, moderately abundant in K and low in Mg. the soil reaction was 5.04 in 1 mol KCl dm^{-3}. The experiment comprised a four-field crop rotation system (potato, spring barley, winter oilseed rape and winter wheat). The design of the experiment, which was set up according to the random block method, involved 8 objects (2 x 4): 1) mixed manure, 2) composted sewage sludge, 3) compost (sewage sludge and cereal straw at a ratio of 1 : 0.5), 4) dried and granulated sewage sludge. The sewage sludge used to make the composts came from wastewater treatment plants in Ostróda (object 2) and Iława (objects 3 and 4). The concentration of macronutrients in the manure and composts has been specified in Table 1.

The composts and manure were introduced to soil once during the whole crop rotation cycle (under potato), adding 10 t d.m. of fertilizer per ha, or twice (under potato and winter oilseed rape) as two rates of 5 t d.m. per 1 ha. In the objects enriched with the organic fertilizers and FYM, nitrogen was balanced to 150 kg·ha^{-1} (2004) and to 120 kg·ha^{-1} (2005), depending on the N-total content in the soil. Spring barley and winter wheat were nourished only with mineral fertilizers.

Before the experiment was established, samples of soil, manure and composts had been collected. In averaged samples, the content of Cu and Zn in 1 mol HCl dm^{-3} was determined by atomic absorption spectrophotometry, using an AA-6800 Shimadzu apparatus.

Before the trials were started, the soil was characterised by moderate zinc and low copper abundance (Table 2). The results of the experiment (from each plot) underwent analysis of variance, which tested significance of differences caused by particular experimental factors, at the significance level of p=0.05.

Table 1

Content of macronutrients in FYM and sewage sludge composts ($g \cdot ha^{-1}$ d.m.)

Element	FYM	Sewage sludge		
		composted	with straw	dried and granulated
N	5.80	46.60	10.70	18.00
P	1.02	29.90	7.60	12.30
K	5.11	-	1.20	1.40
Mg	1.30	7.80	1.80	3.70
Ca	1.10	33.90	10.80	15.10

Results of determinations on certified material

Value ($mg \cdot kg^{-1}$ d.m.)	Virginia Tobacco Leaves CTA-VTL-2	
	Cu	Zn
Certified	18.2±0.9	43.3±2.1
Determined	18.8±0.6	42.3±1.1

Table 2

Content of soluble forms of zinc and copper in soil, sewage sludge and manure before assuming experience ($mg \cdot kg^{-1}$)

Metal	Soil	Manure	Sewage sludge		
			composted	with straw	dried and granulated
Cu	1.47	5.41	340.01	4.48	18.16
Zn	9.11	35.12	1310.0	109.51	270.40

RESULTS AND DISCUSSION

Sewage sludge is most often very rich in organic substance and alkaline cations. They can therefore serve to neutralise acid soils (Żukowska et al. 1999, Czekała 1999). The effect of the different forms of sewage sludge composts tested in this experiment on soil pH depended primarily on how they were applied (Table 3). In the first year, compared to the initial value (pH = 5.04), the sewage sludge composts had a positive effect on the soil reaction on all the plots. However, the subsequent effect of the composts, especially when added to soil as a single rate of 10 t d.m. per ha, was much weaker. In the series consisting of 2×5 t d.m. per ha, the second rate of manure or the composts changed the soil reaction even more profoundly than in the first year of the experiment.

Table 3

Soil reaction after the harvest of plants (pH in 1 mol KCl·dm^{-3})

Year	Way of applying	Manure	Sewage sludge composted	Sewage sludge with straw	Sewage sludge dried and granulated
2004	*a* *b*	5.27 5.06	5.45 5.37	5.36 5.11	5.39 5.37
2005	*a* *b*	4.95 4.90	5.10 5.06	5.02 4.95	5.09 5.03
2006	*a* *b*	5.02 5.03	5.21 5.21	5.18 5.09	5.27 5.21
2007	*a* *b*	5.27 5.11	5.18 5.46	5.22 5.25	5.20 5.46

a – once in the crop rotation 10 d.m. t·ha^{-1}
b – twice in the crop rotation for 5 t d.m.·ha^{-1}

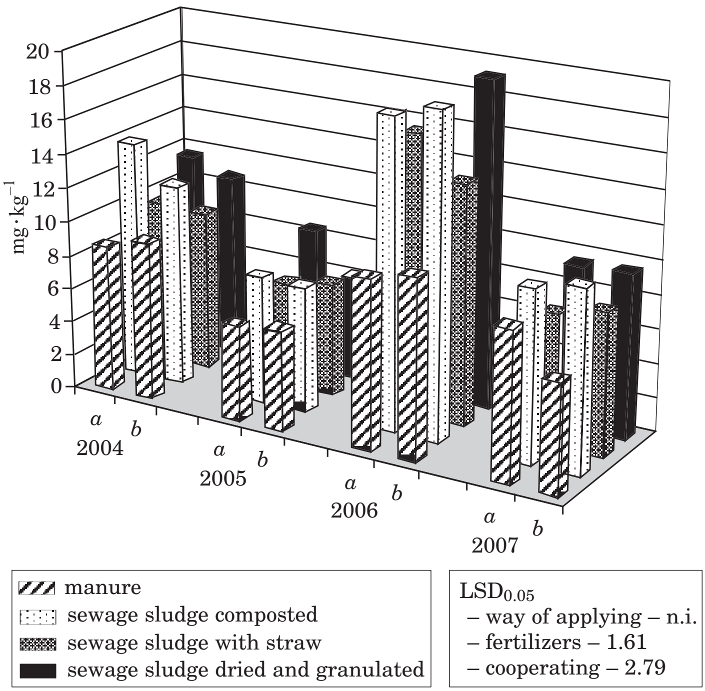

Fig. 1. Content of Zn in soil after the harvest of plants (*a* – fertilizing once in the crop rotation 10 t·ha^{-1}; *b* – fertilizing 2 × 5 t·ha^{-1} in the crop rotation)

Baran et al. (1996) as well as Żukowska et al. (1999) also found out that sewage sludge had alkalizing influence on soil, especially in the first year after its application. In turn, a study completed by Jakubus (2006) suggested that sewage sludge had statistically non-significant influence on soil reaction.

After four years of our trials, the concentration of available form of zinc in FYM fertilized soil was on average 8.2 mg·kg^{-1}, whereas in the soil enriched with different forms of bio-waste composts, it ranged on average from 9.8 mg·kg^{-1} (sewage sludge composted with straw) to 12.3 mg·kg^{-1} (sewage sludge composted alone). In the consecutive years of the experiment, the amount of this form of zinc increased significantly in soil fertilized with composted sludge or dried and granulated sludge relative to that found in FYM fertilized soil (Figure 1). However, in none of the years of the trials, the way these fertilizers were applied (once or twice during the whole crop rotation cycle) had any significant effect on the abundance of soil in zinc.

The tendencies observed while analyzing the effect of the composts on abundance of soil in available copper were similar to those noticed for zinc (Figure 2). After four years of fertilization with manure, the average abundance of soil in this element did not change (1.49 mg·kg^{-1}) when compared to its abundance before the experiment (1.47 mg·kg^{-1}). In the objects fertilized with bio-waste composts, the concentration of Cu in soil was modified by the type of compost applied and ranged on average from 1.59 mg·kg^{-1}

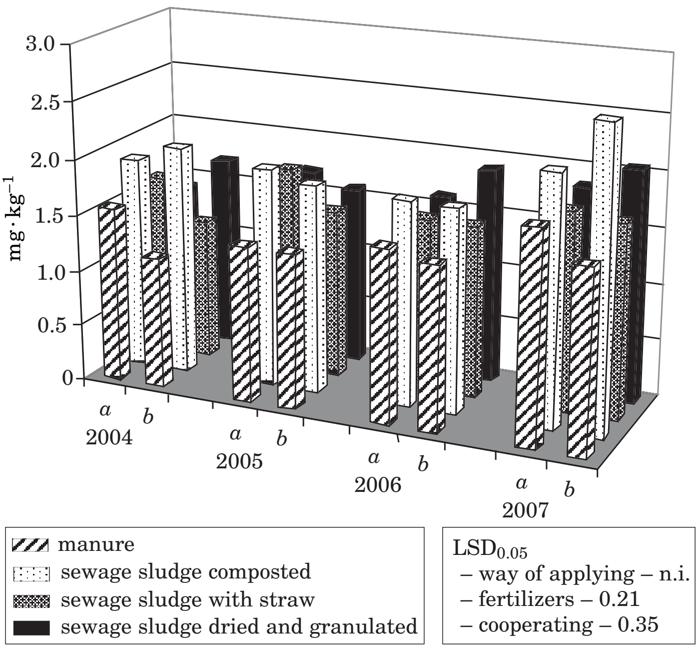

Fig. 2. Content of Cu in soil after the harvest of plants (explanations for Figure 1)

(sewage sludge composted with straw) to 2.15 mg·kg^{-1} (sewage sludge composted alone).

Similar results have been obtained by PATORCZYK-PYTLIK and SPAIK (1996), SZULC and RUTKOWSKA (2002) or IŻEWSKA et al. (2006). CZEKEAŁA (2004), on the other hand, found no significant influence produced by sewage sludge fertilizers on the content of micronutrients extracted by 1 mol HCl dm^{-3} solution.

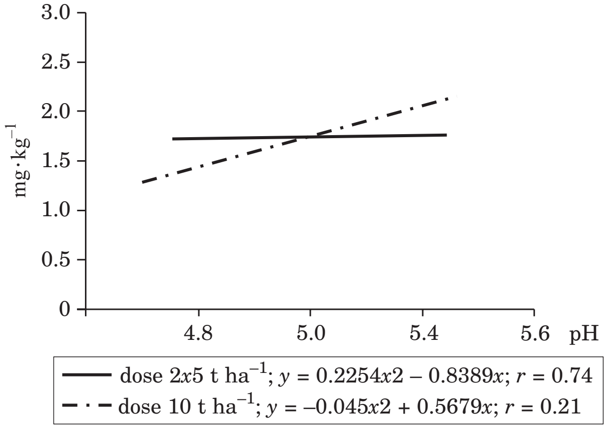

Fig. 3. Relation between the content Cu in the soil and her reaction

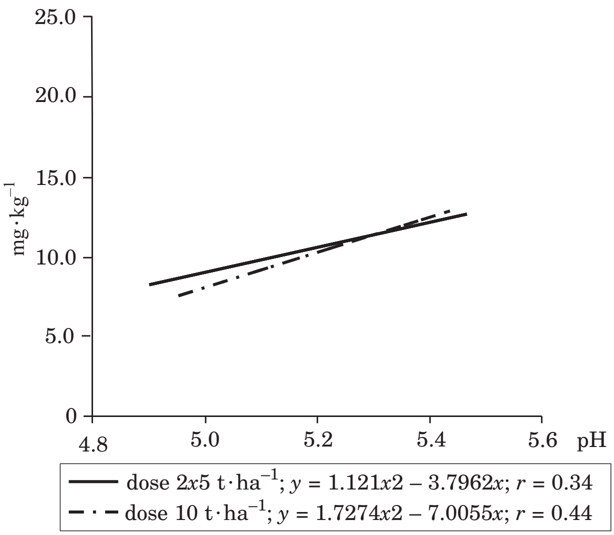

Fig. 4. Relation between the content Zn in the soil and her reaction

The analysis of correlation and regression (Figures 3, 4) showed that the amount of available copper in soil fertilized with manure and organic fertilizers depended on the soil reaction to a greater degree than that of zinc (r = 0.71, 0.21 for copper versus r=-0.34; 0.44 for zinc). Likewise, Kucharzewski et al. (2004) determined positive correlation between the content of zinc or copper and soil reaction.

CONCLUSIONS

1. Fertilization of soil with sewage sludge composts had a positive effect on soil reaction. Double application of the fertilizers during the whole crop rotation cycle (each time 5 t d.m. ha^{-1}) was more favourable than a single treatment (10 t d.m. ha^{-1}).

2. The concentration of available zinc and copper in soil was modified to a greater extent by the type of sewage sludge and sewage sludge composts than the way these fertilizers were introduced to soil.

3. The highest level of available forms of copper and zinc was found when sewage sludge had been used – composted as well as dried and granulated sewage sludge composts.

4. The fertilization of soil with different forms of sludge produced while treating municipal wastewater and sewage increased the soil content of mobile forms of zinc and copper. However, the threshold levels of these elements were never exceeded.

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COMPARATIVE ANALYSIS OF TRACE ELEMENTS CONCENTRATIONS IN DIALYSIS FLUIDS BEFORE AND AFTER DIALYZER

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Abstract

Disturbances of mineral metabolism are one of the many complications observed in patients with renal failure. Fluids used in dialysotherapy may introduce elements to a patient's body. On the other hand, some trace elements may be removed. Dialysis fluids contain chlorides of calcium (Ca), magnesium (Mg), sodium (Na), and potassium (K), but they may also be contaminated by toxic metals. In the first part of our work the amounts of Mg, Ca, zinc (Zn), and iron (Fe) were determined in samples of hemodialysis fluids just before and after a dialyzer. The concentration of copper (Cu), aluminium (Al), lead (Pb), cadmium (Cd), and chromium (Cr) were measured by the atomic absorption spectrometry method (AAS) in a graphite furnace (GFAAS) in the same dialysates. The average concentration of Cu in dialysis fluids before and after dialyzer was 13.51 and 10.51 μg L^{-1} respectively, Al – 8.72 and 7.88 μg L^{-1}, Pb – 24.03 and 22.81 μg L^{-1}, Cd – 1.09 and 1.07 μg L^{-1}, Cr – 5.91 and 6.28 μg L^{-1}. Except for Cr ($p < 0.05$), the comparison of concentrations of all the measured elements before and after haemodialysis did not show any significant differences. Positive significant correlations between the element concentration before and after a dialyzer were found for Al (r = 0.33030 and Cd (r = 0.7496). In the samples of dialysis fluids of patients who had been dialyzed for less than one year, a negative balance of elements was found, except Pb. The balance was positive in patients who had been dialyzed for more than a year. Our findings also show statistically significant negative correlation between duration of dialysis treatments and Al concentration. Statistically, the examined dialysis fluids seem to be safe for dialyzed patients. However, individual data show that it is important to control elemental levels in dialyzates used for many years to prevent some complications in these patients.

Key words: dialysis fluids, trace elements, atomic absorption spectrometry.

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ANALIZA PORÓWNAWCZA STĘŻEŃ PIERWIASTKÓW ŚLADOWYCH W PŁYNACH DIALIZACYJNYCH PRZED I ZA DIALIZATOREM

Abstrakt

Zaburzenia w gospodarce mineralnej to jedno z wielu powikłań obserwowanych u pacjentów ze schyłkową niewydolnością nerek. Płyny stosowane w dializoterapii mogą do organizmu dostarczać pierwiastki, ale mogą je także z niego usuwać. W składzie płynów dializacyjnych znajdują się chlorki Ca, Mg Na i K. Mogą one także zawierać inne metale będące ich zanieczyszczeniami. W pierwszym etapie pracy oznaczono stężenie Ca, Mg, Zn i Fe w 38 próbkach płynów dializacyjnych przed i za dializatorem. Stężenie tych pierwiastków nie zmieniło się w sposób istotny statystycznie, ale stężenie Zn było o ok. 7% wyższe w płynie po zabiegu, a w kilku z nich stwierdzono podwyższone stężenie Fe. Celem pracy było oznaczenie w tych samych dializatach stężeń pierwiastków śladowych istotnie wpływających na funkcje organizmu. Porównawcze oznaczenia stężenia miedzi (Cu), glinu (Al), ołowiu (Pb), kadmu (Cd) i chromu (Cr) wykonano metodą spektrometrii absorpcji atomowej z atomizacją w piecu grafitowym (GFAAS). Zastosowane procedury analityczne zapewniają dobrą czułość i precyzję metody. Średnie stężenie Cu w płynach przed i za dializatorem wynosiło 13,51 i 10,51 µg L^{-1}, Al – 8,27 i 7,88 µg L^{-1}, Pb – 24,03 i 22,81 µg L^{-1}, Cd – 1,09 i 1,07 µg L^{-1}, Cr – 5,91 i 6,28 µg L^{-1}. Z wyjątkiem Cr (p<0,05), stężenie pierwiastków w płynach przed i za dializatorem nie różniło w sposób statystycznie istotny. Dodatnie istotne korelacje między zawartością pierwiastków przed i za dializatorem wyznaczono dla Al (r = 0,3303) i Cd (r = 0,7496). W próbkach płynów dializacyjnych pacjentów dializowanych w czasie krótszym niż rok stwierdzono, z wyjątkiem Pb, ujemny bilans pierwiastków, a powyżej roku – dodatni. Stwierdzono ujemną istotną korelację między czasem trwania dializoterapii a stężeniem Al.

Badane płyny dializacyjne, uwzględniając ocenę statystyczną, nie zwiększają ekspozycji pacjentów dializowanych na oznaczane metale ciężkie. Z analizy danych indywidualnych wynika jednak, że płyny te, ze względu na systematyczne stosowanie w ciągu wielu lat, mogą wywierać wpływ na status mineralny pacjenta, i dlatego też pod tym kątem powinny być kontrolowane.

Słowa kluczowe: płyny dializacyjne, pierwiastki śladowe, spektrometria absorpcji atomowej (GFAAS).

INTRODUCTION

Mineral disturbances which accompany the chronic renal failure (CRF) may be affected by several factors i.e. impaired intestinal absorption and distribution, reduced renal function and urine excretion, hormonal disorders, restricted and unbalanced diet, medication and dialysis treatment. Dialysis osteomalacia, anaemia, cardiovascular diseases, and mental disorders are frequent and serious complications of renal dysfunction, which are observed in dialyzed patients. It has been shown that many elements, including Ca, Mg, Fe, Zn, Cu, Se, Al, Si, Cr and Sr, take part in the pathogenesis of kidney failure complications. Abnormalities of the elemental status have been reported in serum, blood, erythrocytes and tissues (e.g. osseous tissue, hair and brain) of dialyzed patients. Some elements (Al, Cr, Fe, Si, and Sr) excessively accumulate in the body, while others (Ca, Se, and Zn) may demonstrate their deficiency (ŠČANČAR et al. 2003). Medical treatment for renal insufficiency includes pharmacological treatment, special diet, and dialysotherapy. Dialysis fluids may introduce contribute bioelements and toxic metals to a patient's body. On the other hand, some trace elements may be removed. So far, most of the reports have dealt with the Al and Cr concentration in fluids used in haemodialysis and peritoneal dialysis. Aluminium may be responsible for intoxication of dialyzed patients caused by high content of this element present in water used for preparation of dialysis fluids. Between 517-1275 µg Al L^{-1} was determined post mortem in serum of 4 patients treated with aluminium contaminated dialyisis fluids. Additionally, significant amounts of this element were discovered in the liver, bone, and brain of these patients (WOLF et al. 2002). Some authors (ŠČANČAR et al. 2003, MIURA et al. 2002, ŠČANČAR et al. 1999, MILAČIČ, BENEDIK 1999) determined other elements, such as Ca, Mg, Zn, Cu, Fe, Ni, Co, Pb, Cd, Mn, Si, Se, and Rb both in dialysis fluids and in concentrates. It has been shown that dialysis fluids influence the mineral balance in a patient's organism.

Because of a difficult and complicated dialysis fluids matrix (e.g. carbodydrates, large amounts of chloride ions) and trace amounts of most elements present in dialysates (except Ca, Mg, K, and Na), the authors used various techniques of the preliminary chemical treatment of the specimens, for example preconcentration, coprecipitation, addition of high amounts of acids. Instrumental analyses were carried out by neutron activation analysis (NAA) and particle-induced X-ray emission (PIXE), but generally by atomic absorption spectrometry (flame atomic absorption spectrometry FAAS and graphite furnace atomic absorption spectrometry GFAAS) (ŠČANČAR et al. 1999, MIURA et al. 2002, ŠČANČAR et al. 1999, MILAČIČ, BENEDIK 1999, BERKKAN, ERTAŞ 2004, SARACOGLU et al. 2003, ELÇI et al. 1997).

In the study (DŁUGASZEK, KARBOWIAK 2007) the Ca, Mg, Zn, and Fe concentrations were determined in haemodialysis fluids before and after a dialyzer. There were statistically non-significant differences between the concentrations of the examined elements, although the amount of Zn was 7% higher in dialysis fluid after the operation.

As for a possible contamination of dialysis fluids contamination by toxic metals, it seems rational to investigate both transport of elements to a patient's body and their removal from the tissues. Moreover, little is known about these mechanisms at present.

Our present study has been undertaken in order to investigate the Cu, Al, Pb, Cd, and Cr content in fluids used in dialysotheraphy and to compare the metal concentrations before and after a dialyzer.

MATERIALS AND METHODS

The material included fluids used during 38 haemodialyses in patients with chronic renal failure: 22 men (aging 39-87 years) and 16 women (aging 43-80 years). The samples were taken before and after a dialyzer. The specimens of dialysate fluid were obtained from the Department of Internal Medicine of the Military Clinical Hospital in Bydgoszcz.

Capillary dialyzers equipped with cuprophan or polysulfone membranes were used in the dialysis treatment. The dialysate flow was 500 mL min^{-1}, and blood flow rate was 250-300 mL min^{-1}. The dialyzer surface was 1.1, 1.3 or 1.5 m^2 depending on the medicalrecommendations. The conventional dialysate fluid contained approximately 1.25 mmol Ca L^{-1} and 0,5 mmol Mg L^{-1} (values declared by producer). The collected samples of dialysate fluid were initially mineralized with suprapure 65% HNO_3 acid. Afterwards, they were diluted with acid (1 + 1) and the mixtures in closed vessels were allowed to stand for 24 h. Next, the samples were diluted with deionized water, so that the final concentration of HNO as a matrix modifier was 16%.

During the collection of dialysis fluids samples, storage (-20°C), mineralization, and performing instrumental analysis, a possible risk of contaminating the samples contamination was controlled. All the glassware, vessels, plastic tubes and pipette tips were treated with 6 mol L^{-1} HCl and 6 mol L^{-1} HNO_3. For the analyses, suprapure reagents and deionized water (18 M Ω cm^{-1}) were used.

In solutions of dialysis fluids prepared as described above (in two duplicate series), concentrations of copper, lead, cadmium, aluminium, and chromium were determined by the atomic absorption spectrometry method using a spectrometer AVANTA Σ (GBC) equipped with a graphite furnace GF3000, autosampler PAL 3000 and Ultra-Pulse deuterium corrector. The concentrations of Cu, Pb, Cd, Al, and Cr were measured by the graphite furnace atomic absorption spectrometry technique (GFAAS). The analyses were done in pyrolitic graphite tubes in argon atmosphere as a purging gas. The volume of a sample injected to the graphite furnace was 20 µL. The peak area mode was used for the calculation of the tested element concentration. Instrumental parameters and analytical characteristics of the procedures are shown in Table 1. In order to test the accuracy of the determination of the concentrations of the elements, two calibration methods were applied: calibration curve and standard addition method, as well as two reference materials: SRM 1577b and NCS 81002 (Długaszek, Szopa 2007).

The results are expressed as means and medians. The data were analyzed using normality Shapiro-Wilks test and Fisher test verifying homogeneity of variances. The differences between independent groups were assessed by t-Student, Cochran-Cox and Kolmogorow-Smirnov (for non-normally

Table 1

Instrumental parameters and analytical characterization of used methods

Element	Pyrolisis/ atomization temperature (°C)	Wavelenght (nm)	Calibration range[1] (ng mL^{-1})	Limit of detection[3] (ng mL^{-1})	Sensivity[4] (pg)	Precision (%)
Cu	800/2300	324.7	2.5-10.0	0.4	2.6	8.2
Pb[1]	900/2000	283.3	1.5-15.0	0.81	5.8	6.8
Cd[2]	600/1800	228.8	0.15-1.50	0.06	0.36	6.7
Al	1400/2400	309.3	3-20	0.40	8.6	9.1
Cr	1000/2500	357.9	0.5-5.0	0.51	1.44	3.2

Modifiers used:
[1] $NH_4H_2PO_4$
[2] NH_4NO_3
[3] limit of detection (LOD) defined as 3SD (n = 10)
[4] characteristic mass defined as amount of element giving an absorbance of 0.0044

distributed parameters) tests. Correlation analysis between variables was performed using Pearson's test. The level of statistical significance was at $p<0.05$. For statistical analysis a Statistica software package was used.

RESULTS AND DISCUSSION

The results are shown in Tables 2, 3 and 4, where the differences between concentrations of the elements before and after a dialyzer in separate samples of dialysis fluids and the mean concentration of these metals are presented. Moreover, the effect of the dialysis treatment time (below and above 1 year) on amounts of elements in the dialysate leaving a dialyzerwas assessed. Both these results and Pearson's correlation coefficient (r_{xy}) between the time of dialysotheraphy and the concentration of elements in dialysate after a dialyzer are shown in Table 4.

In the examined dialysis fluids, the mean Cu concentration is comparable before and after a dialyzer. However, in three samples its concentration before a dialyzer was much higher than in the others. In the same samples the Cu concentration after a dialyzer was lower and similar to that in the other samples of dialysis fluids. Moreover, in these samples the Fe concentration (before a dialyzer) was also much higher, about 10-fold higher (216.1, 299.2, and 548.6 μg L^{-1}), and, like the Cu levels, the Fe concentration after a dialyzer was at the same level as in the other samples. This means that the dialysis fluids may have been contaminated with these metals and the contaminants may have been retained in a patient's organism. The correla-

Table 2

Differences in concentration of elements (μg L^{-1}), after and before a dialyzer

No	Cu	Al	Pb	Cd	Cu
1	- 7.63	- 2.98	- 21.5	+ 0.04	+ 2.85
2	- 7.24	+ 2.48	+ 2.8	+ 0.59	+ 0.29
3	+ 0.57	- 5.55	- 0.9	+ 0.07	+ 2.27
4	- 2.61	+ 6.58	- 2.1	+ 0.05	+ 3.56
5	+ 4.85	- 1.32	- 0.9	+ 0.03	+ 0.35
6	+ 4.49	+ 3.05	+ 1.0	- 0.07	+ 2.28
7	+ 0.64	+ 2.96	- 0.4	- 0.03	+ 2.48
8	+ 2.25	+ 1.92	- 3.8	+ 0.12	- 1.40
9	+ 2.06	+ 1.14	- 2.6	- 0.08	+ 0.74
10	+ 5.22	+ 2.36	+ 0.2	- 0.06	+ 2.02
11	- 1.74	- 0.38	- 4.3	- 0.19	- 0.37
12	+ 4.63	- 3.26	+ 3.4	+ 0.09	+ 0.97
13	- 4.76	- 6.32	+ 2.0	+ 0.02	+ 1.40
14	- 3.13	- 7.27	- 3.5	+ 0.10	+ 0.81
15	+ 10.29	+ 6.46	+ 2.0	+ 0.07	+ 0.93
16	+ 6.45	+ 0.35	+ 2.1	- 0.04	+ 0.20
17	- 3.15	+ 0.36	- 1.6	- 0.06	- 10.54
18	+ 0.76	+ 4.45	+ 3.4	+ 0.15	+ 0.34
19	- 13.45	+ 2.79	- 6.4	- 0.04	- 0.92
20	+ 17.7	- 4.99	+ 6.7	- 0.02	+ 3.08
21	- 1.07	- 4.44	- 10.4	+ 0.03	+ 0.13
22	+ 6.82	- 2.68	- 6.4	- 0.04	+ 2.78
23	+ 4.48	+ 2.54	- 1.3	- 0.13	+ 0.93
24	+ 4.8	- 11.33	+ 1.1	- 0.03	+ 0.62
25	+ 6.78	- 5.39	- 5.4	- 0.07	+ 0.02
26	- 9.07	- 3.76	+ 12.3	+ 0.09	- 1.50
27	- 1.46	+ 0.67	- 4.1	- 0.01	+ 0.90
28	- 23.95	- 1.75	- 3.7	- 0.28	- 1.60
29	- 1.4	- 3.95	+ 1.8	- 0.10	+ 6.23
30	- 4.82	+ 2.30	- 1.6	- 0.15	+ 1.34
31	+ 2.14	- 5.36	- 1.7	+ 0.14	+ 1.18
32	- 11.4	- 5.66	- 4.5	- 0.02	- 0.98
33	+ 6.78	+ 10.24	- 0.1	+ 0.17	+ 0.79
34	+ 0.2	- 5.21	- 5.2	+ 0.30	+ 0.50
35	- 23.83	+ 1.88	+ 9.5	- 0.20	+ 0.34
36	- 44.68	- 6.63	+ 6.2	- 0.64	+ 0.53
37	- 43.49	- 0.47	- 11.1	- 0.37	- 3.42
38	+ 5.36	+13.86	+ 7.2	- 0.02	- 0.73

Table 3

Concentration of elements (μg L^{-1}) before and after a dialyzer

Element	Cu		Al		Pb		Cd		Cr	
	before	after	before	after	before	after	before	after	before	after
Mean	13.51	10.51	8.27	7.88	24.03	22.81	1.09	1.07	5.91	6.28 $p<0.05$
Median	9.07	9.65	6.83	7.53	23.50	22.85	1.13	1.14	5.79	6.41
S.D.*	12.46	5.20	4.18	4.65	4.58	4.12	0.22	0.29	1.92	1.03
Range (min.- max.)	3.19 59.68	2.68 30.19	2.63 17.89	1.68 21.09	15.10 42.9	13.30 32.6	0.58 1.37	0.42 1.78	2.32 14.89	4.07 8.27
Quartiles (Q_1, Q_3	5.19 18.14	7.18 12.72	5.36 10.07	4.12 9.75	21.2 25.9	19.4 25.4	0.99 1.24	0.88 1.29	4.87 6.22	5.52 7.02

* – standard deviation

Table 4

Concentration of elements (μg L^{-1}) before and after a dialyzer, below (n = 12) and above one year of dialysis treatment (n = 26)

Element	Cu		Al		Pb		Cd		Cr	
	before	after	before	after	before	after	before	after	before	after
< Year										
Mean	14.21	12.36	10.10	8.24	23.40	24.86	1.15	1.11	5.80	6.10
Median	13.67	10.3	9.49	9.05	23.50	25.3	1.35	1.27	5.88	6.23
S.D.*	9.56	6.77	4.54	4.47	2.86	2.74	0.19	0.31	0.90	0.90
Difference		-1.85		-1.86		+1.46		-0.04		+0.30
> Year										
Mean	8.97	9.87	7.45	7.71	24.31	21.85	1.06	1.05	5.75	6.36
Median	7.59	9.09	6.08	7.03	23.80	21.65	2.00	1.08	5.70	6.52
S.D.*	4.96	4.49	3.82	4.81	5.21	4.34	0.24	0.28	2.46	1.10
Difference		+0.90		+0.26		-2.46 $p<0.05$		-0.01		+0.61
$r_{(xy)}$	-0.162		-0.469 $p<0.05$		0.137		0.415		0.098	

* – standard deviation

tion between the Cu concentration in our dialysates before and after a dialyzer was weak ($r = 0.0857$).

The Cu content in concentrates used in haemodialysis determined by ELÇI et al. (1997) was 3.5 ± 0,1 µg L^{-1}, and that reported by SARACOGLU et al. (2003) ranged from 6.7 to 81.0 µg L^{-1}. In turn, the Cu concentration in spent continuous ambulatory peritoneal dialysis (CAPD) fluids ranged from 6.3-94.9 µg L^{-1} (MILAČIČ, BENEDIC 1999), and according to ŠČANČAR et al. (2003) it was 4.9-32.5 µg L^{-1}. In concentrates used in peritoneal dialysis, the amount of 0.006 µmol Cu/L was noted, but in spent dialysates the Cu concentration ranged within 0.120-0.549 µmol L^{-1}. This suggests that Cu clearance from the serum of dialyzed patients is possible (ŠČANČAR et al.1999).

According to the recommendation of the Association for the Advancement of Medical Instrumentation (AAMI) (MACTIER 2007), the Cu concentration in water used for preparing dialysis fluids should not exceed 0.1 mg L^{-1}.

In the analyzed dialysates, an averaged Al concentration did not exceed the acceptable maximum level for water i.e. 0.01 mg L^{-1} (MACTIER 2007). The mean concentration of this element in the dialysis fluids flowing out of a dialyzer was lower than before a dialysis session, but the median value was respectively higher. Statistically significant positive correlation between the Al amount in the dialysis fluids before and after a dialyzer ($r = 0.3303$, $p<0.05$) suggests that Al would not be retained in a patient's organism.

The mean concentration of Al reported by JOFFE et al. (1989) in spent CAPD fluids was 9.0 µg L^{-1} (3.6-16.3 µg L^{-1}). Other authors (ŠČANČAR et al. 2003) have shown that the Al migration from a patient's serum to dialysates during peritoneal dialysis is possible, as they compared concentration of this element in fresh CAPD fluids (< 1.0 µg L^{-1}) and in spent CAPD fluids (1.1--8.6 µg L^{-1}), and < 0.037 µmol L^{-1} vs 0.130 µmol L^{-1} – 0.478 µmol L^{-1}, respectively (ŠČANČAR et al.1999). Y. Miura et al. (2002) also noticed higher Al level in 5 samples of dialysates after a haemodialysis treatment.

In our study, the mean Pb concentration in the dialysis fluids was slightly lower (about 6%) after a dialyzer, but only in 14 out of the 38 samples the Pb concentration was higher in dialysates leaving a dialyzer. Moreover, the correlation between the Pb level in dialysis fluids before and after a dialyzer was weak ($r = 0.0061$).

In the haemodialysis concentrates SARAGOCLU et al. (2003) measured 3.6--61 µg Pb L^{-1}, but ELÇI et al. (1997) reported 1.67 ± 0.05 µg Pb L^{-1}. Other authors (BERKKAN, ERTAŞ 2004) using two atomic absorption techniques (flow injection hydride generation atomic absorption spectrometry FI-HGAAS and electrothermal atomic absorption spectrometry ETAAS) have shown 10-70 ng Pb L^{-1} in 12 samples of dialysis concentrates. In accordance to the AAMI Standards (MACTIER 2007) the Pb acceptable concentration in water is 0.005 mg L^{-1}.

We found that the Cd concentration in dialysates is comparable both before and after a dialyzer. Statistically significant positive correlation between Cd levels in dialysis fluids before and after a dialyzer ($r = 0.750$, $p<0.0001$) suggests that Cd is not transferred to a patient's blood. These results are in agreement with the data presented by SARAGOCLU et al. (2003) – 0.1-0.3 µg L^{-1} and ELÇI et al. (1997) – 0.83 ± 0.04 µg L^{-1}. The acceptable maximum value for Cd concentration in water using for dialysis fluids preparation is 0.001 mg L^{-1} (MACTIER 2007).

In almost 80% samples the mean Cr concentration in the examined dialysates flowing out of a dialyzer was significantly higher than before a dialyzer ($p<0.05$). The median value was also higher (approximately 10%). Negative correlation coefficient ($r = -0.185$) suggests that this element may cross semipermeable membrane of a dialyzer and may be transferred to a patient's blood.

Other authors (MILAČIČ, BENEDIK 1999) found 0.2-1.9 µg Cr L^{-1} in spent CAPD fluids, and 5.1 – 39 µg Cr L^{-1} in concentrates used in haemodialysis (SARAGOCLU et al. 2003). With respect to the AAMI Standards (MACTIER 2007), the acceptable maximum concentration of Cr is 0.014 mg L^{-1}.

In our study, when analyzing the concentrations of metals in dialysates from patients dialyzed less than 1 year we observed a tendency to retain almost all the examined elements, with the exception of Pb, but during the next years of a haemodialysis therapy this tendency decreased, probably as a result of exceeding the capacity of tissues to accumulate elements.

The examined dialysis fluids seem to be safe for patients' health. They do not contribute significant amounts of heavy metals. On the other hand, considering the cases of dialysis fluids samples contaminated with Cu and Fe and the fact that the dialysotheraphy is continued for many years, it is necessary to monitor concentrations of bioelements and heavy metals in fluids used in dialysotheraphy to prevent intoxication of patients with toxic metals.

CONCLUSIONS

1. In the examined dialysis fluids, concentrations of the determined elements did not exceed the recommended maximum concentrations of chemical contaminants in water for dialysis (AAMI), excluding Pb.

2. Differences in the concentrations of Cu, Al, Pb, and Cd before and after a dialysis treatment were not significant. However, the concentration of these elements was higher in dialysis fluids before a dialyzer. On the basis of these results, it could be concluded that some amount of these elements may have been retained in a patient's organism. The opposite was observed in the case of Cr, whose level significantly increased in postdialysis fluids ($p<0.05$).

3. Statistically significant positive correlations for the Al and Cd concentrations in fluids before and after a dialyzer may indicate that transport of both elements to a patient's body via dialysis fluids is restricted.

4. Our findings have shown that the presence of Pb in dialysates requires special attention, because it is likely that this element may cross a dialyzer membrane.

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SOLUBLE FORMS OF ZINC IN PROFILES OF SELECTED TYPES OF ARABLE SOILS

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Abstract

The research was carried out on arable soils of the region of Lublin. The aim of the study was to determine the content of Zn extractable in 1 M $HCl \cdot dm^{-3}$ in profiles of selected types of soils and the total content of Zn (measured in aqua regia) in soil samples from the accumulative layer 0-20 cm of the soils. The investigations included 8 morphological types of soils: Rendzic Leptosols (typical rendzinas), Rendzic Leptosols (humic rendzinas), Haplic Phaeozems, Calcaric Cambisols, Haplic Luvisols, Cambic Arenosols, Haplic Podzols, Eutri-Terric Histosols. The content of zinc (Zn) was measured by Atomic Absorption Spectrometry (AAS). In mineral soils the highest content of total Zn was found in rendzinas (48.0-55.8 $mg \cdot kg^{-1}$ DM) and the lowest one appeared in rusty soil and in podzolic soil – about 13 mg $Zn \cdot kg^{-1}$ each, at average 24.5 $mg \cdot kg^{-1}$. Average concentration of available forms of zinc was 5.2 mg $Zn \cdot kg^{-1}$. The amount of this element in soils was from 2.0 mg $Zn \cdot kg^{-1}$ in the level Cca of typical rendzinas to 17.0 mg $Zn \cdot kg^{-1}$ in the accumulative level of peat soil. In most profiles the highest concentration of soluble form of Zn was present in the accumulative layer and was usually decreasing deeper in the profile. The distribution of Zn in profiles was shaped by the biological accumulation of this element in the humus horizon and natural biogeochemical processes.

Key words: zinc, total contents, available forms, rendzina, chernozem soil, brown soil, lessive, rusty soil, podzolic soil, peat soil.

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ROZPUSZCZALNE FORMY CYNKU W PROFILACH WYBRANYCH TYPÓW GLEB UŻYTKOWANYCH ROLNICZO

Abstrakt

Badania przeprowadzono na glebach użytków rolnych Lubelszczyzny. Celem badań było określenie zawartości cynku przyswajalnego (po ekstrakcji próbek 1 mol HCl·dm^{-3}) w profilach wybranych typów gleb oraz jego zawartości ogólnej w próbkach z poziomu akumulacyjnego 0-20 cm (po ekstrakcji w wodzie królewskiej). Badaniami objęto 8 typów gleb, takich jak: rędzina właściwa, rędzina czarnoziemna, czarnoziem zdegradowany, gleba brunatna, gleba płowa, gleba rdzawa właściwa, gleba bielicowa właściwa oraz gleba torfowa. Stężenie cynku w przesączach glebowych oznaczono za pomocą spektrofotometru absorpcji atomowej (ASA). W glebach mineralnych najwyższą zawartość Zn ogółem stwierdzono w rędzinach (48,0-55,8 mg·kg^{-1} s.m.), najniższą zaś w glebie rdzawej i bielicowej – ok. 13 mg Zn·kg^{-1}, średnio 24,5 mg·kg^{-1}. Średnia zawartość cynku przyswajalnego wynosiła 5,2 mg Zn·kg^{-1}. Zawartość tego składnika wahała się od 2,0 mg Zn·kg^{-1} w poziomie Cca rędziny właściwej do 17,0 mg Zn·kg^{-1} w poziomie akumulacyjnym gleby torfowej. W większości profili zawartość rozpuszczalnej formy Zn jest na ogół zdecydowanie wyższa w poziomie orno-próchnicznym i maleje wraz z głębokością. Takie rozmieszczenie cynku w profilach zostało spowodowane głównie akumulacją biologiczną w poziomie próchnicznym oraz naturalnymi procesami biogeochemicznymi.

Słowa kluczowe: cynk, zawartość ogólna, formy przyswajalne, rędzina, czarnoziem, gleba brunatna, gleba płowa, gleba rdzawa, gleba bielicowa, gleba torfowa.

INTRODUCTION

Zinc is a natural component of soils, and its content depends primarily on the type of mother rocks and soil-forming processes. In agricultural areas, zinc excess originates mainly from man-made sources (industry, transport, waste substances, plant protection chemicals), which contribute to increased zinc concentration, mainly in the accumulative soil layer. Studies on the total content and the amount of available forms of microelements, including zinc, in the surface soil layer, have been carried out for many years. However, fewer smaller publications deal with concentration of available forms of microelements in deeper layers of the soil profile. Zinc occurs in soils as easily soluble compounds, which favors its migration, especially when the soil is acidic in reaction (Terelak et al. 2000, Van Oort et al. 2006). I t an be expected that mobile forms of zinc, which determine its availability to plants, will appear in different amounts in particular genetic horizons of soils belonging to different types. Determination of zinc not only in the arable layer but also in deeper horizons of a profile enables us to evaluate the abundance of zinc and to predict, more precisely, its deficiency or excess to crops.

The present study was completed in order to evaluate and assess total zinc content and zinc available forms profiles of several types of arable soils in the Lublin region.

MATERIAL AND METHODS

Examinations were carried out in October 2003 in the Lublin region. The study material consisted of the following soil morphological types: Rendzic Leptosol developed from calcaric rock, Rendzic Chernozem, Haplic Phaeozem, Calcaric Cambisol developed from loess, Haplic Luvisol developed from dust, Cambic Arenosol, Haplic Podzol developed from loamy sand, and Eutri-Terric Histosol. Two to five samples were collected from each soil type and particular horizons. Selected profiles are represented by arable soils (profiles No 1-7) and durably sodded soils (profile No 8). These profiles (No 1-8) were present in the following sites: Guzówka (No 1), Żdanówek (No 2), Rogów (No 3), Tarnawa (No 4), Łosień (No 5), Kąty (No 6), Wólka Orłowska (Nos 7 and 8).

The soil samples were air-dried, then ground in a porcelain mortar and passed through a 1 mm mesh sieve. The following properties were then determined: granulometric composition with Casagrande's areometric method as modified by Prószyński, pH by potentiometry in 1 mol $KCl \cdot dm^{-3}$, hydrolytical acidity (Hh) with Kappen's method, total carbon content with Tiurin's method. Concentrations of soluble zinc forms were determined by AAS after extraction with 1 $mol \cdot dm^{-3}$ hydrochloric acid solution (Rinkis's method). The total zinc content was analyzed after dissolving each sample in aqua regia composed of acids mixed at a 3:1 proportion, according to the Polish norm PN-ISO 11466. Zinc concentrations in soil filtrates were determined by means of the AAS flame technique. Zinc solubility was expressed as a percentage of zinc forms extracted with HCl solution in the total zinc content.

RESULTS AND DISCUSSION

Basic physicochemical properties of the soil are presented in Table 1, while the data related to the total zinc content and its forms extractable in 1 mol $HCl \cdot dm^{-3}$ can be found in Table 2.

The analysis of total zinc revealed that the soil types chosen for the study were not abundant in this element. In the accumulative soil layer (0-20 cm), the total Zn concentration varied from 13.2 to 55.8 $mg \cdot kg^{-1}$ of soil DM, with the mean level of 24.5 mg $Zn \cdot kg^{-1}$. Typical rendzina (Rendzic Leptosols) and humic rendzina (Rendzic Leptosols) were characterized by the highest zinc contents (55.8 $mg \cdot kg^{-1}$ and 48.0 $mg \cdot kg^{-1}$, respectively). Lower zinc levels were found in Chernozem, Cambisol, and Luvisol soils: 39.5; 37.8, and 27.2 $mg \cdot kg^{-1}$, and the lowest concentration of zinc (about 13 $mg \cdot kg^{-1}$) occurred in soils of light and very light granulometric composi-

Table 1

Physicochemical properties of soils

Profile No	Type	Horizon	Depth (cm)	pH_{KCl}	Hh (mmol) $(+)\cdot kg^{-1}$	Org. C $(g\cdot kg^{-1})$	(%) fraction of diameter (mm)		
							0.1-0.02	0.02-0.002	<0.002
1	Rendzic Leptosols (typical rendzinas)	Apca Cca	0-27 < 27	6.84 7.08	3.75 1.50	17.6 7.4	27 30	33 14	26 15
2	Rendzic Leptosols (humic rendzinas)	Apca Apca Cca	0-30 30-55 < 55	6.94 7.07 7.13	4.50 3.00 2.25	24.25 8.26 11.61	16 16 15	21 34	18 32 32
3	Haplic Phaeozems (chernozem)	Ap Ah AhBbr BbrC Cca	0-20 20-42 42-60 60-90 < 90	6.69 6.95 6.25 7.29 7.31	9.00 4.50 0.75 0.75 0.70	17.54 14.19 6.97 6.19 3.87	57 58 59 59 59	30 30 27 27 28	7 8 12 12 11
4	Calcaric Cambisols (brown soil)	Ap Bbr BbrC C	0-24 24-65 65-110 < 110 < 140	4.32 4.53 4.98 5.33 7.00	43.50 23.25 15.00 10.50 3.00	11.61 4.13 3.10 2.32 4.13	50 49 46 61 56	30 28 27 25 37	15 19 16 12 4
5	Haplic Luvisols (lessive)	ApEet Eet (AEt) Bt BtR	0-24 24-40 40-70 70-95	6.27 6.05 5.80 3.80 -	8.25 7.50 7.50 37.50 -	11.09 4.13 3.61 2.84	50 49 45 28 -	33 33 27 23 -	7 10 22 29 -
6	Cambic Arenosols (rusty soil)	Ap Bv C	0-30 30-80 < 80	4.60 3.68 3.80	23.25 13.50 6.00	14.70 4.64 2.32	28 5 1	7 0	2 3 0
7	Haplic Podzols (podzolic soil)	Ap Ees Bfe C	0-30 30-50 50-85 < 85	6.44 5.14 5.48 5.76	7.13 4.50 10.50 8.25	9.68 1.55 1.81 0.90	42 49 25 17	10 11 31 0	3 4 12 5
8	Eutri-Terric Histosols (peat soil)		0-22 22-32 <32	6.34 5.93 5.66	12.00 12.01 12.75		peat	peat	peat

Table 2

The content and solubility of zinc in soils

Profile No	Type	Horizon	Zn total (mg·kg^{-1})	Zn in 1M HCl·dm^{-3} (mg·kg^{-1})	Solubility of Zn (%)*
1	Rendzic Leptosols (typical rendzinas)	Apca Cca	55.8 -	8.4 2.0	15.0 -
2	Rendzic Leptosols (humic rendzinas)	Apca Apca Cca	48.0 - -	6.7 3.2 2.8	14.0 - -
3	Haplic Phaeozems (chernozem)	Ap Ah AhBbr BbrC Cca	39.5 - - - -	9.6 5.2 4.8 4.9 4.5	24.3 - - - -
4	Calcaric Cambisols (brown soil)	Ap Bbr BbrC C	37.8 - - - -	5.7 3.0 4.6 3.5 6.6	15.1 - - - -
5	Haplic Luvisols (lessive)	ApEet Eet (AEt) Bt BtR	27.2 - - - -	5.7 3.1 3.9 3.5 -	21.0 - - - -
6	Cambic Arenosols (rusty soil)	Ap Bv C	13.2 - -	4.2 5.5 2.6	31.9 - -
7	Haplic Podzols (podzolic soil)	Ap Ees Bfe C	13.7 - - -	6.9 2.3 3.1 3.2	50.4 - - -
8	Eutri-Terric Histosols (peat soil)	Mt O_1tni O_2tni	- - -	17.0 8.3 4.6	- - -
Mean			24.5	5.2	-

*percentage of soluble forms in total content of metal

tion, i.e. Arenosol and Podzolic soils. The analysis of the experimental data indicates that the highest zinc amount was present in soils characterized by a high humus content and large amounts of finest particles. According to TERELAK et al. (2000), zinc content in soil depends on a soil type, and is strongly conditioned by the soil's granulometric composition. In acidic brown soils, SKŁODOWSKI and ZARZYCKA (1997) determined about 35 mg Zn·kg^{-1} in the humus horizon, and that concentration decreased deeper in the profile. These authors claimed that zinc accumulation in the humus layer is a product of biological accumulation of this element and agricultural use of the soil. Different sub-types of gypsum rendzinas examined by NIEMYSKA-ŁUKASZUK and CIARKOWSKA (1999) were characterized by the highest total zinc concentrations in surface layers, which tended to decrease in deeper layers of the profile. These authors found statistically significant dependence of total zinc on colloid clay content. Also TERELAK et al. (2000) confirmed significant correlation between zinc amounts in soils and such properties as < 0.02 mm fraction content, organic matter content, and pH, which indicates, in the authors' opinion, that zinc presence in soils also depends on other factors.

Total zinc content in the 0-20 cm layer of the soils we examined did not exceed values accepted as the natural background in evaluation of soil contamination, which is 50 $mg \cdot kg^{-1}$ for very light and light soils, and 100 $mg \cdot kg^{-1}$ for heavy soils (KABATA-PENDIAS et al. 1993).

Concentration of zinc extractable in 1 mol $HCl \cdot dm^{-3}$ varied between particular soil profiles. In most of the profiles, this form appeared in higher amounts in the humus horizon, where it reached the levels from 4.2 to 17.0 $mg \cdot kg^{-1}$, than in deeper layers. Brown soil was an exception (profile No 4), as it contained 6.6 mg $Zn \cdot kg^{-1}$ in the mother rock horizon, hence more Zn than within surface layer Ap (5.7 $mg \cdot kg^{-1}$). Another exception was Arenosol, containing slightly more zinc in Bv (5.5 $mg \cdot kg^{-1}$) than in Ap horizon (4.2 $mg \cdot kg^{-1}$). The content of the zinc form examined in 5 soil types (Rendzic Leptosol, Rendzic Chernozem, Haplic Phaeozem, Cambic Arenosol, and Eutri-Terric Histosol) apparently decreased with the profile depth. Such a tendency did not occur in Cambisol and Luvisol soils. However, large differentiation in the content of zinc in particular horizons confirmed the influence of elution processes on the distribution of this element within a profile. VAN OORT et al. (2006), when examining the dynamics of Zn behavior, observed that the metal was moved in soil mainly in a dissolved form, unlike Pb which moved mainly in a colloidal form. The authors also found that the interaction of the soil solution and specific pedological features leads to enhanced Zn accumulation in clay-iron coatings characteristic of illuvial B horizon. BARAN et al. (2003) reported that it was only the genetic horizon that affected the content of zinc extractable in 1 mol $HCl \cdot dm^{-3}$ in Podzolic soils. According to these authors, higher concentrations of this form of zinc, like total zinc content, occurred in the humus horizon rather than in deeper layers. KORZENIOWSKA and STANISŁAWSKA-GLUBIAK (2004) determined a high correlation coefficient between organic matter and zinc extractable in 1 mol $HCl \cdot dm^{-3}$, although they did not achieve significant correlations between organic matter and zinc amounts in plants. Also GAMBUŚ et al. (2004) did not find strong correlations between Zn concentration in plants and Zn extracted from the soil using 1 mol $HCl \cdot dm^{-3}$, except for oats roots. However, these authors recorded a very strong correlation between zinc content in plants and the metal level extracted with non-buffered solutions with low extraction strength. On the basis of our results regarding available zinc forms in the examined mineral soil types from the Lublin region, it can be stated that profiles Nos 1-5, characterized by the granulometric composition of heavy soil, showed low zinc abundance, while very light and light soils (profiles Nos 6 and 7) revealed high abundance (ZALECENIEA NAWOZOWE 1990).

Zinc solubility in rendzinas and Calcaric Cambisol was poor (14-15%), while higher solubility was recorded in Luvisol (21%) and Haplic Phaeozem (24%); the best zinc solubility was observed in Arenosol and podzolic soils (32% and 50%, respectively). BADORA (2002) reported that binding of heavy metals ions by organic matter depended on the soil acidity. Zinc at pH 5.8 is bound by humic acids up to 60% of its cationic concentration, whereas at lower pH values, its sorption almost disappears. This may explain low Zn solubility in the rendzinas and high one in Arenosol and podzolic soils. Furthermore, a relatively large percentage of soluble forms in the total zinc content in light soils may indicate that Zn was supplied from anthropogenic sources. According to TERELAK et al. (2000), zinc migration within the environment is favored by low acidity of soil as well as humus substances, namely fulvic acids and some fractions of humic acids forming soluble complexes.

CONCLUSIONS

1. The mean content of available zinc (extractable with 1 mol $HCl \cdot dm^{-3}$) in the soils was 5.15 $mg \cdot kg^{-1}$ DM. In most of the soils examined, except Cambisol and Arenosol, the highest amounts of available zinc were present in the humus horizon, decreasing deeper in a soil profile depth.

2. Cambisol and luvisol soils were characterized by high abundance in zinc extractable in 1 mol $HCl \cdot dm^{-3}$, while rendzinas and Chernozem by were low in this form of zinc; the highest zinc concentration was recorded in Eutri-Terric soil.

3. The zinc solubility in studied soils can be put in the following order: Rendzic Chernozem < Rendzic Leptosol = Calcaric Cambisol < Haplic Luvisol < Haplic Phaeozem < Cambis Arenosol < Haplic Podzol.

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CONTENT OF MAGNESIUM AND OTHER FERTILIZER COMPOUNDS IN STABILIZED AND DEWATERED SEWAGE SLUDGE FROM THE MUNICIPAL SEWAGE TREATMENT PLANT IN RECZ

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Abstract

The aim of this study was to determine the content of magnesium and other fertilizer compounds (Ca, K, Na, P, N and S) in stabilized and dewatered sewage sludge stored on dewatered sites at the Municipal Treatment Plant in Recz in 1994-2003. Discharge of post galvanic sewage to the municipal sewer system was evaluated at approximately 10% processed sewage at this treatment plant .The fertilizer value and possible utilization of the sludge was evaluated.

When evaluating possible use of the sewage sludge for fertilization purposes in agriculture, it was found that the concentration of magnesium in sludge samples was in the range of 0.2-0.5, on average 0.33%, and was substantially lower than the level of this compound given in literature. The content of this compound in sewage sludge is found in the range 0.02 do 7.6% and depends on the type of a treatment plant, treatment process, and also on the share of industrial sewage. Sewage sludge applied in agriculture should be characterized by a high content of magnesium (approximately 0.6%).

Some physical and chemical properties of the examined sewage sludge were very good (loose soil consistency, lack of odor, humidity from 40 to 80%, suitable pH and high concentration of Ca, K, Na, P, N and S).

The reaction was in the pH range from 5.6 to 7.0 (from slightly acid to neutral), which is typical of sewage sludge obtained during the biological processing of municipal sewage.

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The mean content of main nutrient compounds in the sludge, which was N – 2.7%, P – 4.7 and K – 0.18%, enables classification of this material as suitable for use in agriculture.

Taking under consideration the content of all macronutrients and physical properties of the sludge produced at the Municipal Treatment Plant in Recz, it can be concluded that this sewage sludge may be applied on agricultural land and used for reclamation of degraded soils. But every batch of sewage sludge should be analyzed and evaluated individually because it may contain excessive amounts of heavy metals due to periodical discharge of post galvanic sewage to municipal sewerage.

Key words: magnesium, nutrient compounds, post galvanic sewage, sludge, utilisation.

ZAWARTOŚĆ MAGNEZU I INNYCH SKŁADNIKÓW NAWOZOWYCH W USTABILIZOWANYCH I ODWODNIONYCH OSADACH ŚCIEKOWYCH Z MIEJSKIEJ OCZYSZCZALNI ŚCIEKÓW W RECZU

Abstrakt

Celem pracy było określenie zawartości magnezu i innych składników nawozowych (Ca, K, Na, P, N i S) w ustabilizowanych i odwodnionych osadach ściekowych zgromadzonych w latach 1994-2003 na kwaterach odwadniających Miejskiej Oczyszczalni Ścieków w Reczu, do której dopływa ok. 10% ścieków galwanicznych. Ponadto zdefiniowano wartość nawozową tych osadów oraz możliwości ich wykorzystania.

Oceniając przydatność badanych osadów ściekowych do celów nawozowych, stwierdzono, że w przebadanych próbkach koncentracja Mg była niższa niż zawartość tego pierwiastka podawana w literaturze i wynosiła 0,2-0,5% średnio 0,3%. Zawartość tego pierwiastka w osadach ściekowych zależy od rodzaju oczyszczalni ścieków, sposobu oczyszczania, a także ilości ścieków przemysłowych, i może wynosić od 0,02 do 7,6% s.m. W osadach ściekowych wykorzystywanych w rolnictwie jako nawóz jest zazwyczaj wysoka (ok. 6% s.m.) zawartość magnezu.

Badane osady charakteryzowały się bardzo dobrymi właściwościami fizycznymi, były bowiem sypkie, ziemiste i prawie zupełnie bezzapachowe, o uwilgotnieniu od 40 do 80%, miały odpowiedni odczyn i dużą zawartość Ca, P i S. Ich odczyn – od lekko kwaśnego do obojętnego (pH od 5,6 do 7,0) – był typowy dla osadów ściekowych powstających podczas biologicznego oczyszczania ścieków komunalnych. Średnia zawartość podstawowych składników pokarmowych w osadach (N – 2,7%, P – 4,7% K – 0,18%) pozwala na zaklasyfikowanie ich do grupy osadów ściekowych nadających się do stosowania w rolnictwie. Biorąc pod uwagę zawartość wszystkich makroskładników oraz ich cechy fizyczne, osady z miejskiej oczyszczalni ścieków w Reczu mogą być wykorzystywane na cele rolne i rekultywacyjne, pod warunkiem jednak, że każdą partię tych osadów należy przebadać pod kątem zawartości metali ciężkich ze względu na dopływ do oczyszczalni ścieków pogalwanicznych.

Słowa kluczowe: magnez, składniki pokarmowe, osad ściekowy, ściek pogalwaniczny, wykorzystanie.

INTRODUCTION

Amount of sewage sludge emerging from treatment plants depends on the sewage composition, manner and degree of their treatment and time of organic matter decomposition during the sludge stabilization process. But it also depends on the hydration degree of sewage sludge.

In 2000-2007, amounts of sewage sludge produced in municipal treatment plants steadily increased, which can be directly attributed to the increasing length of sewer network in our country and constantly growing households and industrial plants served by sewage treatment plants (GUS 2005). It is easy to foresee that production of sewage sludge will continue to grow in the next years.

Many authors pointed out that specific characteristics of sewage sludge depend on a number of factors such as the kind of treated sewage, technology of sewage treatment and manner of sludge stabilization (OUTWATER 1994, IMHOFF, IMHOFF 1996, KALEMBASA, KALEMBASA 1997, SĄDECKA, JĘDRCZAK 2004). These authors underline that increasing quantities of permanently produced sewage sludge are a perfect fertilized material, which may be applied on agricultural land and used for reclamation of degraded soils, simultaneously decreasing their amounts dumped on landfills.

According to the Polish legislation (*Ustawa o odpadach*... 2001), municipal sewage sludge can be used if it is stabilized and appropriately prepared for the purpose of use. Such preparation involves biological, chemical and thermal processing sewage sludge or other processes which reduce susceptibility of sewage sludge to putrefaction and eliminate threats posed by such material to environment or human health. The most popular method of using sewage sludge in Poland is its utilization on agricultural land.

It is often emphasised in literature that the fertilizer value of municipal sewage sludge is conditioned mostly by its content of organic matter, nitrogen, phosphorus and trace elements. The presence of these compounds is necessary for the proper development of plants and animals. (MAZUR 1996, BARAN et al. 1999, GAMBUŚ 1999, JOHANSSON et al. 1999, BORUSZKO et al. 2000). It is also important when making a decision on how to use particular batches of sewage sludge.

The aim of this study was to determine the content of magnesium and other fertilizer compounds (Ca, K, Na, P, N and S) in stabilized and dewatered sewage sludge stored on dewatered sites at the Municipal Treatment Plant in Recz in 1994-2003. The fertilizer value of the sludge as well as possibilities of its utilization were evaluated.

MATERIALS AND METHODS

Twenty four composite samples of stabilized and dewatered sewage sludge stored on dewatered sites at the Municipal Treatment Plant in Recz in 1994--2003 were collected from the depth 0-20 cm for further analysis using Egner's sampler.

Composite sample (ca1 kg) of fresh materials were dried and crushed in a laboratory mortar and than sieved through ř 1 mm sieve. The amount of 1 g of air dry sewage sludge was digested in a microwave in a mixture of concentrated nitric and perchloric acids at a ratio 3:1 (V / V) and with addition of 30% perhydrol for further analysis of macroelements (Mg, K, Na, Ca, S). Nitrogen and phosphorus were determined using the wet mineralization method in open configuration with sulphur acid.

The reaction, electric conductivity, content of organic matter and moisture in fresh samples of stabilized and dewatered sewage sludge were also determined. The employed methods are shown in Table 1.

In every analysis a test of blind samples was conducted as the control of all results.

Table 1

Range of analysis and applied methods of sewage sludge samples

Analysed materials	Range of analysis	Methods of analysis
Stabilized and dewatered sewage sludge	fresh samples of sewage sludge	
	pH	potentiometrically, using combine glass electrodes
	conductivity	conductometrically using combine graphite electrodes
	moisture	using of radwag measure with direct lecture of moisture
	contents of organic matter	method of dry incinerating in 450°C in a muffle oven
	air dry samples of sewage sludge	
	phosphorus and sulphur	colorimetrically with use of a Marcel Media Eko spectrometer
	potassium and sodium	flame emission photometry using a Solaar Unicam 929 spectrophotometer
	calcium and magnesium	atomic absorption using a Solaar Unicam 929 spectrophotometer
	nitrogen	distillation method with use of a Vapodest 30 by Gerhardt

RESULTS AND DISCUSSION

Stabilized sewage sludge stored in years 1994-2003 on dewatering sites in amounts ca 265 Mg d.m. manifested very good physical properties. This material, as indicated by the results presented in Table 2, was loose, looked like earth, was odourless and had a moisture content in the range 40 to 80%. These properties of sludge substantially differ from the ones reported in literature (stickiness, odour, formation of clods during drying) (BIEŃ 2002).

The reaction of the tested sewage sludge was from slightly acidic to neutral (pH 5.6-7.0) and typical of sludge produced during the biological treatment of municipal sewage (SEBASTIAN, SZPADT 1999. KALISZ et al. 2000). The electric conductivity widely ranged from 0.1 to 4.1, on average 2.25 mS cm^{-1}, and showed substantial variability (V 58%).

The evaluation of the electric conductivity of salinity of water suspension prepared from the sewage sludge shows that most of the sewage samples contained a toxic level of salinity (1 g NaCl$\cdot dm^{-3}$) for majority of cultivated crops.

Noteworthy is the fact that the content of organic matter in the sewage sludge samples from the Municipal Treatment Plant in Recz is high, ranging from 40.0 to 59.7%, on average 53.5%, (Table 2) and shows only small differences between individual samples (V–9%), which proves that it has good fertilizer properties.

Table 2

Basic parameters of selected properties of stabilized and dewatered sewage sludge samples from the Municipal Treatment Plant in Recz collected in years 1994-2003

n = 24	pH (H_2O)	Conductivity ($mS\cdot cm^{-1}$)	Salinity (g NaCl$\cdot dm^{-3}$)	Moisture (%)	Content of organic matter (%)
x	6.3	2.25	1.4	60.2	53.5
Min	5.6	0.1	0.7	39.6	40.0
Max	7.0	4.3	2.4	79.0	59.7
S	0.5	1.25	0.4	10.3	4.6
V (%)	7.3	55.7	31.5	17.1	8.6

As show in Table 3, the sewage sludge samples from the Municipal Treatment Plant in Recz was characterized by a high content of nitrogen, sulphur and phosphorus but the content of magnesium (0.2-0.5, on average 0.3%) was substantially lower than given in literature.

The studies conducted by BIEŃ (2002) and BIEŃ et al. (2002) showed a high content of calcium and very low magnesium in municipal sewage sludge. These authors pointed out that concentration of these macronutrients mainly depended on the kind of discharged industrial sewage. In some cases the content of calcium in sewage sludge exceeded 10% of d.m., with an average of 2-4%, while the content of magnesium was in the range 0.1 to 1.8% d.m. In sewage sludge from medium size sewage treatment plants the content

Table 3

Contents of fertilizer components in stabilized and dewatered sewage sludge samples from the Municipal Treatment Plant in Recz

n = 24	N	P	K	S	Mg	Na	Ca
	(%)						
x	2.7	4.7	0.18	2.8	0.3	0.06	1.5
Min	1.3	1.9	0.08	1.8	0.2	0.02	0.9
Max	3.7	6.1	0.24	4.8	0.5	0.11	2.3
S	0.5	1.0	0.04	0.9	0.07	0.02	0.4
V (%)	19.8	21.8	21.9	31.6	22.0	33.9	23.96

of magnesium ranged from 0.02 up to 7.6% d.m. and was similar to the range of the magnesium content (0.2 to 0.5%, on average 0.3%) in sewage sludge from the Municipal Treatment Plant in Recz.

The low content of magnesium in the sewage sludge examined may have resulted from some disturbance of the treatment process caused by periodical inflow of insufficiently purified post galvanic sewage to the treatment plant. This discharge of technological sewage to the municipal sewerage system substantially affected the efficiency of the treatment process caused by excessively high concentrations of heavy metals in the influx of post galvanic sewage.

Kalembasa and Kalembasa (1997) as well as Gambuś (1999) emphasise that the content of magnesium in sewage sludge applied on agricultural land as fertilizer should usually be higher (ca 6%). Consequently, the examined sewage sludge with the maximum content of magnesium equal 0.5% is not good as fertilizer and cannot be qualified as material potentially used for agricultural purposes.

There are no substantial differences between the properties of sewage sludge samples from the Municipal Treatment Plant in Recz and sludge from other municipal treatment plants (Wang et al. 2005, Kalisz et al. 2000). Such a comparison reveals mainly the similarity of the chemical composition of the sludge from the Municipal Treatment Plant in Recz, especially its pH, content of organic matter and total nitrogen to the sludge examined by Piotrkowska and Dutka (1987). However, the former has a considerably higher content of phosphorus and lower concentrations of calcium, magnesium, potassium and sodium.

The content of nitrogen and phosphorus found in sewage sludge samples from the Municipal Treatment Plant in Recz is relatively high and similar to the content of these compounds in composts produced from waste plant residues (Kokot, Zabłocki 2003) or compost produced with addition of sewage sludge (Czekała 2000, Baran 2004, Oleszczuk 2006) or the content of these fertilizer compounds given by BOJANOWSKA et al. (1982), PIOTRKOWSKA and DUTKA (1987) and MERRINGTON et al. (2003).

These findings confirm the high fertilizer value of stabilized and dewatered sewage sludge samples from the Municipal Treatment Plant in Recz, mainly because of their high content of nitrogen, phosphorus, organic matter and very good physical properties. Such sewage sludge, although low in magnesium, may successfully be used in agriculture and for reclamation of degraded sites.

Despite all positive characteristics of dewatered sewage sludge, such material is often excluded from application in agriculture because of its high content of heavy metals, which cause contamination of environment, especially soil. Thus, every batch of sludge from the Municipal Treatment Plant in Recz, before it is used in agriculture or for reclamation purposes, should be analyzed to ensure that its content of heavy metals is not excessive.

In addition, the Municipal Treatment Plant in Recz periodically receives industrial sewage, which excludes the use of generated sewage sludge from agricultural utilization because of the high concentrations of heavy metals.

CONCLUSIONS

1. The tested sewage sludge was characterized by very good physical properties (loose soil consistency, lack of odour, moisture from 40 to 80%), suitable pH from 5.6 to 7.0 and high concentration of C, Ca, P and S. The pH ranged from 5.6 to 7.0 (from slightly acidic to neutral), which is typical of sewage sludge obtained during the biological processing of municipal sewage. The content of C, Ca. P and S was high.

2. The concentration of magnesium in sludge samples was 0.2-0.5 (mean 0.33%), and was substantially lower than the level of this compound given in literature.

3. The mean content of the main nutrients in the sludge, N – 2.7%, P – 4.7% and K – 0.18%, means that this material is suitable for use in agriculture.

4. Considering the content of all macronutrients and physical properties of the sewage sludge produced at the Municipal Treatment Plant in Recz, this sewage may be applied on agricultural land and used for reclamation of degraded soils.

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EFFECT OF SILICATE FERTILIZERS ON YIELDING OF GREENHOUSE CUCUMBER (*CUCUMIS SATIVUS* L.) IN CONTAINER CULITIVATION

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Abstract

Silicone (Si), a very abundant element in the Earth's crust, is beneficial for plants, animals and humans. Despite its abundance in nature, it is often unavailable in sufficient quantities. Cucurbits are believed to accumulate elevated quantities of Si and benefit from Si fertilization. It is believed that higher Si content in cucumber plant is connected with increased yields as well as improved resistance to diseases and tolerance to abiotic stresses, for example drought. The beneficial effects of Si have been confirmed by the present study, in which cucumbers were grown in soil and in liquid nutrient solutions. The aim of the experiments has been to evaluate the effect of several silicates supplementing peat-based growing substrates on yield and Si content in growing media and in cucumber plants. For this purpose, pot experiments were carried out in an unheated greenhouse in 2005-2007. Cucumber plants were cultivated in 12-liter containers filled with substrates amended with Na-, K-, Ca- and ammonium silicates at rates of 2 or 4 g per liter. The results indicated that slow-release Ca- and NH_4-silicates contributed to increased yield and elevated Si content in cucumber leaves and fruits. The effect of the other silicates was not certain and, additionally, dependent on their concentrations. Water-soluble Na- and K-silicates caused increased Na or K concentration and raised pH of substrates. The results revealed that increased yields depended on the number of fruits rather than their average weight. The silicates of calcium and ammonium can be valuable, slow-release fertilizers in cucumber cultivation on organic (peat) substrates. Even in quantities as high as 4 g per liter of substrate, they did not cause drastic changes of the pH and salinity of growing media and were a good source of Si available to cucumber plants.

Key words: silicates, fertilization, cucumber, growing medium, yield.

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WPŁYW NAWOZÓW KRZEMOWYCH NA PLON OGÓRKA SZKLARNIOWEGO W UPRAWIE WAZONOWEJ

Abstrakt

Krzem jest zaliczany do pierwiastków dobroczynnych dla roślin, zwierząt i ludzi. Pomimo jego obfitości w przyrodzie pobierany jest jednak niejednokrotnie w zbyt małych ilościach, co zależy również od systematycznej przynależności poszczególnych gatunków. Ogórek należy do gatunków korzystnie reagujących na nawożenie krzemem i kumulujących jego większe ilości. Uważa się, że zwiększenie zawartości krzemu w roślinach przyczynia się również do wzrostu odporności roślin na niektóre choroby oraz stresy abiotyczne. Stwierdzono korzystne działanie krzemu w uprawie glebowej oraz na pożywkach płynnych. Celem badań było określenie wpływu kilku krzemianów na plonowanie ogórka Milenium F_1 i zawartość pierwiastków w substratach torfowych i roślinach. W latach 2005-2007 przeprowadzono badania wazonowe w szklarni nie ogrzewanej. Rośliny ogórka uprawiano w wazonach zawierających po 12 dm^3 substratu torfowego uzupełnianego krzemianami sodu, potasu, wapnia lub amonu w ilości 2 lub 4 g w 1 dm^3 substratu. Stwierdzono korzystne oddziaływanie spowolnionych krzemianów wapnia i amonu na plonowanie roślin oraz wzrost zawartości krzemu w liściach i owocach ogórka. Działanie pozostałych krzemianów nie było jednoznaczne i zależało także od stężeń nawozów. Rozpuszczalne krzemiany sodu i potasu powodowały wzrost zawartości tych pierwiastków oraz odczynu substratu. Wykazano, że zwyżka plonów ogórka wiązała się raczej ze wzrostem liczby owoców, a nie z ich masą. Krzemiany wapnia i amonu mogą w uprawie ogórka na substratach organicznych stanowić cenne nawozy o spowolnionym (długotrwałym) działaniu. Nawet w znacznych ilościach (4 g w 1 dm^3 substratu) nie powodują drastycznych zmian odczynu pH i zasolenia oraz są źródłem krzemu przyswajalnego przez rośliny.

Słowa kluczowe: krzemiany, nawożenie, ogórek, podłoże uprawowe, plon.

INTRODUCTION

Silicone is one of the most abundant elements on the surface of the Earth (Hou et al. 2006). Although its physiological and nutritional role is still uncertain (Belanger et al. 1995), there is growing interest in silicone, especially with regard to the cultivation of cucumber, a species known to accumulate high quantities of Si. Plants can extract very high quantities of silicone per unit of surface (Carnelli et al. 2001). It is also known that silicone can interact with Al and other toxic elements i.e. Mn, elevating their toxicity to plants (Iwasaki, Matsumura 1999, Badora, Grenda 2002, Grenda, Skowrońska 2004). It was found that Si application had beneficial effects in cucumber cultivation as well in soil as in soilless cultures (Miyake and Takahashi 1983, Lee et al. 2000). The aim of the experiments reported in this paper was to evaluate the effect of several silicates used as amendments to peat-based growing substrates on yield and Si content in growing media and in cucumber plants.

MATERIALS AND METHODS

The experiment was carried out in an unheated greenhouse at the Research Institute of Vegetable Crops in Skierniewice, in 2005-2007. Seeds of cv. Milenium F_1 greenhouse cucumber were planted at the beginning of May, and 4 weeks later transplants were transferred to growing containers. The experiment was terminated at the end of September. Cucumber plants were grown in 12-liter containers filled with peat substrate. The control substrate of pH 6.2 contained per 1 dm^3: $N\text{-}NO_3$ – 140 mg, P – 110 mg, K – 160 mg, Ca – 2250 mg, Mg – 165 mg and micronutrients. The experimental treatments consisted of the control substrate amended with different silicates (sodium, potassium, calcium and ammonium). In 2004, preliminary trials were performed to estimate proper rates of silicates to be used in further experiments. A range of 1.0-6.0 g of silicates per 1 dm^3 of growing medium was tested. Eventually, it was decided that the experimental rates of silicates would be 2.0 and 4.0 g per 1 dm^3. In 2006 and 2007 sodium silicate was not tested because in 2005 at the rate of 4 g per 1 dm^3 it caused an adverse effect on the substrate's pH, Na content and appearance of cucumber plants. Each treatment consisted of 16 plants (4x4 replications). During the growing period plants were watered with tap water and fertilized every second watering with liquid fertilizer according to a current chemical analysis of the growing media. Fruits were usually collected twice a week; their weight and number were recorded. The experiments were arranged in a one-factorial design. The experimental results were evaluated statistically with analysis of variance. Mean values were compared with Newman-Keuls test at p=0.05. For chemical analysis, the substrates and plant material were extracted with acetic acid at concentrations of 0.02% and 2%, respectively. The chemical analyses of the growing media, leaves and fruits were performed using an ICP analyser. Phosphorus was analyzed with the colorimetric method using a Spekol apparatus and $N\text{-}NO_3$ with a colorimetric automatic flow system.

RESULTS AND DISCUSSION

The results are given in Tables 1-3 and Figure 1. During the preliminary experiments performed in 2004 it was found out that silicates added to the substrates at rates over 4 g per 1 dm^3 of media were excessive, particularly in the case of water-soluble Na- and K-silicates. The results obtained in 2005 clearly indicated that supplying the media with the tested silicates, except $(NH_4)_2SiO_3$, caused increased concentration of particular elements at the end of the growing season (Table 1). Also the content of soluble Si was raised in all the treatments. Na-, K- and Ca-containing silicates at both

Table 1

Effect of growing medium amendment with silicone fertilizers on content of elements at the end of the growing season and yield of cucumber fruits, 2005

Treatment ($g\ dm^{-3}$)	pH	Salinity	$N\text{-}NO_3$	P	K	Ca	Mg	Na	Si	Yield
		($g\ dm^{-3}$)	($mg\ dm^{-3}$)							($dag\ plant^{-1}$)
Control	6.5	0.2	<5	86	62	2754	180	55	4.5	186 *b*
Na_2SiO_3 – 2.0	7.2	0.5	<5	100	59	2588	176	261	14.2	177 *b*
Na_2SiO_3 – 4.0	7.7	0.6	<5	90	60	2411	162	336	18.6	177 *b*
K_2SiO_3 – 2.0	7.1	1.0	<5	115	398	2571	158	88	13.6	215 *a*
K_2SiO_3 – 4.0	7.5	1.1	<5	119	675	2455	169	90	22.4	186 *b*
$CaSiO_3$ – 2.0	7.0	1.0	<5	122	61	3112	183	212	14.5	181 *b*
$CaSiO_3$ – 4.0	7.0	1.2	<5	132	67	3390	171	280	15.1	179 *b*
$(NH_4)_2SiO_3$ – 2.0	6.4	0.9	<5	76	54	2623	148	287	6.6	216 *a*
$(NH_4)_2SiO_3$ – 4.0	6.5	1.1	<5	68	50	2373	139	311	8.8	176 *b*

Data marked with the same letters within columns did not differ statistically, according to Newman-Keuls test at $p = 0.05$.

Table 2

Effect of medium amendment with potassium-, calcium- and ammonium-silicates at rates of 2 and 4 g dm^{-3} on yield and growth of cucumber. Data per plant, 2006

Treatment	Yield of fruits		Fruits number		Weight of 1 fruit		Fresh wt of 1 plant	
	(dag)	(%)	(no)	(%)	(dag)	(%)	(dag)	(%)
Control	190 *b*	100	12.7 *ab*	100	15.0	100	36 *b*	100
K_2SiO_3 2 g dm^{-3}	162 *c*	85	10.4 *b*	82	15.7	105	34 *b*	94
K_2SiO_3 4 g dm^{-3}	159 *c*	84	10.3 *b*	81	15.4	103	38 *b*	106
$CaSiO_3$ 2 g dm^{-3}	152 *c*	80	12.8 *ab*	101	11.9	79	49 *a*	136
$CaSiO_3$ 4 g dm^{-3}	163 *c*	80	10.8 *ab*	85	15.1	100	38 *b*	106
$(NH_4)_2SiO_3$ 2 g dm^{-3}	230 *a*	121	15.3 *a*	120	15.0	100	51 *a*	142
$(NH_4)_2SiO_3$ 4 g dm^{-3}	220 *a*	116	14.0 *a*	110	15.7	100	53 *a*	147

Data marked with the same letters within columns did not differ statistically, according to Newman-Keuls test at $p = 0.05$.

tested rates caused increase of pH. K- and NH_4 – silicates at lower rates caused statistically proven yield increase of cucumber fruits. In 2006 the highest yield and fruit number were obtained with $(NH_4)_2SiO_3$ at the lower rate of 2 g per liter. The fresh weight of whole plants also increased under the influence of $(NH_4)_2SiO_3$ and $CaSiO_3$ at the rate of 2 g per 1 dm^3 of substrate (Table 2). The chemical analysis of the growing substrates as well

Table 3

Effect of growing medium amendment with 2 g dm^{-3} of calcium silicate (Ca Si) and 2 g dm^{-3} ammonium silicate (N Si) on the content of elements in the substrate, leaves and fruits, analyzed twice in 2007

Material date	Treatment	pH H_2O	Salinity	$N\text{-}NO_3$	P	K	Mg	Ca	Si
			(g NaCl dm^{-3})						
Substrate Aug. 07	control	7.8	0.46	10	79	234	224	2294	10.5
	Ca Si	7.8	0.62	10	133	187	208	2236	9.73
	N Si	7.7	0.89	58	93	130	219	2454	10.4
				($mg\ kg^{-1}$ d.m.)					
Leaves Jul. 20	control			1160	4500	28 019	4595	43820	263.7
	Ca Si			3770	2900	35 683	4168	50460	381.7
	N Si			12120	4100	35 512	4518	48200	308.9
Fruits Jul. 20	control			113	6610	32 348	2839	3940	3.9
	Ca Si			199	4240	39 614	2860	5290	2.38
	N Si			1050	7310	39 965	2529	4220	0.98
Leaves Aug. 07	control			1500	4700	26 454	7897	52300	454.8
	Ca Si			1620	3100	27 092	6194	53830	517.6
	N Si			3280	3800	25 339	6386	60420	620.8
Fruits Aug. 07	control			964	6700	42 312	3038	3840	< 0.1
	Ca Si			500	4300	38 752	2849	4060	8.74
	N Si			796	5800	41 193	2853	3630	4.96

as leaves and fruits, which was performed twice in 2007 (Table 3), indicated that enrichment of peat substrate with Ca- and NH_4 – silicates caucused increased salinity and P content as well as decreased K content. The content of elements in cucumber leaves and fruits depended strongly on the time when plant parts were sampled. The results showed that leaves accumulated several-fold more Si than fruits and that silicates-amended growing media caused higher Si accumulation in leaves and fruits (Table 3). It was also demonstrated the lower rate of silicates usually evoked the response of cucumber plants, expressed as increased yields (Figures 1a, b). These figures clearly show that higher yields (Figure 1a) were connected with the number of fruits per plant (Figure 1b)

Miyake and Takahashi (1983) reported beneficial effect of soil fertilization with silicates on the growth and yield of cucumber plants and reduced damage caused by wilt disease. Excessive silicate fertilization resulted in increased soil pH and inferior growth of cucumber. Application of organic mat-

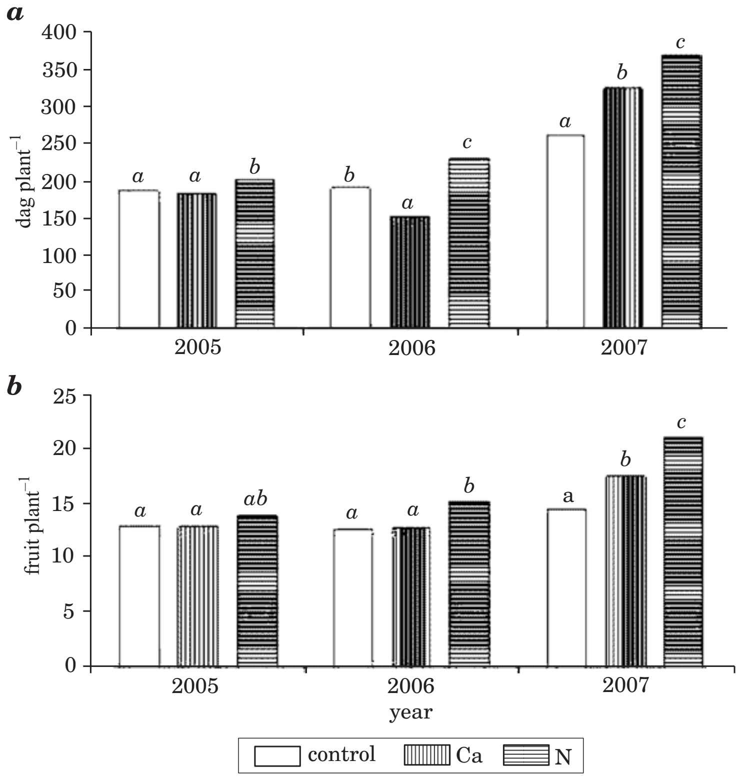

Fig. 1. The effect of substrate amendment with 2 g dm^{-3} calcium silicate (Ca) or ammonium silicate (N) on the yield (*a*) and fruit number (*b*) in 2005-2007. Data marked with the same letters did not differ significantly within years, according to Newman-Keuls test at p=0.05

ter helped to improve soil pH. Rodgres-Gray and Shaw (2004) also stated that organic matter amendment to soil altered plants' tolerance to foliar and stem diseases in winter wheat. It is of interest that the yield increase in our experiments was connected with the number of fruits. In our previous work (Górecki et al. 2004) on eggplant, we reported that Si-fertilizers caused more numerous seed set. Distribution of silicone in cucumber plants has been described by Abd Elmoniem et al. (1997) and Samuels et al. (1991). Fawe et al. (1998) and Dragisić Maksimović et al. (2007) discussed the physiological role of silicone in modulation and metabolism of different compounds in cucumber plants.

CONCLUSIONS

1. Insoluble, slow-release calcium- and ammonium-silicate fertilizers proved to be valuable amendments of peat-based organic growing media for cucumber cultivation.

2. At doses of 2 g per 1 dm^3 of growing media, they contributed to increased cucumber yield and Si contents in leaves and fruits of cucumber plants.

3. Increased fruit yields were more strongly connected with the fruit number per plant rather than the average fruit weight.

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ASSESSMENT OF CHEMICAL COMPOSITION AND SANITARY STATE OF SAND IN SELECTED SANDBOXES IN KRAKOW

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Abstract

The aim of the research was to assess the chemical composition and sanitary state of sandboxes in Krakow. Samples of sand were collected from 42 sandboxes located on playgrounds in housing estates and municipal (urban) parks. In the samples the following were determined: reaction, organic matter and the content of total and soluble forms of several elements. The sand in the analyzed sandboxes had highest content of Zn, while the concentrations of other metal appeared in the following decreasing order: > Pb > Cr > Ni > Cu > Cd (total forms) and Zn > Pb > Cu > Ni > Cr > Cd (soluble forms). The highest potential for ingesting heavy metals by humans due to accidental consumption of sand was found for Zn, followed by Pb > Cu > Ni > Cr > Cd. Children were at a higher risk of exposition to heavy metals than adults. On no occasion, the permissible limits of heavy metals for urbanized and built-up areas (group B) – set up by the regulation of the Minister for Environment on soil and earth quality – were exceeded. The same applies to the threshold levels of contaminants established for soils polluted by man-made sources. However, the sandboxes were found to be in poor sanitary conditions.

Key word: heavy metals, sanitary condition, sandbox, children, environmental hazard.

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OCENA SKŁADU CHEMICZNEGO I STANU SANITARNEGO PIASKU W WYBRANYCH PIASKOWNICACH NA TERENIE KRAKOWA

Abstrakt

Celem badań była ocena składu chemicznego i stanu sanitarnego piasku w wybranych piaskownicach na terenie Krakowa. Próbki piasku pobrano z 41 piaskownic znajdujących się na osiedlowych placach zabaw oraz w miejskich parkach. Oznaczono: odczyn, materię organiczną oraz zawartość form całkowitych i rozpuszczalnych w 1 mol $HCl \cdot dm^{-3}$ wybranych pierwiastków. Analizowane piaskownice zawierały najwięcej cynku, a poziom metali malał w następującej kolejności > Pb > Cr > Ni > Cu > Cd (formy całkowite) oraz Zn > Pb > Cu > Ni > Cr > Cd (formy rozpuszczalne). Największe potencjalne pobranie metali ciężkich w wyniku przypadkowego spożycia piasku wykazano dla Zn, a następnie Pb > Cu > Ni > Cr > Cd. Grupą bardziej narażoną na szkodliwe działanie metali ciężkich są dzieci niż dorośli. W żadnym przypadku nie stwierdzono przekroczenia zawartości dopuszczalnych metali ciężkich dla terenów zurbanizowanych i zabudowanych (grupa B), biorąc pod uwagę rozporządzenie Ministra Środowiska dotyczące standardów jakości gleby i jakości ziemi oraz granicznych wartości dla gleb zawierających zanieczyszczenia pochodzenia antropogenicznego. Ogólnie stwierdzono zły stan mikrobiologiczny badanych piaskownic.

Słowa kluczowe: metale ciężkie, stan sanitarny, piaskownice, dzieci, narażenie środowiskowe.

INTRODUCTION

The relationship between the level of urban environment pollution and some direct health effects on people dwelling in areas directly exposed to immediate influence emission of toxic substances is well known. Pollution raises concern especially about the state of health and development of children (Biesiada et al. 2006). Children are most sensitive to the negative effect of most chemical and biological pollutants present in the environment (Dutkiewicz et al. 1982, Kulka 2004, Franciszek et al. 1990). Children's exposure to environmental pollution in urban areas is strongly connected with their place of residence, localisation of playgrounds, nursery schools and children's behaviour, for example putting dirty hands and toys to the mouth or ignoring rules of hygiene (Kulka 2004).

Heavy metals comprise strongly toxic elements (lead, cadmium or mercury), whose excessive presence is undesirable. Particularly toxic elements tend to accumulate in parenchymous organs, primarily in the liver, kidneys or pancreas, and under prolonged exposure also in bones and brain tissue (lead) and in hair bulbs (cadmium) (Kondej 2007, Jakubowski et al. 2000). Lead and cadmium disturb many metabolic processes, particularly blood formation or functions of the nervous systems (Marzec 2006). The influence of these metals on a child's organism is often described as deceitful because the effects are usually far-reaching and may appear as disturbances in the mental development, which affects the future state of health and life. Be-side chemical pollution, microbiological contamination poses a grave hazard to human health, often causing food poisoning, allergies, upper respiratory system diseases or skin lesions (OLAŃCZUK-NEYMAN 1992, ZMYSŁOWSKA 2003). Numerous toxicological investigations conducted in cities demonstrated that the main way of introducing pollutants to a child's organism is the digestive system. Among sources of pollutants other than food, sand in sandboxes, dust deposited on the ground, dirt on hands and dust at home have the greatest share (KULKA 2004, PIOŚ 1993, KONDEJ 2007). According to DUTKIEWICZ et al. (1982), up to 50-70% of lead and cadmium ingested by a child's organism may originate from these sources.

Considering the above information, the present research has been conducted to assess the chemical composition and sanitary state of sand in selected sandboxes in Krakow.

MATERIAL AND METHODS

The investigations were conducted in the spring of 2008. Samples of sand were collected from 41 sandboxes located in housing estates and parks (Table 1). Sand was taken from many points in each sandbox and the collected samples were then mixed to obtain a mean sample. These were subjected to chemical and microbiological analyses. Prior to the chemical analysis the material was dried at room temperature. The following assessments were made in the sand samples: pH in 1 mol $KCl \cdot dm^{-3}$, organic matter using Tiurin method and the contents of macroelements and heavy metals. Total element contents were determined after hot mineralisation in a mixture of HNO_3 and $HClO_3$ acids, whereas soluble forms of heavy metals were determined in 1 mol $HCl \cdot dm^{-3}$. Concentrations of elements in the solutions were assessed using inductively coupled plasma atomic emission spectroscopy (ICP-EAS) on a JY 238 ULTRACE apparatus (Jobin Von Emission). Total nitrogen was determined using Kjeldahl distillation method. Potential uptake of heavy metal in case of accidental sand swallowing by children was assessed. Micro-

Table 1

Sample collection sites of the sand from sandboxes

Parks and squares	Decjusza, Jordana, Sikorskiego
Streets, Avenues	Bydgoska, Wysłouchów, Straszewskiego, Mazowiecka, Aleksandry, Witosa Przychodnia, Strzelców, Lublańska, Młyńska, Fiołkowa, Medweckiego, Kłosowskiego, M. Dąbrowskiej, Bohaterów Września, Majora, Młodej Polski, Rejmonta, Podchorążych, Grenadierów, Łokietka, Pużaka, Kozłówek, Nowosądecka, Seweryna, 29 Listopada
Housing estates	Niepodległości, Teatralne, Górali, Sportowe, Szkolne, Hutnicze, Willowe, Na stoku, Piastów, 1000-Lecia, Oświecenia

biological analyses were conducted by means of serial dilutions. Dilutions of the tested material prepared in physiological salt solutions were placed on media. After an appropriate period of incubation culture colonies with features characteristic for individual groups were counted. The test was conducted in three replications, the results were averaged and expressed as in the number of colony forming units (CFU) per 1 g of soil. The following were counted in the samples: total saprotrophic bacteria, total moulds, coli group bacteria, *Salmonella* bacteria, enterococci, staphylococci and *Clostridium perfringens* anaerobic spore-forming bacteria (Polish Standards: PN-Z--19000-1:2001, PN-Z-19000-2:2001, PN-Z-19000-3:2001, OLAŃCZUK-NEYMAN 1992).

RESULTS AND DSICUSSION

The sand samples collected from the analyzed sandboxes were alkaline in reaction, with the pH values ranging from 7.36 to 8.17. Organic matter content fluctuated between 1.80 and 6.80 $g \cdot kg^{-1}$ (Table 2). The highest content of organic matter was in the sand from the sandbox located in Kłosowskiego Street, followed by the samples gathered in Wysłouchów St., Straszewskiego St., M. Dąbrowskiej St. and the Górali Housing Estate.

The analyses revealed moderate diversity in the content of macroelement depending on the location of sandboxes (Table 2). The largest differences occurred for nitrogen and magnesium, while the smallest ones concerned sodium. Regarding the macroelements, the tested sand samples contained the greatest amounts of calcium, followed by magnesium > potassium > phosphorus > nitrogen > sodium. The highest contents of biogenic elements, i.e. nitrogen and phosphorus, was found, like for organic matter

Table 2

Some parameters of chemical composition of the sand ($g \cdot kg^{-1}$)

Parameter		Mean	Median	Min.	Max.	SD*	V(%)
pH	KCl	7.93	7.97	7.06	8.17	0.20	2.52
Organic matter	$g \cdot kg^{-1}$	3.30	2.90	1.80	6.80	1.10	33.33
N-total		0.03	0.02	0.004	0.17	0.03	93.33
Phosphorus	$g \cdot kg^{-1}$	34.52	28.75	4.68	88.75	17.90	52.09
Calcium		1209.3	1167.5	209.0	3575.0	645.2	53.35
Magnesium		299.5	255.0	136.3	940.0	170.4	56.90
Potassium		117.0	100.0	59.25	337.5	61.14	52.26
Sodium		27.96	24.15	15.05	68.00	10.99	39.31

*standard deviation

content, in the sandbox in Kłosowskiego St., which was also the most abundant in organic matter. Potassium, magnesium and sodium were the most abundant in the sandbox in Górali Housing Estate, whereas the content of calcium was the highest in the sandbox in Wysłouchów St.

The content of total and soluble forms of heavy metals is presented in Table 3. Both forms in which the metal occurred in the sand samples from individual sandboxes were highly diverse, as evidenced by high variation coefficients (Table 3). The greatest variation of the total form (V = 97.87%) was assessed for cadmium and soluble form for lead (V = 101.65%). The least diversity was determined for copper (V = 69.71%) and cadmium (V = 61.74). As for the heavy metals, the sandboxes contained the greatest quantities of zinc, while the other elements appeared in the quantities put in the following decreasing order: >Pb >Cr >Ni >Cu >Cd (total forms) and Zn >Pb> Cu >Ni >Cr >Cd (soluble forms). The analysis of 1 mol $HCl \cdot dm^{-3}$ soluble forms revealed that soluble zinc constituted 66% of the total form, copper 62%, nickel 13%, chromium 7% and lead 64%. Cadmium prevailed as a soluble form in all the samples. It is common knowledge that acid pH increases solubility of heavy metals. Thus, we could conclude that the reaction was not a factor causing higher solubility of heavy metals in the tested sand samples as their pH value was high.

Table 3

Content of heavy metals in the sand ($mg \cdot kg^{-1}$)

Metal	Mean	Median	Min.	Max.	SD*	V(%)
Total forms						
Zinc	66.24	57.75	7.10	210.0	52.86	79.80
Copper	1.27	1.00	0.65	4.95	0.88	69.71
Nickel	1.72	1.23	0.73	6.98	1.43	83.23
Lead	13.69	9.18	1.83	46.75	12.77	93.24
Chromium	2.28	1.83	1.00	13.75	1.98	87.13
Cadmium	0.08	0.05	0.00	0.30	0.05	97.87
Soluble forms						
Zinc	39.89	28.60	0.52	147.0	38.07	95.45
Copper	0.79	0.49	0.03	2.94	0.78	98.59
Nickel	0.22	0.11	0.00	1.41	0.30	97.78
Lead	8.81	5.44	0.18	33.40	8.96	101.65
Chromium	0.16	0.11	0.04	0.52	0.11	66.09
Cadmium	0.14	0.13	0.03	0.48	0.08	61.74

*standard deviation

The highest content of total forms of the analyzed metal was found in the sand from the sandboxes situated in the following locations: Grenadierów St. (Zn), Seweryna St. (Cu), Bydgoska St. (Cr) Górali Housing Estate (Ni) and Młodej Polski St. (Pb and Cd). As for the the soluble forms, the highest levels were found in the sand samples collected from the sandboxes in Grenadierów St. (Zn, Pb), Bydgoska St. (Cu), Kłosowskiego St. (Ni, Cr) and in Decjusza Park (Cd).

According to KABATA-PENDIAS et al. (1995), the limit values of heavy metals in soils containing anthropogenic pollutants are as follows: 150 mg Zn; 25 mg Cu; 100 mg Cr; 70 mg Pb; 1 mg Cd $\cdot$ kg^{-1}. On the other hand, the Regulation of the Minster for Environment (2002) on the quality standards of soil and earth allows the following concentrations of heavy metals in the top layers of build-up and urbanized grounds (group B): 300 mg Zn; 150 mg Cu; 100 mg Ni and Cr; 100 mg Pb and 4 mg Cd $\cdot$ kg^{-1}. According to these criteria In the sand samples, the permissible levels of heavy metals were not exceeded in the analyzed sand samples.

The uptake heavy metal by children and adults after accidental swallowing of sand was calculated. Accidental sand swallowing happens mainly to children aged 1-6, who frequently play in a sandbox or put dirty hands or toys to their mouth. The literature states that a daily consumption of soil in this age group is 200 mg $\cdot$ d^{-1}, compared to 100 mg of soil $\cdot$ d^{-1} among children above 6 years old, and 60 mg $\cdot$ d^{-1} for adults (BIESIADA et al. 2006). The absorbed dose [mg $\cdot$ (kg b.w. $\cdot$ $day)^{-1}$] of individual metals was computed according to the following formula (SZCZEPANIEC-CIĘCIAK, SZYMCZAK 1995, SZYMCZAK, SZESZENIA-DĄBROWSKA 1995):

$$D = C \cdot \frac{\mathrm{WK}}{\mathrm{MC}} \cdot \frac{\mathrm{CN} \cdot \mathrm{DN}}{T},$$

where:

- *C* – concentration of a chemical substance in individual environmental medium (mg $\cdot$ kg^{-1} of soil);
- WK – the length of contact with an individual environmental medium per time unit (mg of soil $\cdot$ d^{-1});
- CN – frequency of exposure (daily 350 days);
- DN – the length of exposure period (6 years – children, 70 years – adults);
- MC – body weight (children below 6 yrs. – 15 kg, adults – 70 kg);
- *T* – averaging period, usually assumed as 6 (70 years) $\cdot$ 350 days a year

As may be seen from this formula, quantities of heavy metals ingested by children and adults depend primarily on the content of a given element in the sand and the individual's body weight. Amounts of heavy metals ingested by children aged 1-6 years and adults due to accidental swallowing of sand are gathered in Table 4.

Table 4

Uptake of heavy metals by children (1-6 years) and adults [$\mu g \cdot (kg \cdot d)^{-1}$]

Metal	Group	Mean	Median	Min.	Max.
Zinc	children	0.53	0.38	0.007	1.96
	adults	0.03	0.02	$4 \cdot 10^{-4}$	0.13
Copper	children	0.01	0.007	$4 \cdot 10^{-4}$	0.039
	adults	$7 \cdot 10^{-4}$	$4 \cdot 10^{-4}$	$9 \cdot 10^{-5}$	0.002
Nickel	children	0.003	0.001	$4 \cdot 10^{-4}$	0.019
	adults	$2 \cdot 10^{-4}$	$1 \cdot 10^{-4}$	$9 \cdot 10^{-5}$	0.001
Lead	children	0.12	0.07	0.002	0.44
	adults	0.007	0.004	$1.5 \cdot 10^{-4}$	0.03
Chromium	children	0.002	0.001	0.001	0.007
	adults	$1.4 \cdot 10^{-4}$	$9 \cdot 10^{-5}$	$3.4 \cdot 10^{-5}$	$4.4 \cdot 10^{-4}$
Cadmium	children	0.002	0.0017	$7 \cdot 10^{-4}$	0.006
	adults	$1.2 \cdot 10^{-4}$	$1.1 \cdot 10^{-4}$	$9 \cdot 10^{-5}$	$4 \cdot 10^{-4}$

On the basis of the data in Table 4, it was found that children aged 1-6 years take up over 90% more heavy metals than adults due to accidental swallowing of sand. Obviously, children are more sensitive than adults to effects produced by heavy metals because of their from slower excretion process, smaller body weight and weaker resistance to environmental poisons. The greatest potential uptake, both by children and adults, was demonstrated for Zn, followed by Pb >Cu >Ni >Cr >Cd (Table 4, Figure 1).

Among the analyzed sandboxes, the most severe hazard of heavy metals entering a child's organism via accidental sand swallowing was attributed to the sandbox in Grenadierów St. (Zn), Bydgoska and Wysłouchów St. (Cu), Łokietka and Grenadierów St. (Pb), Kłosowskiego St. (Ni and Cr) and in Decjusza Park.

The evaluation of the sanitary state of the sand samples is presented in Table 5. Considering the total number of saprotrophic bacteria, it was found that only 15% of the investigated sandboxes provided clean sand samples, whereas 75% of sandboxes contained polluted or strongly polluted sand. The lowest number of saprotrophic bacteria, up to 10^6 (CFU)$\cdot g^{-1}$ of sand, was detected in the sandboxes localized at the following housing estates: Sportowe, Hutnicze, Na Stoku, Piastów and Bohaterów Września. Strongly polluted sand was found in the sand samples collected from the sandboxes in Reymonta St., Podchorążych St. and in Decjusza Park. No serious hazard posed by the total amount of moulds and yeasts was attributed to most of the sandboxes, because several thousands of colony forming units per gram is normal soil microflora. Coli group bacteria and enterococci are indicators

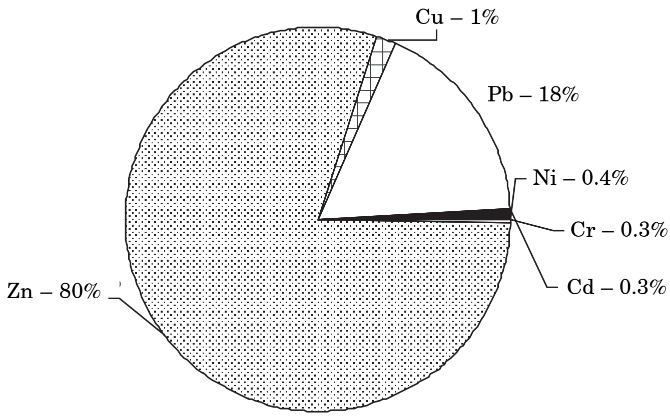

Fig. 1. Percentages of heavy metals in the total sum of their amount ingested by children (1-6 years) and adults

Table 5

Sanitary assessment of the sand

Amount ($CFU \cdot g^{-1}$)	Mean	Range	*Assessment of the sand
Saprotrophic bacteria	$3.1 \cdot 10^6$	2.10^5-$9.6 \cdot 10^6$	clean up to106, moderately polluted: 1-$2.5 \cdot 10^6$, polluted: 2.5-$10 \cdot 10^6$, strongly polluted: > $10 \cdot 10^6$
Moulds	2388	10-15 000	if present in big amounts, they evidence presence of organic matter necessary for their development; mould and yeast should not be present in sand
Yeasts	718	0-4000	
Coli group bacteria	3046	10-33 600	their presence denotes biological contamination evidencing fecal pollution
Enterococci	15	0-440	
Salmonella	25	0-370	absent – the sand is clean
Staphylococci	74	0-510	no standards available
Count	median	range	sand assessment
Coli group bacteria	10^{-2}	10^{-4}-10^{-1}	clean up to 10^{-2} polluted < 10^{-2}
Enterococci	0	0-10^{-2}	
Clostridium perfringens	0	0-10^{-1}	clean up to 10^{-3} polluted < 10^{-3}

* The assessment by Zmysłowska (2003)

of the sanitary state of soil (sand), since their presence suggests some faecal pollution in the nearest past. The present study has demonstrated that the sand in 59% of the sandboxes was free from coli group bacteria but 41% of the sandboxes were polluted. The lowest count, i.e. 10^{-4} (strongly polluted sand) was revealed in the sandboxes in Decjusza Park, Bydgoska St. and Seweryna St. As regards enterococci, the sand in 98% of the sandboxes proved clean, with these bacteria occurring only in the sandbox in Seweryna St. *Clostridium perfringens* anaerobic spore forming bacteria are also an indicator used for assessment of the sanitary condition of soil (sand), as their presence proves former faecal contamination. In this study, spore forming bacteria were not found in any of the analyzed sandboxes.

In conclusion, metals and microbiological contamination may be a cause of acute and chronic poisonings. Acute poisoning is usually caused by exposure to high pollutant concentrations, whereas chronic poisoning results from repeated or continuous exposure leading to accumulation of a toxic substance in the human organism. Chronic exposure to heavy metals and harmful microorganisms may occur in a workplace or at home but may be also connected with environmental pollution (KONDEJ 2007, JAKUBOWSKI 1997), as was demonstrated in the present paper. It should be emphasized that health effects of exposure to environmental pollutants raise concern among societies in many countries and the problem is one of the top priorities of social health policy, raised in numerous conferences and reports (BIESIADA et al. 2006, SMITH et al. 1995). Heavy metals in the analyzed sand might originate from metal bearing dusts generated by various processing plants operating in Krakow but also from very heavy traffic in this town. On the other hand, microbiological sand contamination was caused by dogs and other animals leaving their excrements and excretions in sandboxes. Due to their high sensitivity and close contact with environment, children require special protection against environmental pollution. Therefore, it is necessary to undertake preventive and remedial measures aimed at reducing chemical and biological contamination in individual natural environment media through improvements in the sanitary and hygienic conditions at home, in nursery schools and on playgrounds (KULKA 2004).

CONCLUSIONS

1. The sandboxes contained the highest amounts of zinc and the level of the other heavy metals was declining in the following order >Pb >Cr >Ni >Cu >Cd (total forms) and Zn >Pb >Cu >Ni >Cr >Cd (soluble forms).

2. The highest potential uptake caused by accidental sand swallowing was revealed for Zn, followed by Pb > Cu >Ni >Cr >Cd. Children are most prone to harmful effects of heavy metals.

3. No case of exceeding the values of heavy metals permissible for urbanized and built-up areas (group B) – as stated in the regulation of the Minister for Environment on soil and earth quality standards or the limit values or soils containing anthropogenic pollutants – was revealed.

4. Generally, the sandboxes analysed were found to be of poor microbiological state. The worst microbiological contamination occurred in sandboxes situated in the following locations: Młyńska St. , Nowosądecka St., Seweryna St. and 29 Listopada Ave., followed by Bydgoska, Aleksandry, Witosa, Reymonta, Podchorążych streets, as well as Niepodległości and Teatralne housing estates and Decjusza Park.

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EFFECT OF DIFFERENT FACTORS ON CHEMICAL COMPOSITION OF GRASS-LEGUMES SWARD

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Abstract

The biological value of fodder is estimated on the basis of its content of particular macroelements (N, P, K, Ca, Mg). Concentration of these components in fodder depends on many factors, mainly on the properties of soil, type of land use and growth phase of crops.

The aim of this paper was to estimate the effect of soil properties, land use and species composition of a sward mixture on the content of macroelements, total protein and acid detergent fibre in grass-legumes sward. In 2002-2005 a field study was carried out on mineral and organic soil in Sosnowica (near the Wieprz-Krzna Canal). Two land use types were tested: pasture (sward grazed by cattle) and simulated (sward frequently cut, proportionally to the grazings). Six grass-legumes mixtures were sown, including the following species: *Poa pratensis*, *Festulolium braunii*, *Festulolium loliaceum* (2 strains), *Lolium perenne* and *Festuca pratensis*. Tetraploid hybrids of *Festulolium loliaceum* [*Festuca pratensis* (4x) x *Lolium perenne* (4x) were obtained at the Institute of Plant Genetics PAS in Poznań. Pasture sward was grazed by Limousine cattle 5-6 times during the grazing season, while the simulated sward was cut at the same time. Chemical composition of fodder (total protein, ADF, P, K, Ca, Mg) was estimated. Sward on organic soil was characterized by a significantly higher content of total protein, phosphorus, calcium and magnesium as well as a significantly lower content of potassium in comparison to sward on mineral soil. Moreover, a significantly higher content of potassium and significantly lower content of magnesium in pasture sward were observed. Sward was of perfect quality (content of ADF) and had an optimum content of basic macroelements. No influence of the examined species in the mixtures on feed quality was observed. Consequently, compared to the other species, *Festulolium loliaceum* hybrids prove to be suitable for to pasture mixtures in a postboggy habitat. .

Keywords: ADF, macroelements, soil, total protein, utilization method.

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WPŁYW RÓŻNYCH CZYNNIKÓW NA SKŁAD CHEMICZNY RUNI TRAWIASTO-MOTYLKOWATEJ

Abstrakt

Wartość biologiczną paszy oceniana się na podstawie zawartości poszczególnych składników pokarmowych, zwłaszcza makroelementów (N, P, K, Ca, Mg). Koncentracja tych składników w paszy zależy od wielu czynników, takich jak warunki glebowe, sposób użytkowania, faza rozwojowa roślin.

Celem badań była ocena wpływu warunków glebowych, sposobu użytkowania i składu gatunkowego mieszanki na zawartość makroelementów, białka ogólnego i kwaśnego włókna detergentowego w runi trawiasto-motylkowatej. Badania przeprowadzono w latach 2002-2005 w Sosnowicy (rejon Kanału Wieprz-Krzna) na glebie mineralnej i organicznej. Ponadto uwzględniono pastwiskowe użytkowanie runi (naturalny wypas zwierząt) oraz symulowane, czyli częste, koszenie, proporcjonalne do ilości wypasów. W doświadczeniu wysiano 6 mieszanek trawiasto-motylkowatych z gatunkami testowanymi (*Poa pratensis*, *Festulolium braunii*, *Festulolium loliaceum* – 2 rody, *Lolium perenne* i *Festuca pratensis*). Tetraploidalne mieszańce *Festulolium loliaceum* [*Festuca pratensis* (4x) x *Lolium perenne* (4x)] wyhodowano w Instytucie Genetyki Roślin PAN w Poznaniu. Ruń wypasano bydłem rasy mięsnej Limousine 5-6 razy w ciągu sezonu pastwiskowego, natomiast ruń w użytkowaniu symulowanym koszono w tym samym czasie. W badaniach określono skład chemiczny paszy: białko ogólne, ADF (kwaśne włókno detergentowe), P, K, Ca i Mg. Ruń na glebie organicznej zawierała istotnie więcej białka ogólnego, fosforu, wapnia i magnezu oraz istotnie mniej potasu, w porównaniu z runią na glebie mineralnej. W warunkach użytkowania pastwiskowego zanotowano istotnie wyższą zawartość potasu, natomiast w użytkowaniu symulowanym – istotnie wyższą zawartość magnezu. Ruń odznaczała się doskonałą jakością (zawartość ADF) oraz optymalną zawartością podstawowych makroskładników. Nie zaobserwowano wpływu gatunku testowanego w mieszance na jakość paszy, w związku z tym, na tle innych gatunków, mieszańce *Festulolium loliaceum* potwierdzają swoją przydatność do mieszanek pastwiskowych w siedlisku pobagiennym.

Słowa kluczowe: ADF, białko ogólne, makroelementy, sposób użytkowania, gleba.

INTRODUCTION

One of the most important factors which determine the quality of grasslands is the chemical composition of sward, which conditions determines the value of feed produced from the grass. Content of different nutrients, particularly macroelements (N, P, K, Ca, Mg), as well as the digestibility and the ADF (acid detergent fibre) determine the biological value of sward. The concentration of the above components in fodder depends on many factors, mainly on soil conditions, land use and growth phase of plants (BORAWSKA-JARMUŁOWICZ 2003). On pasture, the most important is the influence of cattle's faeces on abundance of soil nutrients and their availability to plants (ROGALSKI et al. 2000). The nutritive value of fodder is also dependent on species composition of sward. In their search for better species of pasture grass, breeders focus on intergeneric hybrids. Recently, *Festulolium loliaceum* (Huds.) P.V. Fourn hybrids [*Festuca pratensis x Lolium perenne*] have been bred at the Institute of Plant Genetics PAS in Poznań. They are now available for further research (KULIK et al. 2005). The aim of this paper was to estimate the effect of soil conditions, land use and species composition of a sward mixture on the content of macroelements, total protein and acid detergent fibre in grass-legumes sward.

MATERIAL AND METHODS

The study were carried out in 2002-2005 in Sosnowica (near theWieprz-Krzna Canal). The experiments were set up in a 4-replication split-plot design on mineral soil (degraded black soil) and on organic soil (peat-muck soil). Chemical properties of the soils were varied, depending on the type of soil, land use and year of the study (Table 1).

Table 1

Chemical properties of soil

Specificatiom	2001		2003				2004			
	M	O	M		O		M		O	
			S	P	S	P	S	P	S	P
pH 1n KCl	5.3	4.8	5.6	6.0	5.0	5.2	6.0	5.3	5.2	5.7
P (mg · 100 g^{-1} soil)	4.1	27.3	4.7	4.1	20.7	30.5	7.5	2.6	19.5	32.0
K (mg · 100 g^{-1} soil)	6.7	20.7	6.8	7.5	18.9	19.9	3.7	2.1	14.1	16.6
Mg (mg · 100 g^{-1} soil)	6.4	34.4	7.8	13.6	116.5	176.5	3.9	13.3	159.1	281.2

M – mineral soil; O – organic soil; S – simulated use; P – pasture

Two types of grassland use were considered: pasture (5-6 grazings by Limousine cattle) and simulated (frequent cuts at pasture maturity, proportionally to the number of grazingz). In the study, 6 grass-legumes mixtures including such species as *Phleum pratense* cv. Obra (35%), *Dactylis glomerata* cv. Areda (10%) and *Trifolium repens* cv. Romena (25%) were sown. Every mixture contained a 30% share of the tested species as follows: 1. *Poa pratensis* cv. SKIZ, 2. *Festulolium braunii* cv. Felopa, 3. *Festulolium loliaceum* I strain – spreading type, 4. *Festulolium loliaceum* II strain – erect type, 5. *Lolium perenne* cv. Solen and 6. *Festuca pratensis* cv. Skra. The initial hybrids between tetraploid forms of *Festuca pratensis* and *Lolium perenne* were obtained at the Institute of Plant Genetics PAS in Poznań. During the whole study controlled mineral fertilization was applied, including: N – 75, P – 31 and K – 75 kg ha^{-1} (in spring N – 24, P – 31, K – 60 kg ha^{-1}; after 2^{nd} regrowth – N – 17, K – 15 kg ha^{-1}; after 3^{rd} and 4^{th} regrowth – N – 17 kg ha^{-1}). The area of a pasture plot was 30 m^2 and that of a simulated grassland was 15 m^2. Before every regrowth, yield of pasture sward was assessed by mowing part of a plot covering 5.5 m^2. Representative samples of plants were collected in order to determine the chemical composition of fodder: protein, ADF – acid detergent fibre, P, K, Ca and Mg. Chemical analyses were performed at the Szelejewo Plant Breeding Station (protein and ADF) and at the District Chemical-Agricultural Station in Lublin (P, K, Ca and Mg). The content of protein was determined with Kiejdahl's method, while the amount of ADF was measured on an American Ankom Fiber Analyzer (Ankom Technology – 10/99). Phosphorus was determined colorimetrically, potassium and calcium were tested by flame photometry, and magnesium was detected by the ASA method. The results underwent statistical analysis of variance with Tukey's test.

RESULTS AND DISCUSSION

Each grass-legumes sward contained the species sown in a mixture, herbs and weeds as well as grass species which had not been sown in the mixture. The sward value of the tested mixtures was assessed on the basis of the content of total protein, acid detergent fibre (ADF) as well as macroelements (phosphorus, potassium, calcium and magnesium). In this paper, the mean results of 2003-2005 are presented, namely 1^{st} and 3^{rd} regrowths and the mean of both regrowths. The content of the particular components in the sward was dependent on the soil type and grassland use. No significant differentiation depending on the sown mixture was observed, which is why these results were not put in the figures. However, it should be noticed that the *Festulolium loliaceum* strains compared favourably to other valuable pasture species. The sward with the tested hybrids was characterized by good quality, which was confirmed by an appropriately good content of total protein, ADF as well as the basic macroelements with respect to animals' nutritional needs. The study confirms suitability of these hybrids for pasture mixtures in postboggy habitats.

The content of total protein was varied depending on the type of soil. The sward on the organic soil was characterized by a higher content of total protein compared with the sward on mineral soil. However, significant variation was observed only in the 3^{rd} regrowth and the mean of regrowths (organic soil (o) – 23.76% d.m; mineral soil (m) – 20.77% d.m.). This is undoubtedly connected with a higher content of nitrogen in organic soils (BARYŁA 1992). In contrast, the grassland use did not significantly affect the total protein content in sward (Figure 1). In our study, more protein was found in the 1^{st} regrowth than in the 3^{rd} one.

Another analyzed macronutrient was phosphorus, which plays an important role in the photosynthesis process, breathing, metabolism of fats as

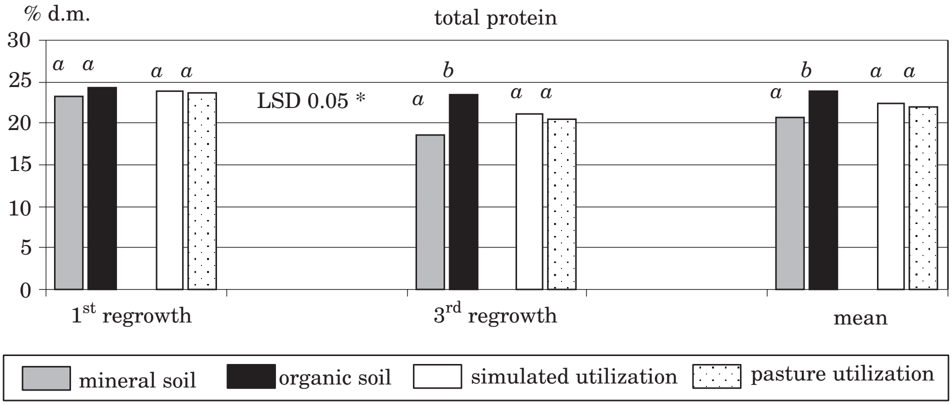

Fig. 1. Mean content of total protein in the sward in 2003-2005

well as nitrogen transformations. It is an essential macroelement, whose optimal content in feed, according to animals' nutritional needs, is approximately 0.3% of dry matter (FALKOWSKI et al. 1990). The analysis of phosphorus concentrations showed the same tendencies as those noticed for the total protein content. Significantly more phosphorus was determined in the 3rd regrowth and the mean of the regrowths of swards on peat-muck soil (0.40% d.m.). This could be attributed to the better moisture conditions of such soils. According to FALKOWSKI et al. (1990), phosphorus content in dry matter sward is lower in habitats where there is shortage of water.

There were no significant differences in the phosphorus content with respect to the grassland use type. Analogously to other studies (ĆWINTAL 1999, KRZYWIEC 2000), the feed we analyzed contained on average more phosphorus when produced from the first regrowth (0.43% d.m.) than the third one (0.34% d.m.) – Figure 2.

Another macronutrient which is important for the growth and development of plants is potassium, which has a positive impact on photosynthesis and plays an important role in the plant water management. The optimum content of this element in sward is about 1.7% d.m. (FALKOWSKI et al. 1990). In our study, sward on mineral soil contained significantly more potassium than that growing on organic soil (Figure 2). Such a relationship is confirmed by other researchers (ĆWINTAL 1999, KRZYWIEC 2000). Organic soils are characterized by a lower availability of potassium than mineral soils (Guz 1982). In addition, the analyzed sward contained more potassium when maintained as pasture (mean 2.18% d.m.) than when cut (mean 1.96% d.m.) – Figure 2. This was caused by a large concentration of this element in spots covered by animals' faeces (ROGALSKI et al. 2000). Enrichment of soil in nutrients derived from excrements of grazing animals increases potassium in dry matter of pasture sward (WARDA 1994).

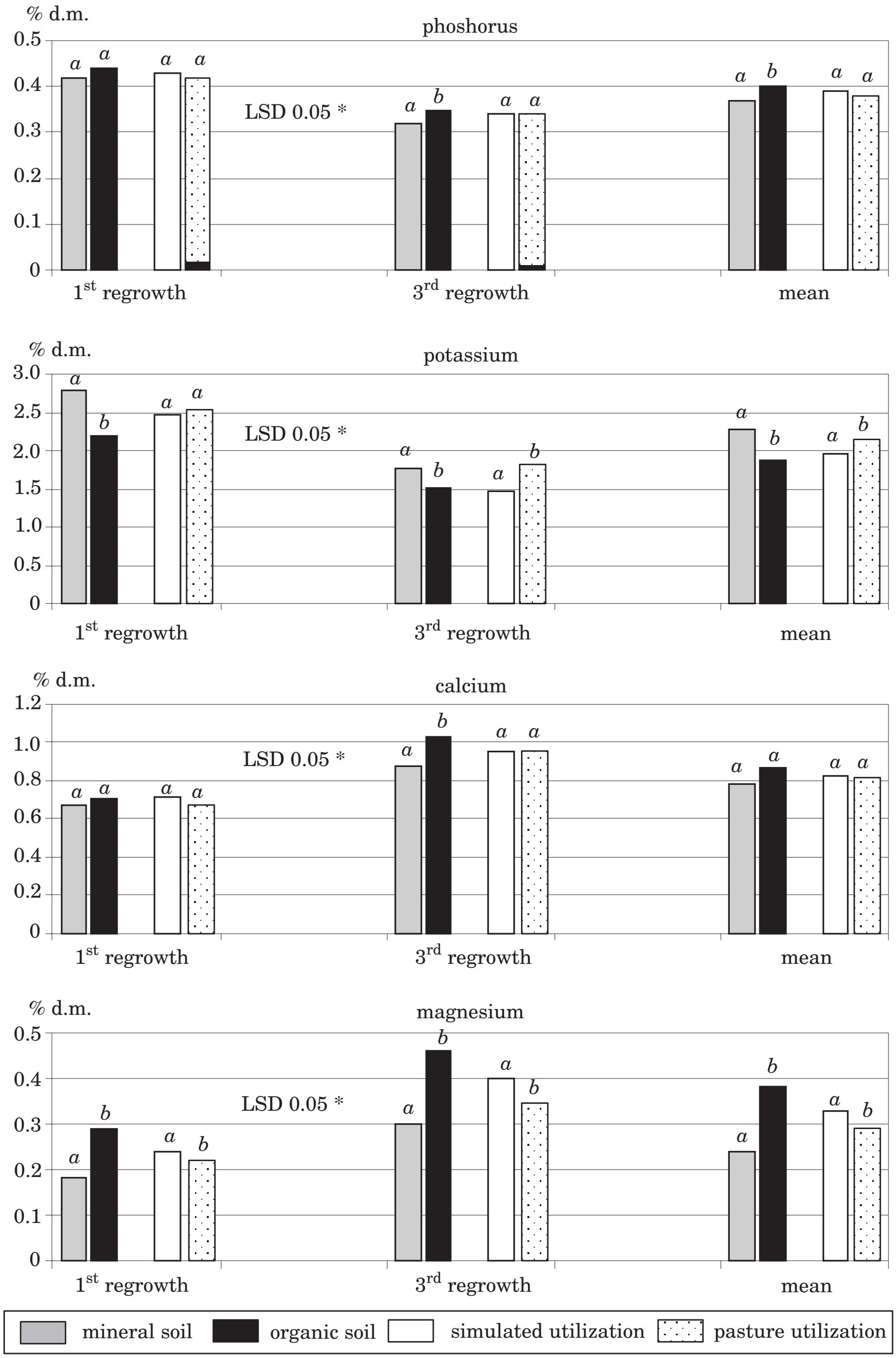

Fig. 2. Mean content of macroelements in the sward in 2003-2005

Calcium is another essential macronutrient. It plays a selective regulatory function in the uptake of mineral salts by plant roots. The optimal calcium content in grassland plants is about 0.7% of dry matter (FALKOWSKI et al. 1990). Significant variation was observed only in the 3rd regrowth, when sward on organic soil characterized by a higher calcium content (1.03% d.m.) than sward on mineral soil (0.88% d.m.) – Figure 2. Similar results were obtained by ĆWINTAL (1999), although a more intensive mineralization process on organic soil reduces the amount of calcium absorbed by plants (ŁĘKAWSKA 1989). However, a higher calcium content in the dry matter of sward on organic soil was caused by a larger share of *Trifolium repens* as well as herbs and weeds, especially species with a large ability to accumulate calcium (TRZASKOŚ 1997). Another factor which led to a higher calcium content was the improved water status of soil, which affects the uptake of calcium by plants (FALKOWSKI et al. 1990).

Being a component of chlorophyll magnesium, a life essential element, affects photosynthesis, phosphorus management and the formation of protein compounds in plants. The optimum content of magnesium in animal feed, according to nutritional needs, is about 0.2% of the dry matter (FALKOWSKI et al. 1990). While analyzing the effect of soil, it should be noticed that sward on organic soil had a significantly higher content of magnesium (0.38% d.m.) than sward on mineral soil (0.24% d.m.). The sward on peat-muck soil comprised more *Trifolium repens* as well as herbs and weeds, especially species such as *Ranunculus repens* or *Taraxacum officinale*, which are markedly better at accumulating magnesium (TRZASKOŚ 1997). Significant differences were also observed in the content of magnesium depending on the land use (simulated – 0.33% d.m, pasture – 0.29% d.m.) – Figure 2. The differences were mainly due to a higher share of herbs and weeds in the simulated grassland, especially species capable of accumulating much magnesium, such as *Achillea millefolium* or *Taraxacum officinale* (TRZASKOŚ 1997).

For assessment of feed digestibility, it is important to know the content of the ADF. The acid detergent fibre combines cellulose and lignin, which are bulk compounds, only incidentally digested by monogastric animals. The content of the ADF ranges from 18 to 44% d.m. (DUFRASNE et al. 1998, GUTMAN, ADAMOVICH 2004, HARASIM 2001). The content of this fibre fraction is growing very quickly during the growth and subsequent phases of plant development (KRZYWIECKI, KOZŁOWSKI 2003). In our study, sward was cut on optimum dates, i.e. during the phase of pasture maturity, so it was characterized by good parameters. The results regarding the ADF content were not processed statistically as an analysis of an average sample from 4 replications was performed. Nonetheless, the ADF levels formed part of the feed quality assessment.

The content of the ADF in the sward ranged between 24.74% d.m. (1st regrowth – mineral soil) to 28.63% d.m. (3rd regrowth – mineral soil) – Figure 3. Comparing these results to the American ranges of the ADF

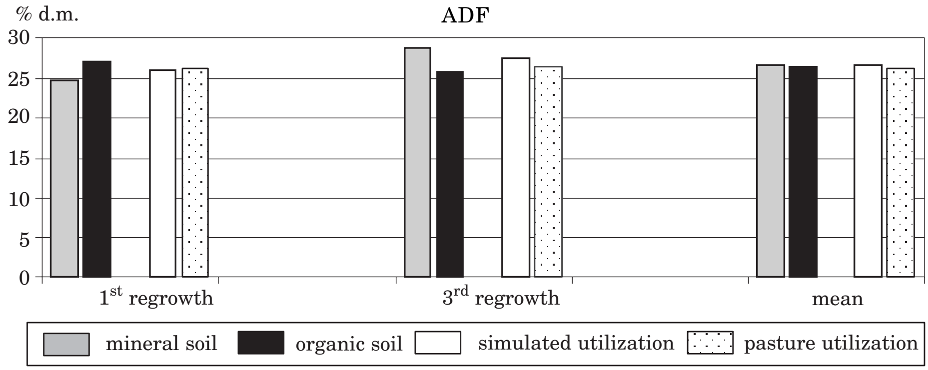

Fig. 3. Mean content of acid detergent fiber (ADF) in the sward in 2003

(STEEVENS 1998), it can be concluded that the feed obtained in our study was of almost perfect quality with respect to this component.

CONCLUSIONS

1. Sward on organic soil was characterized by a significantly higher content of total protein, phosphorus, calcium and magnesium as well as a significantly lower content of potassium compared to sward on mineral soil.

2. Sward maintained as pasture had a significantly higher content of potassium and significantly lower content of magnesium compared to sward on simulated grassland.

3. Regardless of the factors taken into account, the tested sward was characterized by excellent quality (the ADF) and an optimum content of the basic macronutrients with respect to the dietary needs of animals.

4. No influence of the mixture species studied on feed quality was observed, which proves that *Festulolium loliaceum* hybrids are suitable for pasture mixtures in postboggy habitat.

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INITIAL GROWTH OF *PHLEUM PRATENSE* UNDER THE INFLUENCE OF LEAF WATER EXTRACTS FROM SELECTED GRASS SPECIES AND THE SAME EXTRACTS IMPROVED WITH $MgSO_4 \cdot 7H_2O$

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Abstract

In multi-species grassland communities, plant growth and development are modified by both a number of habitat-related factors and physico-chemical processes resulting from the neighbourhood of other species. Plant interactions mediated through chemical substances are identified within the allelopathic processes. The allelopathic process involves excretion of bioactive compounds from plant or microorganisms that inhibit or stimulate physiological processes of the neighbour plants. The allelopathic compounds can exert a harmful impact on the emergence of seedlings, initial development and installation. Therefore, it is essential to reduce the allelopathic influence of the old sward on the plants sown as well to limit the interaction between these new plants. It is claimed that, among others, fertilizer components may partially reduce effects of allelopathic influences

In this study we show the differences in growth inhibition of Ph. *pratense* seedlings caused by the water extracts of leaves of selected grass species and the amelioration of growth inhibition by addition of magnesium sulfate. The bioassays were performed on Petri dishes under the laboratory conditions. The activity of allelopathic substances in the leaf extracts was evaluated by the degree of inhibition of seed germination, seedling height and root length compared to the control objects (supplied with distilled water). The amelioration of the negative allelopathic effects by a complete nutrient component with or without the addition of magnesium sulfate was also evaluated against the appropriate controls and compared to the objects where blotting-paper was moistened only with leaf extracts.

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The present studies confirmed the defensive activity of magnesium sulfate against the allelopathic compounds of the tested grass species affecting the initial growth and development of *Phleum pratense*. The obtained results indicate potential elimination of the allelopathic negative influence of plants through suitable fertilization.

Key words: allelopathy, grasses, magnesium sulphfate, *Phleum pratense*.

POCZĄTKOWY WZROST I ROZWÓJ *PHLEUM PRATENSE* W WARUNKACH ODDZIAŁYWANIA WYCIĄGÓW WODNYCH Z LIŚCI WYBRANYCH GATUNKÓW TRAW ORAZ TYCH SAMYCH WYCIĄGÓW WZBOGACONYCH $MgSO_4 \cdot 7H_2O$

Abstrakt

W wielogatunkowych zbiorowiskach roślinnych użytków zielonych wzrost i rozwój roślin jest modyfikowany zarówno przez wiele czynników siedliskowych, jak i procesy fizyczne i chemiczne wynikłe z sąsiedztwa innych gatunków. Wzajemne oddziaływania roślin za pośrednictwem substancji chemicznych są utożsamiane z allelopatią. Polega ona na wydzielaniu przez rośliny (lub mikroorganizmy) aktywnych biologicznie substancji chemicznych, które hamują lub stymulują procesy życiowe roślin sąsiadujących. Substancje allelopatyczne mogą ujemnie wpływać na wschody, początkowy rozwój i instalację siewek (EMETERIO i in. 2003). Ważne jest zatem ograniczenie allelopatycznych wpływów starej darni na wsiewane rośliny, a także wzajemnych oddziaływań roślin wsiewanych. Uważa się, że m.in. składniki nawozowe mogą częściowo niwelować efekty zahamowania na skutek oddziaływań allelopatycznych.

W badaniach podjęto próbę wykazania różnic w zahamowaniu wzrostu siewek *Ph. pratense* w warunkach oddziaływania wyciągów wodnych z liści badanych gatunków traw oraz tych samych wyciągów wzbogaconych o wybrane składniki pożywki. Biotesty wykonano na płytkach Petriego w warunkach laboratoryjnych. Za kryterium obecności oraz aktywności substancji allelopatycznych występujących w wyciągach z liści przyjęto stopień hamowania kiełkowania nasion, wysokości siewek i długości korzeni w stosunku do obiektów kontrolnych (woda destylowana). Efekty niwelowania ujemnych skutków allelopatii przez składniki pożywki oceniano na tle odpowiedniej kontroli w porównaniu z obiektami, gdzie bibułę zwilżano tylko wyciągami z liści. W badaniach potwierdzono ochronne oddziaływanie $MgSO_4 \cdot 7H_2O$ przed allelozwiązkami testowanych gatunków traw oddziałujących na początkowy wzrost i rozwój *Phleum pratense*. Wykazano możliwość eliminowania ujemnych skutków oddziaływania allelopatycznego roślin poprzez zastosowanie odpowiedniego nawożenia.

Słowa kluczowe: allelopatia, trawy, siarczan magnezu, *Phleum pratense*.

INTRODUCTION

Withdrawal of some plant species from the grass ecosystems and invasion of others usually accounts for the changes in the soil environment. A progressive decline of the valuable grass species recorded in the grass ecosystems induces their infestation growth, productivity drop and deterioration of feeds obtained. Therefore, it is imperative to restore them. One of the methods recommended to improve the sward species composition proves to be undersow, which is conditioned by numerous factors of an economic and natural character. It is assumed that a problem of ineffective undersow is also connected with allelopathy. Although seeds of some grass species are provided with sufficient moisture and light, their emergence may not proceed or be delayed owing to the negative allelopathic impact of the old sward or interactions between the emerging plants. As a consequence, a limited share of the species sown in the sward or even elimination of some species more susceptible to the allelopathic influence has been recorded (EMETERIO et al. 2003, LEIGH et al. 1995).

In multispecies plant associations present in a typical grassland, various species constitute a source of allelopathic substances. Their presence has been confirmed in all plant organs. They may be identified in the top (generative and vegetative) and underground ends of plants, in both dead and living parts either on the soil surface or inside it (BERTIN et al. 2003, SMITH, MARTIN 1994).

Most allelopathic substances, demonstrating a broad spectrum of activity, are detected in leaves. A number of them are water soluble so they can be eluted by rain, fog or dew drops. The presence of allelopathic compounds in the leaves of numerous grass species has been detected in many investigations (LIPIŃSKA 2005, LIPIŃSKA, HARKOT 2005, SMITH, MARTIN 1994, CHUNG, MILLER 1995, RICE 1984, SUTHERLAND et al. 1999).

Allelopathic compounds can exert a harmful impact on the emergence of seedlings, initial development and installation (EMETERIO et al. 2003). Therefore, it is essential to reduce the allelopathic influence of the old sward on the plants sown as well to limit the interaction between these new plants. It is claimed that, among others, fertilizer components may partially reduce effects of allelopathic influences (BLUM et al. 1985). One of the bioelements importantly affecting physiological as well as matter building functions is magnesium. Its deficiency in grasses especially at the beginning of their vegetation, may cause hypomagnesaemia, which is dangerous for the livestock. Increased magnesium doses do not cause over- fertilization, unlike other components (eg. N or K), which deteriorate fodder quality (FILIPEK 1996).

The objective of the present investigations was to evaluate the influence of magnesium as its sulfate salt (a compound used for grassland fertilization) applied to lessen the allelopathic effects of water extracts from leaves of selected grass species on the germination, initial growth and development of *Phleum pratense* seeds.

EXPERIMENTAL PROCEDURES

The investigations were conducted under controlled laboratory conditions on Petri dishes (to avoid the chemical and microbiological interactions which occur in soil). The bioassays were performed under artificial light under a photoperiod of 12 h (7.00-19.00) provided by high-pressure lamps SON-T Agro (the average light density at the table level circa 3000 lux). Its unique setting (framing/fixture) of SGR 140 type ensured the homogenous light density used for growing plants. The room temperature ranged from 22 to 25°C.

The studies covered four series of experiments set up according to a fully randomized method in four replications. The initial growth and development of *Ph. pratense w*as compared as following:

Combination	Control Object	Object studied	Denotation of treatment
1	H_2O	leaf water extracts	BP
2	H_2O + Hoagland 2	leaf water extracts + Hoagland 2	PP
3	H_2O + Hoagland 2 + + $MgSO_4 \cdot 7H_2O$	leaf water extracts + Hoagland 2+ $MgSO_4 \cdot 7H_2O$	PP + Mg
4	H_2O + Hoagland 2 + 2 x $MgSO_4 \cdot$ $\cdot 7H_2O$	leaf water extracts + Hoagland 2 + 2 x $MgSO_4 \cdot 7H_2O$	PP + 2Mg

Hoagland 2 composition: Ca $(NO_3)_2 \cdot 4H_2O$ – 0.95 $g \cdot l^{-1}$; KNO_3–0.61 $g \cdot l^{-1}$; $MgSO_4 \cdot 7H_2O$ – – 0.49 $g \cdot l^{-1}$; $NH_4H_2PO_4$ – 0.12 $g \cdot l^{-1}$; H_3BO_3 – 620 mg; $MnCl_2 \cdot 4H_2O$ – 290 mg; $CuSO \cdot 5H_2O$ – – 60 mg; $ZnSO_4 \cdot 7H_2O$ – 60 mg; $(NH_4)6Mo7O_{24}$– 50 mg; KJ – 30 mg; $CoCl_2$ – 60 mg.
Explanations: BP – without Hoagland 2 nutrient solution; PP – with Hoagland 2 nutrient solution; PP+Mg – with Hoagland 2 nutrient solution + $MgSO_4 \cdot 7H_2O$ – 0.49 $g \cdot l^{-1}$; PP+2Mg – with Hoagland 2 nutrient solution + $MgSO_4 \cdot 7H_2O$ – 0.98 $g \cdot l^{-1}$

To obtain the water extracts, leaves of *Festuca arundinacea* (*Fa*), *Lolium multiflorum* (*Lm*), *Lolium perenne* (*Lp*), *Phleum pratense* (*Php*) and *Poa pratense* (Pp) were collected from the plants at the tillering stage. The plant material (50 g of dried leaves from each species) was submerged with 1000 ml of distilled water for 24 h and the solution was percolated through filter paper. The extracts were stored at 5°C.

Phleum pratense seeds (each sample of 20 seeds selected manually) were laid in Petri dishes onto 3-ply layer of chromatography paper (Whatman No 3001917). The paper was moistened every day with 3 ml of suitable water extracts from the studied grass leaves (leaf extract, extract + nutrient solution; extract + nutrient solution + $MgSO_4 \cdot 7H_2O$ and finally, extract +

+ nutrient solution + double dose of $MgSO_4 \cdot 7H_2O$). The control was made up by the objects in which the blotting paper was moistened only with distilled water, distilled water with nutrient solution, distilled water with nutrient solution enriched with $MgSO_4 \cdot 7H_2O$ and finally distilled water with nutrient solution improved with double dose of $MgSO_4 \cdot 7H_2O$.

Germination energy of *Phleum pratense* seeds was assessed after five days (DORYWALSKI 1964) and the results were given as a percentage of germinated seeds. On the same day, measurements of the root system length and seedlings height were performed. The experimental results were analysed statistically using standard ANOVA. To verify the significance of differences between the studied means the Tukey confidence intervals ($p \leq 0.05$) were applied.

RESULTS AND DISCUSSION

The research results proved that the water extracts from leaves of all the grass species studied significantly inhibited the initial growth and development of *Ph. pratense* (Figure 1).

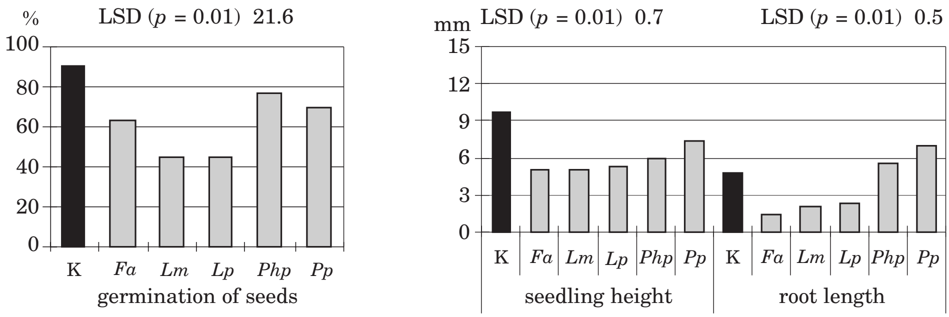

Fig. 1. Germination of seeds, seedling height and length of *Ph. pratense* roots under *Fa, Lm, Lp, Php* and *Pp* leaf water extracts and control treatments (K)

Irrespective of the BP, PP, PP+Mg and PP+2Mg objects used, the poorest germination of seeds of a tested species was reported in the objects with the water extracts from leaves of *L. multiflorum* and *L. perenne*. Substantial germination inhibition was also induced by the extracts from *F. arundinacea,* while the lowest from *Ph. pratense* and *P. pratensis* (Figure 2a). On the other hand, the addition of nutrient solution with or without magnesium sulfate significantly reduced the inhibitory effect of the extracts. The inhibitory influence of water extracts from *Fa, Lm, Lp, Php* and *Pp* leaves was neutralized by Hoagland 2 (PP) nutrient solution alone. However, a magnesium supplement contributed extremely to the increase of germinated seed number of a tested species (PP+Mg, Pp+2Mg) and limited most of all the allelopathic activity of *L. perenne* and *L. multiflorum* (Figure 2b).

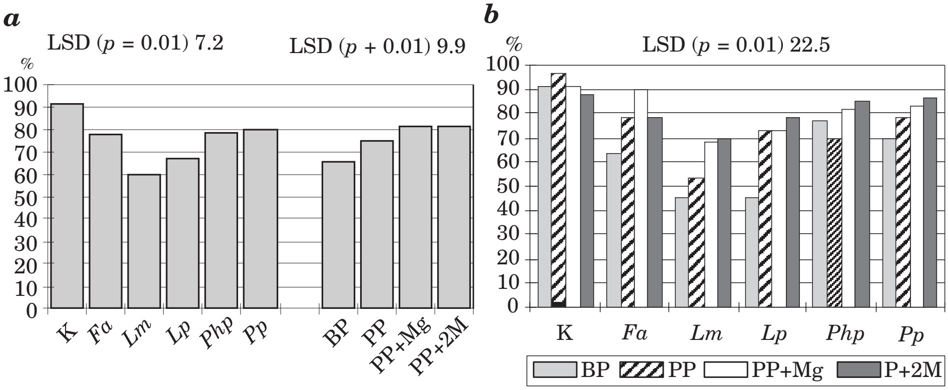

Fig. 2. Germination of *Ph. pratense* seeds under *Fa, Lm, Lp, Php,* and *Pp* (BP) leaf water extracts treatments, leaf water extracts treatments, without any nutrient solution (PP), with addition of nutrient solution enriched with Mg or 2Mg and control treatments (K)

Among the species investigated in this research, growth of *Ph. pratense* seedlings was mostly inhibited by *L. perenne* and *F. arundinacea* and to a lesser extend by *L. multiflorum* leaf extracts. The seedlings height, though, was limited to the smallest extent by the leaf water extracts of *P. pratensis* compared to the other species. These differences were statistically significant (Figure 3a).

Supplementation with either nutrient solution or magnesium sulfate to leaf water extracts (BP) promoted growth of *Ph. pratense* leaves. A single dose of magnesium sulfate proved most efficient in the objects with *L. multiflorum* and *Ph. pratense*. However, *Ph. pratense* seedlings supplied with extracts made from *F. arundinacea* and *P. pratensis* leaves were taller when a double dose of magnesium sulfate was supplied compared to the objects supplied with the extracts alone (Figure 3b).

Irrespective of the applied neutralizers, the highest inhibition of *Ph. pratense* roots development was imposed by leaf extracts of *L. multiflorum*, *F. arundinacea* and *L. perenne*. However, longer roots of the tested species were observed in the objects with water extracts from *Ph. pratense* compared to the control (Figure 4a). Irrespective of species, a double dose of $MgSO_4 \cdot 7H_2O$ (PP+2Mg) reduced the negative influence of the extracts from leaves (BP) most efficiently. A defensive mechanism of $MgSO_4 \cdot 7H_2O$ at higher concentrations (PP+2Mg) was apparent especially in the objects with extracts made from *L. perenne* and *Ph. pratense* leaves, whereas to a smaller extent from *F. arundinacea* (4b). The employed doses of magnesium did not

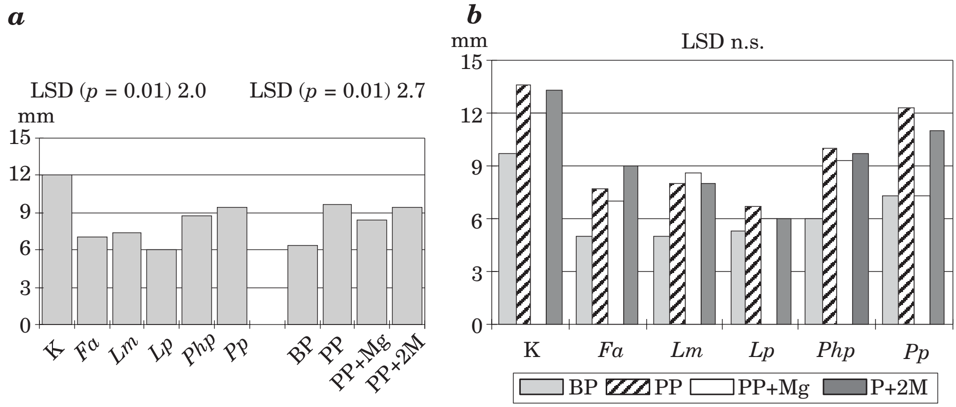

Fig. 3. *Ph. pratense* seedling height under *Fa, Lm, Lp, Php*, and *Pp* (BP) leaf water extracts treatments, leaf water extracts treatments, without any nutrient solution (PP), with addition of nutrient solution enriched with Mg or 2Mg and control treatments (K)

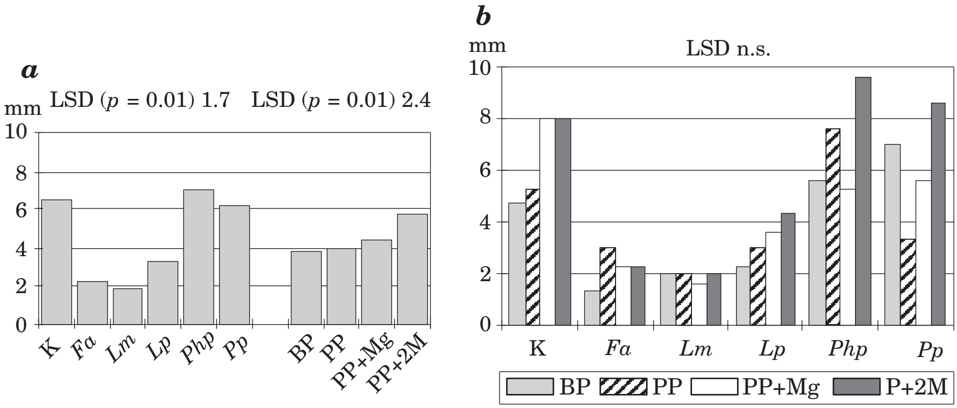

Fig. 4. Length of *Ph. pratense* roots under *Fa, Lm, Lp, Php*, and *Pp* (BP) leaf water extracts treatments, without any nutrient solution (PP), with addition of nutrient solution enriched with Mg or 2Mg and control treatments (K)

ameliorate the negative impact of the extracts prepared from *L. multiflorum* leaves.

According to previous studies, supplementation with active carbon can reduce the negative effects of allelochemicals (Callaway, Aschehoug 2000, Mahall, Callaway 1992). Zackrisson et al. (1996) claim that charcoal produced during the fires of the boreal forests causes appreciable reduction of phenols activity. Charcoal can play a key role in the neutralization of some detrimental effects of *Empetrum hermaphroditum* on the neighbouring species through the absorption of the allelopathic substances secreted from the tissues of this species (Nilsson et al. 2000).

It was found that deficit of minerals in a number of plant species induces the increased production of allelopathic compounds (Inderjit, Duke 2003, Camacho-Cristobal et al. 2002). Blum et al. (1993) report that the presence of nitrates or carbon compounds in a soil modifies the allelopathic effect of *p*-coumaric acid. It was stated that a high nitrogen content in a form of nitrates enhanced its activity, whereas glucose or methionine reduced it of *Ipomea hederacea* growth. The research results of Blum et al. (1985) revealed that regeneration of cucumber seedlings after inhibiting by ferulic acid proceeded more promptly in an environment abundant in mineral components as compared to mineral deficits.

Among numerous fertilizer components, magnesium is of primary importance (Filipek 1996). The presence of its ions contributes to the adaptation process of plants to the stress conditions caused, among others, by the allelopathic activity (Palta 1990). The activity of allelopathic substances activity is reported to disturb the course of metabolism as well as the physiological processes occurring in plants (Baziramakenga et al. 1995, Politycka 1997, Galindo 1999). Growth inhibition of cucumber root cells (*Cucumis sativus*) in the presence of alleopathic compounds was attributed to the disturbances in lipid metabolism and reduction of protein synthesis (Burgos et al. 2004). Moreover, the allelocompounds can inactivate some of enzymes, producing e.g. insoluble complexes with enzymatic proteins (Padhy 2000). They inhibit the intake of micro- and macroelements through a change in the hydraulic conductance of cell membrane (Inderjit, Duke 2003). The allelocompounds can also diminish the activity of H^+-ATP`s plasmalemma in the roots (Hejl, Koster 2004). Magnesium, as a positive ion, regulates the cell pressure and charge balance in a plant cell. It also participates in the enzyme activation. The most important function, though, is the phosphorylation of energy carriers which, if impaired, may inhibit plant growth (Palta 1990).

CONCLUSIONS

1. Water extracts from the leaves of the tested grass species reduced germination of *Phleum pratense* and significantly modified its initial growth.

2. Application of $MgSO_4 \cdot 7H_2O$ in the research had a beneficial effect on elimination of the inhibitory influence of extracts from leaves of the tested species of meadow grasses on germination of *Phleum pratense* seeds. The addition of magnesium sulfate positively influenced the root length and height of *Phleum pratense* seedlings.

3. The obtained results indicate possible elimination of the inhibitory effects of extracts from leaves of some grass species by the use of $MgSO_4 \cdot 7H_2O$ during the initial stage of *Phleum pratense* growth and development.

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CONTENT OF MACROELEMENTS IN EGGPLANT FRUITS DEPENDING ON VARIED POTASSIUM FERTILIZATION

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Abstract

Eggplant fruits are abundant in potassium, the amount of which ranges from 200 to 600 mg K·100 g^{-1} FM, depending on a variety. They are also a rich source of phosphorus, magnesium, calcium, and iron. As there are no fertilization recommendations for eggplant cultivation under cover, this study been undertaken to evaluate the vegetable's requirements. The aim was to test how the type and dose of potassium fertilizer influences nitrogen, phosphorus, calcium, and magnesium levels in eggplant fruits. The experiment on cv. Epic F_1 eggplant was carried out in unheated polyethylene tunnel in 2004-2005. The eggplant was cultivated on peat subsoil in 10 dm^3 capacity cylinders made of rigid plastic. The experiment was set up in a two-factor, completely randomized design. The influence of two factors was examined: I – type of potassium fertilizer (KCl, K_2SO_4, KNO_3), and II – potassium rate (8, 16, 24 g K·$plant^{-1}$). Fruit samples for laboratory determinations were collected in mid-August, in the middle of fruiting stage. Fruits were harvested at the stage of technological maturity and the following were determined: N_{tot}, P, K, Ca, Mg. The results were processed by variance analysis. Significantly higher total nitrogen and potassium concentrations in fruits of plants fertilized with potassium nitrate as compared to the other two fertilizer types were recorded. Increasing potassium doses, regardless the fertilizer type, considerably increased the element content in eggplant fruits and widened the K:Ca ratio value. The diversification of potassium fertilization did not have significant influence on phosphorus and magnesium concentrations in eggplant fruits. No significant changes in calcium content in fruits were observed when applying potassium sulfate or nitrate, while higher potassium chloride rates significantly decreased the concentration of this element in fruits.

Key words: eggplant fruit, potassium fertilizer, K dose, macroelements.

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ZAWARTOŚĆ MAKROELEMENTÓW W OWOCACH OBERŻYNY W ZALEŻNOŚCI OD ZRÓŻNICOWANEGO NAWOŻENIA POTASEM

Abstrakt

Owoce oberżyny należą do warzyw zasobnych w potas. Jego zawartość w zależności od odmiany wynosi od 200 do 600 mg K·100 g^{-1} świeżej masy. Są również źródłem fosforu, magnezu, wapnia i żelaza. Ze względu na brak informacji o zaleceniach nawozowych do uprawy oberżyny pod folią, podjęto badania nad określeniem potrzeb nawożenia tego warzywa. Celem pracy było określenie wpływu rodzaju nawozu potasowego oraz dawki na zawartość azotu, fosforu, potasu, wapnia i magnezu w owocach oberżyny. Badania oberżyny odmiany Epic F_1 wykonano w latach 2004-2005 w nieogrzewanym tunelu foliowym w latach 2004-2005. Oberżynę uprawiano w cylindrach z folii sztywnej o pojemności 10 dm^3, w torfie ogrodniczym. Doświadczenie przeprowadzono w układzie kompletnej randomizacji. Badano wpływ 2 czynników: I – nawozów potasowych (KCl, K_2SO_4, KNO_3), II – dawek potasu (8, 16, 24 g K·roślina^{-1}). Próby owoców do badań laboratoryjnych pobrano w 2. dekadzie sierpnia, w połowie okresu owocowania. Owoce zbierano w fazie dojrzałości użytkowej i oznaczono w nich N-og., P, K, Ca, Mg. Wyniki opracowano metodą analizy wariancji. Wykazano istotnie większą zawartość azotu ogółem i potasu w owocach roślin nawożonych saletrą potasową w porównaniu z roślinami nawożonymi dwoma pozostałymi nawozami. Wzrastające dawki potasu – niezależnie od zastosowanych nawozów potasowych – istotnie zwiększały zawartość tego składnika w owocach oberżyny oraz rozszerzały stosunek K: Ca.

Zróżnicowane nawożenie potasem nie miało istotnego wpływu na zawartość fosforu i magnezu w owocach oberżyny. Nie wykazano znaczących zmian w zawartości wapnia w owocach po zastosowaniu siarczanu i azotanu potasu, w przypadku zaś większych dawek chlorku potasu zawartość tego składnika była istotnie mniejsza.

Słowa kluczowe: owoce oberżyny, nawozy potasowe, dawki potasu, makroelementy.

INTRODUCTION

Eggplant fruits are attracting a growing interest of consumers and producers on the Polish market of fresh vegetables. Eggplant fruits are valuable dietetically due to their low caloricity along with rich and varied mineral composition. First of all, they are abundant in potassium, calcium, phosphorus, magnesium, and microelements (Kaufmann, Vorwerk 1971, Herrmann 1996, Lawende, Chavan 1998, Kowalski et al. 2003, Golcz et al. 2005, Michałojć, Buczkowska 2007, 2008a).

Vegetables of *Solanaceae* family require much potassium (Kaufmann, Vorwerk 1971, Golcz 2001, Nurzyński et al. 2001). Therefore, this vegetable may be a potassium source in human daily human diet.

The growing interest in eggplant cultivation means that it is necessary to define nutritional and fertilization requirements of this vegetable when grown under cover.

The up-to-date fertilization recommendations for eggplant have referred to tomato's nutritional needs (Uliński, Glapiś, 1998).

The present study has aimed at evaluating the influence of the type and dose of potassium fertilizer on nitrogen, phosphorus, potassium, calcium, and magnesium contents in eggplant fruits grown in transitional peat.

MATERIAL AND METHODS

The study on cv. Epic F_1 eggplant was carried out in unheated polyethylene tunnel in 2004-2005 at the Experimental Farm of the University of Life Sciences in Lublin, Felin. Eggplant seedlings were prepared in a greenhouse, in 8-cm diameter pots on peat subsoil in accordance with the rules approved for this species. In both experimental years, plants were transferred to a tunnel at the beginning of June. The cultivation period, from the seeding until the termination of the experiment, lasted for about 7 months (beginning of March until mid- September).

Eggplants were cultivated in 10 dm^3 capacity cylinders made of rigid plastic, on transitional peat (initial pH 4.6), which was limed using $CaCO_3$ to achieve pH 6.5. The experiment was set up in a two-factor, completely randomized design.

The influence of these two factors was examined:

1) type of potassium fertilizer: KCl, K_2SO_4, KNO_3;

2) potassium rate: 8, 16, 24 g $K \cdot plant^{-1}$.

The experiment included 9 combinations (3 types of potassium fertilizer plus 3 potassium rates). Each combination was represented by 8 experimental units consisting of a cylinder with a single plant.

Fertilization was applied at the amount of (in g · $plant^{-1}$): nitrogen – 11 (as NH_4NO_3 – 34% N, some of the nitrogen was introduced with potassium in combination with KNO_3, while the remaining quantity was added as ammonium nitrate, so that all the plants received the same nitrogen rate); phosphorus – 7.0 in the form of superphosphate ($Ca(H_2PO_4)_2 \cdot H_2O$ – 20.2% P); potassium – 8, 16, and 24 as potassium chloride (KCl – 50% K), potassium sulfate (K_2SO_4 – 41.6% K), or potassium nitrate (KNO_3 – 37.4% K, 15% N); magnesium – 6.0 as magnesium sulfate ($MgSO_4 \cdot H_2O$ – 17.4% Mg). Microelements were applied in following forms: EDTA – Fe, $CuSO_4 \cdot 5H_2O$, $ZnSO_4 \cdot 7H_2O$, $MnSO_4 \cdot H_2O$, H_3BO_3, $(NH_4)_2Mo_7O_{24} \cdot 4H_2O$ at amounts as for peat subsoils. All microelements, half of the phosphorus rate, and 1/7 nitrogen, potassium, and magnesium doses were applied during the subsoil preparation just before plant setting. The remaining nitrogen, potassium, and magnesium amounts were post-crop introduced in six doses every 10 days.

Plants grew naturally with no cutting. Fruits were harvested at the stage of technological maturity, which was indicated by the purple color and characteristic metallic glow (weight of harvested fruits ranged from 250 to

300 grams). Harvests were made every 7-10 days from the end of July to mid-September.

Fruit samples for laboratory determinations were collected in mid-August, in the middle of fruiting stage. Following items were determined in fruits: total N – by means of Kjeldahl's method after wet digestion (Klej--Foss) and after combustion at 550°C: P – colorimetrically using ammonium molybdate, and K, Ca, Mg – applying the AAS technique (Perkin – Elmer). All determinations were performed in three replications.

The results were statistically processed by means of variance analysis. The difference significance was estimated on the basis of Tukey's multiple confidence intersections at the error probability level of 5%.

RESULTS AND DISCUSSION

The results related to total nitrogen, phosphorus, potassium, calcium, and magnesium achieved in 2004 and 2005 are presented in Table 1 as means due to the similar values attained.

Total nitrogen content in eggplant fruits was from 19.1 to 22.2 g $N_{tot} \cdot kg^{-1}$ d.m. Type and rate of the applied potassium fertilizer significantly affected its content in plants. Higher level of this element was found in fruits of plants fertilized with potassium nitrate as compared to the other two fertilizers. Moreover, increasing potassium rates applied in the form of sulfate and nitrate caused considerable increase in the nitrogen content in eggplant fruits. Such dependence was not recorded when applying potassium chloride. The positive potassium influence on nitrogen content in plants can be explained by the share of K^+ ions in transport of NO_3^- through a plant (Nowotny-mieczyńska 1976). Lower nitrogen concentration in fruits of plants fertilized with various potassium doses (KCl) results probably from a high concentration of chlorides in subsoil (Michałojć, Buczkowska 2008b). Literature data report lower nitrate uptake by plants, which is the consequence of antagonism between NO_3^- and Cl^- ions (Nurzyński et al. 2001, Starck 2003).

Phosphorus concentration in eggplant fruits ranged from 2.5 to 3.0 g $P \cdot kg^{-1}$ d.m. No significant influence of the experimental factors on the content of this element in fruits was revealed. Abdel Hafeez and Cornillon (1976) as well as Sewiader and Morse (1982) found similar phosphorus levels in eggplant fruits in their studies on phosphorus fertilization. Golcz et al. (2005) reported twice as much phosphorus in fruits of eggplant cultivated on organic subsoils (peat, bark).

Potassium content ranged from 23.4 to 35.1 g $K \cdot kg^{-1}$ d.m. and, similarly to nitrogen, its amount was significantly differentiated by the experimental factors. Its highest level was found in fruits of eggplant fertilized with potas-

Table 1

The content of N-total, P, K, Ca, Mg (g· kg^{-1} d.m.) in fruit of eggplant depending on type and dose of potassium fertilizer

Type of potassium fertilizer	Dose (g K·plant^{-1})	N-total	P	K	Ca	Mg
KCl	8	20.0	2.5	24.5	1.9	1.0
	16	20.0	2.7	28.5	1.4	1.2
	24	20.3	2.8	29.9	1.3	1.3
Average for KCl		20.1	2.7	27.6	1.5	1.2
K_2SO_4	8	19.5	2.9	24.2	1.5	1.2
	16	19.1	2.6	23.7	1.2	1.2
	24	20.5	3.0	29.6	1.4	1.2
Average for K_2SO_4		19.7	2.8	25.8	1.4	1.2
KNO_3	8	20.4	2.7	23.4	1.6	1.0
	16	22.2	2.6	28.2	1.4	1.3
	24	22.2	2.7	35.1	1.6	1.4
Average for KNO_3		21.6	2.7	28.9	1.5	1.2
Average for dose K	8	19.9	2.8	24.1	1.6	1.0
	16	20.5	2.6	26.8	1.3	1.2
	24	21.0	2.8	31.5	1.5	1.3
Average		20.5	2.7	27.5	1.5	1.2
$LSD_{p=0.05}$						
for type of potassium fertilizer		0.27	n.s.	0.58	n.s.	n.s.
for dose of potassium fertilizer		0.27	n.s.	0.58	n.s.	n.s.
for interaction		0.63	0.33	1.36	0.24	0.24

sium nitrate, lower when nourished with potassium chloride, and the lowest when receiving potassium sulfate (Table 1). Regardless the fertilizer type, significant increase of its content in eggplant fruits was recorded (Table 1). Potassium is a nutrient that can be easily taken up and transported through a plant, hence its higher content was also found in generative parts. The following authors also reported similar and higher potassium concentrations in eggplant fruits: Kaufmann and Vorwerk (1971), Savvas and Lenz (1994), Russo (1996), Golcz et al. (2005), as well as Michałojć and Buczkowska (2008a).

Calcium content in eggplant fruits was from 1.2 to 1.9 g Ca·kg^{-1} d.m. The variance analysis revealed no significant influence of the varied potassium fertilization on the element concentration in eggplant fruits when applying potassium sulfate and nitrate, while higher rates of potassium chloride resulted in considerably lower calcium content. Lower calcium concentration in tomato and paprika fruits caused the apical dry-rot (Golcz 2001, NURZYŃSKI et al. 2001). Present study did not reveal any symptoms of this disease in any combination.

Magnesium level in eggplant fruits was also similar to that of calcium and ranged from 1.0 to 1.4 g $Mg \cdot kg^{-1}$ d.m. No significant effects of the varied potassium fertilization on its content in fruits were recorded. A study by GOLCZ et al. (2005) on eggplant cultivated on organic subsoils (peat, bark) revealed similar calcium and magnesium contents.

The potassium to calcium contents ratio in eggplant fruits seems to be interesting. Regardless the potassium fertilizer type, the widening of K:Ca ratio was observed along with the potassium rate increase (Table 2). Such dependence apparently proves the antagonistic action of K^+ ions towards Ca^{2+} intake. Potassium to magnesium did not reveal similar correlation (Table 2). KULCZYCKI (2006), in his studies on corn, found that increasing potassium doses considerably decreased magnesium concentration and widened the K:Mg ratio value.

Table 2

Values of K: Ca and K: Mg ratios in fruit of eggplant depending on type and dose of potassium fertilizer

Type of potassium fertilizer	Dose ($g K \cdot plant^{-1}$)	K: Ca	K: Mg
KCl	8	12.9	24.5
	16	20.4	23.8
	24	23.0	23.0
Average for KCl		18.4	23.0
K_2SO_4	8	16.1	20.2
	16	19.8	19.8
	24	21.1	24.7
Average for K_2SO_4		18.4	21.5
KNO_3	8	14.6	23.4
	16	20.1	21.7
	24	21.9	25.1
Average for KNO_3		19.2	24.1
Average for dose K	8	15.1	24.1
	16	20.6	22.3
	24	21.0	24.2
Average		18.3	22.9

CONCLUSIONS

1. Significantly higher total nitrogen and potassium concentrations in fruits of plants fertilized with potassium nitrate as compared to the other two fertilizer types were recorded.

2. Increasing potassium doses, regardless the fertilizer type, considerably increased the element content in eggplant fruits and widened the K:Ca ratio value.

3. The varied potassium fertilization did not have significant influence on phosphorus and magnesium concentration in eggplant fruits.

4. No significant changes of calcium content in fruits when applying potassium sulfate or nitrate were observed, while higher potassium chloride rates significantly decreased that element concentration in fruits.

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AN ATTEMPT AT EVALUATING THE INFLUENCE OF WATER QUALITY ON THE QUALITATIVE AND QUANTITATIVE STRUCTURE OF EPIPHYTIC FAUNA DWELLING ON *STRATIOTES ALOIDES* L., A CASE STUDY ON AN OXBOW LAKE OF THE ŁYNA RIVER*

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Abstract

The paper contains the results of a study on the dependence of the qualitative and quantitative structure of the phytophilous macrofauna dwelling on *Stratiotes aloides* L. (water soldier) on the quality of waters in a lentic oxbow lake of the Łyna River. The observations were carried out during the vegetative season (April – June) 2006 at high and moderate water levels. During the study, a total of 18 taxa of invertebrates dwelling on the above plant species were identified, with the exact number of taxa varying in time: 11 taxa were noticed in April and May, and in June their number went up to 13. The examination of hydrochemical parameters of the oxbow lake waters revealed that the density of macrofauna was lower at higher values of proper conductivity and macronutrients, ammonia nitrogen and COD, increasing at high levels of sulphates. High concentrations of ammonia nitrogen and non-organic components coincided with decreased biomass of epiphytic animals on water soldier. Additionally, it has been observed that elevated concentrations of potassium ions have a negative influence on the biomass of most epiphytic animals (except *Erpobdella* sp.).

Key words: epiphytic macrofauna, water chemism, oxbow lake, the Łyna River.

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PRÓBA OCENY WPŁYWU JAKOŚCI WÓD NA STRUKTURĘ JAKOŚCIOWO-ILOŚCIOWĄ EPIFAUNY ZASIEDLAJĄCEJ *STRATIOTES ALOIDES* L. NA PRZYKŁADZIE STARORZECZA ŁYNY

Abstrakt

W pracy przedstawiono wyniki badań nad próbą określenia zależności struktury jakościowo-ilościowej makrofauny fitofilnej zasiedlającej *Stratiotes aloides* L. od jakości wód w lentycznym starorzeczu rzeki Łyny. Badania prowadzono w okresie wegetacyjnym (IV-VI) 2006 r. przy wysokich i średnich stanach wód. W czasie badań zidentyfikowano łącznie 18 taksonów bezkręgowców zasiedlających ten gatunek roślinny, przy czym ilości te podlegały zmienności czasowej: w kwietniu i maju zanotowano 11 taksonów, a w czerwcu 13. Spośród badanych parametrów hydrochemicznych wód starorzecza zagęszczenie makrofauny epifitycznej było niższe w przypadku wysokich wartości przewodnictwa właściwego i makroskładników, azotu amonowego i ChZT, natomiast wzrastało w przypadku wysokich stężeń siarczanów. Wysokie stężenia azotu amonowego i składników nieorganicznych towarzyszyły spadkowi biomasy zwierząt epifitycznych zamieszkujących osokę. Ponadto stwierdzono negatywny wpływ podwyższonych stężeń jonów potasu na biomasę zwierząt naroślinnych (z wyjątkiem *Erpobdella* sp.).

Key words: epifauna, chemizm wody, starorzecze, rzeka Łyna.

INTRODUCTION

Oxbow lakes as ecosystems are valuable for a large number of hydrobionts, which has been given recognition in the Habitat Directive, where the EU has established legal protection of old river beds (Directive 92/43/EEC). Among the EU members, Poland is one of the richest countries regarding the number of oxbow lakes. Therefore, our country should become one of the principal locations where ecology of such habitats is conserved. However, since oxbow lakes are one of the least known parts of river valleys, serious problems occur in the implementation of general European regulations pertaining the environmental conservation of such habitats (GLIŃSKA-LEWCZUK 2004, JEZIERSKA-MADZIAR et al. 1999, OBOLEWSKI 2006, OBOLEWSKI, STRZELCZAK 2008).

The latest guidelines on the monitoring of natural environment suggest the importance of biological assessments, with chemical assays becoming now a mere background (KOWNACKI 2000, KUDELSKA, SOSZKA 2001, SOSZKA, KUDELSKA 2000). Owing to their limited mobility and easy identification, benthos invertebrates appear as a principal object of studies for biological assays involved in bio-monitoring of waters (KAJAK 1998).

Oxbow lakes are dynamically changing ecosystems, in which habitat conditions vary depending on a hydrologic season. The period of spring thaws and high water levels induces fresh influx of river waters to oxbow lakes and temporary improvement of dwelling conditions for animals which live in such water bodies (OBOLEWSKI 2005). Simultaneously, the merging of river and oxbow lake waters creates ecological channels, which enable larger animals, for example fish, to migrate and this may largely affect the qualitative and quantitative structure of benthos fauna (JEZIERSKA-MADZIAR et al. 1999). Oxbow lakes are the water bodies where macrolytes develop, which accelerate succession processes and become inhabited by aquatic animals. This is the role that the water soldier (*Stratiotes aloides* L.) plays. This plant grows large leaves, which can sometimes cover up the whole water surface (KRASOWSKA, MIKULSKI 1960, KORNATOWSKI 1976, 1980). As a result, habitats are formed for all kinds of invertebrates migrating from anaerobic benthic waters (LINHART 1999, LINHART et al. 1998, OBOLEWSKI 2005). Such migration of animals must be included in the monitoring of oxbow lakes so as to obtain full information about ecological status of these ecosystems.

The aim of this study has been to try and demonstrate relationships between the qualitative and quantitative composition of epiphytic fauna dwelling on *Stratiotes aloides* and the quality of water in an oxbow lake of the Łyna River, overgrown with plants. In order to focus exclusively on the effect of environmental conditions on the structure of fauna dwelling on plants, trophic relations occurring in this ecosystem were excluded. Thus, the results presented in this paper should be treated as a preliminary step for further research, which will include laboratory experiments.

MATERIAL AND METHODS

The oxbow lake examined (S8) is a water reservoir situated on the left bank of the Łyna River, near the village of Łaniewo, between Dobre Miasto and Lidzbark Warmiński (Figure 1). This lake maintains water all year, with the average annual fluctuations of the water table reaching 1.5 m, which affects the surface area of the lake, its depth and the quality of the lake water. When the water volume is moderate, the maximum depth of the oxbow lake is 2m and the surface area equals 1.8 ha (GLIŃSKA-LEWCZUK 2005). This lake was created as a result of the erosion processes in the valley of the Łyna River. At present, this oxbow lake is separated from the river and represents typical features of the so-called lentic oxbow lakes (GLIŃSKA-LEWCZUK 2008). Its waters are ‘refreshed’ by high water during the mid-winter and early spring thaw, which nevertheless is not sufficient to halt intensive biogeochemical processes in this lake. Consequently, the lake is being silted up and overgrown by macrophytes.

During our study, conducted in the vegetative season of 2006, the water level was high (April) and medium high (May-June) while the water table was overgrown with communities of pleuston, with two dominant species, *Lemma trisulca* L. and *Spirodela polyrhiza* L., which were accompanied by compact patches of *Stratiotes aloides* L. and *Potamageton natans* L., sur-

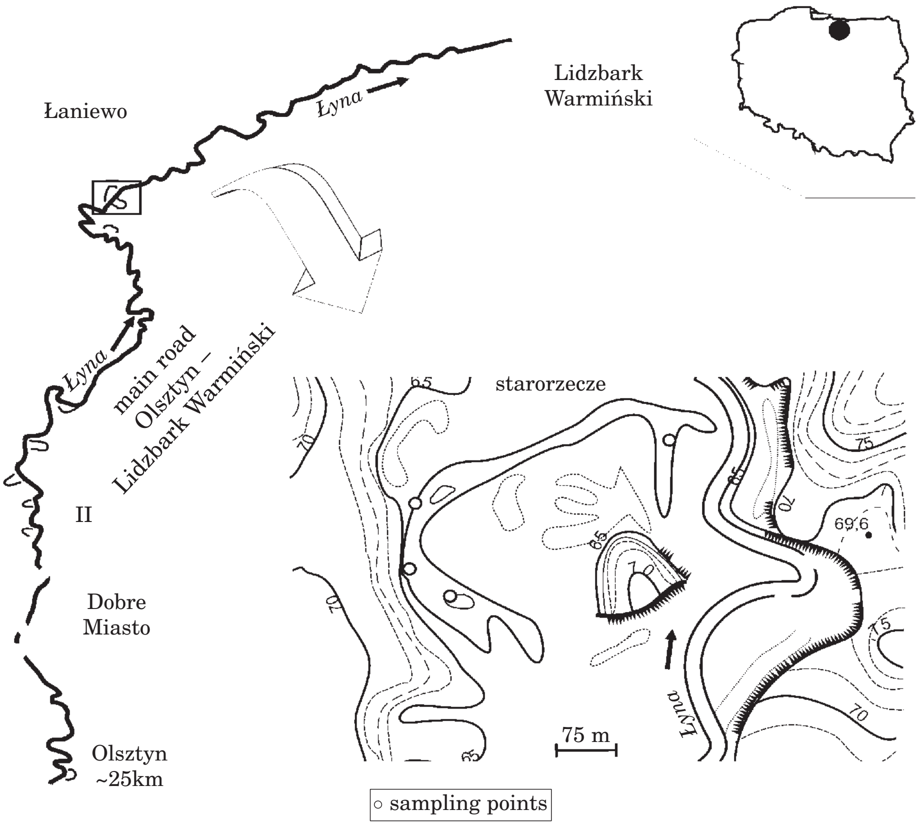

Fig. 1. Location of the oxbow lake and sampling sites in the middle Łyna River valley

rounded by a dense zone of reed *Phragmites australis* (CAV.) TRIN and STUED and *Glyceria maxima* Martman. Water soldier plants when in bloom (maximum emergence) contributed a 20.5% share to the plant cover of the water surface.

The analysis of the epiphytic fauna on *S. aloides* was carried out from April to June 2006 in two series. Each series consisted of 3 samples which included from 12 to 14 cormi of water pineapple. The wet mass of water pineapple ranged from 3.9 to 5.7 kg. The examinations were completed according to the methodology described by OBOLEWSKI (2005), i.e. phytophilous fauna and leaf mining fauna were separated from the plant material and identified under laboratory conditions. The representatives of macrozoobenthos found in the samples were identified to appropriate systematic levels, according to the operation monitoring guidelines.

The sampling of biological material was accompanied by field analyses of the physicochemical parameters of the oxbow lake water (*in situ*) and collection of water samples for laboratory assays. In field, near the site where water soldier cormi were collected, thermal and oxygen profiles were performed in the vertical column of the water body. In addition, proper electrolytic conductivity and pH of the water were measured. The laboratory analysis of other physicochemical parameters (N-NO_2, N-NO_3, N-NH_4, P-PO_4, COD and major ions) was performed according to the methodology cited by HERMANOWICZ et al. (1999). Chemical quality of the water and the interpretation of the results, including determination of the type of water, were referred to the currently binding classification (Ordinance of the Minister, Journal of Laws 32, item 248). Biocenotic indices, which illustrate structural relationships within a benthos macrofauna community, i.e. domination (D), frequency (F) and ecologic importance indices (Q), were used for the analyses. Dominance Index was computed with reference to density and biomass. The most numerous species as well as the species characterised by the highest biomass in a given assemblage were divided according to the suggestion formulated by KASPRZAK and NIEDBAŁY (1981). In order to assess species diversity, the Shannon-Wiener biodiversity index was computed .

Significance of differences between the average values obtained was tested with Cochran and Cox test applied at the level of significance α=0.05. Cochran and Cox test is helpful in studies which involve few objects whose variations differ significantly, and that was the case in the months covered by our study. On the other hand, lack of differences between compared objects ($C < C_{\&}$) suggests that the samples originate from the same general population, and the differences are accidental.

Cochran and Cox test

$$C = \frac{\bar{x}_1 - \bar{x}_2}{\sqrt{E_{\bar{x}_1}^2 + E_{\bar{x}_2}^2}}$$ E = standard deviation error

$$C_\alpha = \frac{E_{\bar{x}_1}^2 \cdot t_{1_\alpha} + E_{\bar{x}_2}^2 \cdot t_{2_\alpha}}{E_{\bar{x}_1}^2 + E_{\bar{x}_2}^2}$$ a = 0.05 (from t-Student test distribution)

The matrix of Pearson’s correlation was also established in order to determine the dependence of the density and biomass of epiphytic fauna on the determined physicochemical parameters of water in the oxbow lake of the Łyna River.

RESULTS AND DISCUSSION

Oxbow lakes which are lentic. i.e. contain stagnant waters, are naturally predisposed to strong growth and development of pleuston macrophytes, which are either capable of travelling vertically in water (water soldier) or float on the surface of a water table (duckweed). The effect produced by these plants on lake ecosystems and their eutrophisation has been largely examined and clarified (PIECZYŃSKA 1988). However, relatively less information is available on the interaction of a biotic substratum, epiphytic animals and abiotic conditions (GIERE 1993, HIGLER 1975, LALONDE, DOWNING 1992, LINHART 1999, OBOLEWSKI 2005, 2006, TARKOWSKA-KUKURYK 2006).

The quality of water in the examined oxbow lake was low, especially with respect to the amount of dissolved oxygen (Table 1), which is why it was classified as Water Quality Class V. Moreover, the water in this oxbow lake had a very high COD and a very high concentration of phosphates and

Table 1

Hydrological and hydrochemical conditions in the oxbow lake of the Łyna River near Łaniewo in April-June 2006

Parameter	Unit	Month of water sampling			Average±SD
		April	May	June	
Zone of water levels	m	high	mean	mean	
Reaction	pH	8.49	8.20	7.6	8.1±0.4
Temperature	°C	8.20	13.50	17.9	13.2±0.86
DO	mg O_2 dm^{-3}	11.26	5.48	5.00	7.23±3.50
DO	$\%O_2$	94.70	52.60	52.70	66.67±24.28
COD	mg O_2 dm^{-3}	28.4	56.0	52.4	45.6±15.0
SEC	µS cm^{-1}	364	471	453	429±57.3
TDS	mg dm^{-3}	208	208	204	207±2.3
$N\text{-}NO_2$	mg dm^{-3}	0.0066	0.0088	0.0076	0.0081±0.0011
$N\text{-}NO_3$	mg dm^{-3}	0.088	0.086	0.068	0.081±0.011
$N\text{-}NH_4$	mg dm^{-3}	0.235	0.234	0.195	0.221±0.023
TIN	mg dm^{-3}	0.333	0.329	0.271	0.311±0.035
TP	mg dm^{-3}	0.29	1.09	1.9	1.10±0.81
$P\text{-}PO_4$	mg dm^{-3}	0.12	0.63	1.31	0.68±0.60
Ca	mg dm^{-3}	55.4	68.9	62.6	62.3±6.7
Na	mg dm^{-3}	9.2	6.0	5.6	6.9±2.0
K	mg dm^{-3}	2.4	2.2	1.4	2.0±0.5
Mg	mg dm^{-3}	12.90	10.30	8.9	10.7±2.0
Cl	mg dm^{-3}	12.0	7.0	6.0	8.3±3.2
SO_4	mg dm^{-3}	142.20	6.62	17.71	55.51±75.28
HCO_3	mg dm^{-3}	154	200	196	183±25.5

general phosphorus, which in June was twice as high as the permissible norms of water quality class V waters (Journal of Laws 32, item 284). Such high levels of biogens prove that the lake was strongly eutrophic. In the first month of the study, when young water soldier plants grew rapidly, high levels of sulphates occurred in the water (142.20 mg dm^{-3}), some of which may have been later assimilated by macrophytes and, as SMOLDERSKA et al. (2003) suggest, most likely bounded via iron in bottom sediments.

The development of vascular plants in eutrophic waters makes water bodies shallower. This is due to high production of organic matter, which intensifies decomposition and causes oxygen deficits, thus eliminating oxybionts (KAJAK 1998). This unfavourable influence of macrophytes on oxbow lakes is set off by the fact that they create large areas of biotic substratum, which is inhabited by epiphytic and periphytic fauna. Some of our previous studies on the same oxbow lake (OBOLEWSKI et al. 2006, OBOLEWSKI, STRZELCZAK 2008) made it evident that the poor benthos, in terms of its quality and quantity, was set off by fauna dwelling on water plants, where animals could grow and develop abundantly, thus contributing considerably to the biodiversity of this water body.

The water soldier community growing in the oxbow lake of the Łyna River near Łaniewo was inhabited by 11-13 taxa, whose qualitative composition was typical of macrozoobenthos. As Figure 2 shows, the density of epiphytic fauna ranged from 253 to 917 individuals kg^{-1} and its biomass varied from 2,770.8 to 5,065.9 g_{mm} kg^{-1}. In other oxbow lakes (OBOLEWSKI 2005, OBOLEWSKI et al. 2006), the density and biomass of epiphytic fauna were similar to the above values. The most favourable conditions for the development of epiphytic invertebrates occurred in April, when the density of these animals was 3.6-fold higher than in May. This may have been stimulated by a high level of oxygen dissolved in waters as the oxbow lake waters had merged with the river and thaw water. Another favourable event was the high intensity of photosynthesis during that time.

The intensive growth of young individuals in spring and summer is confirmed by the statistically lower values of their biomass in April (0.607) versus the data obtained in May (0.894) and June (0.847) (Tab. 2). Despite such large variation in the biomass, the oxbow lake showed very little species diversity, which resembled that found only in extremely simple ecosystems (KAJAK 1998). Shannon's index reached values comparable to the ones determined for another oxbow lake, Koński Staw, separated from the river trough of the Słupia River and overgrown with water plants (OBOLEWSKI 2005).

Hirudinea was represented by *Erpobdella* sp., *Helobdella stagnalis* L., *Glossiphonia complanata* L., *Hemiclepsis marginata* O.F. Müller. They made up from 6% in June to 9% in April of the total density of the epiphytic fauna and from 2.5% in May to 28% in April of the total biomass of this fauna dwelling on water soldier (Figure 2). The highest ecological role in this class (Q index) was assigned to *Helobdella stagnalis* (Q=8.7%), at F=100% (Table 2).

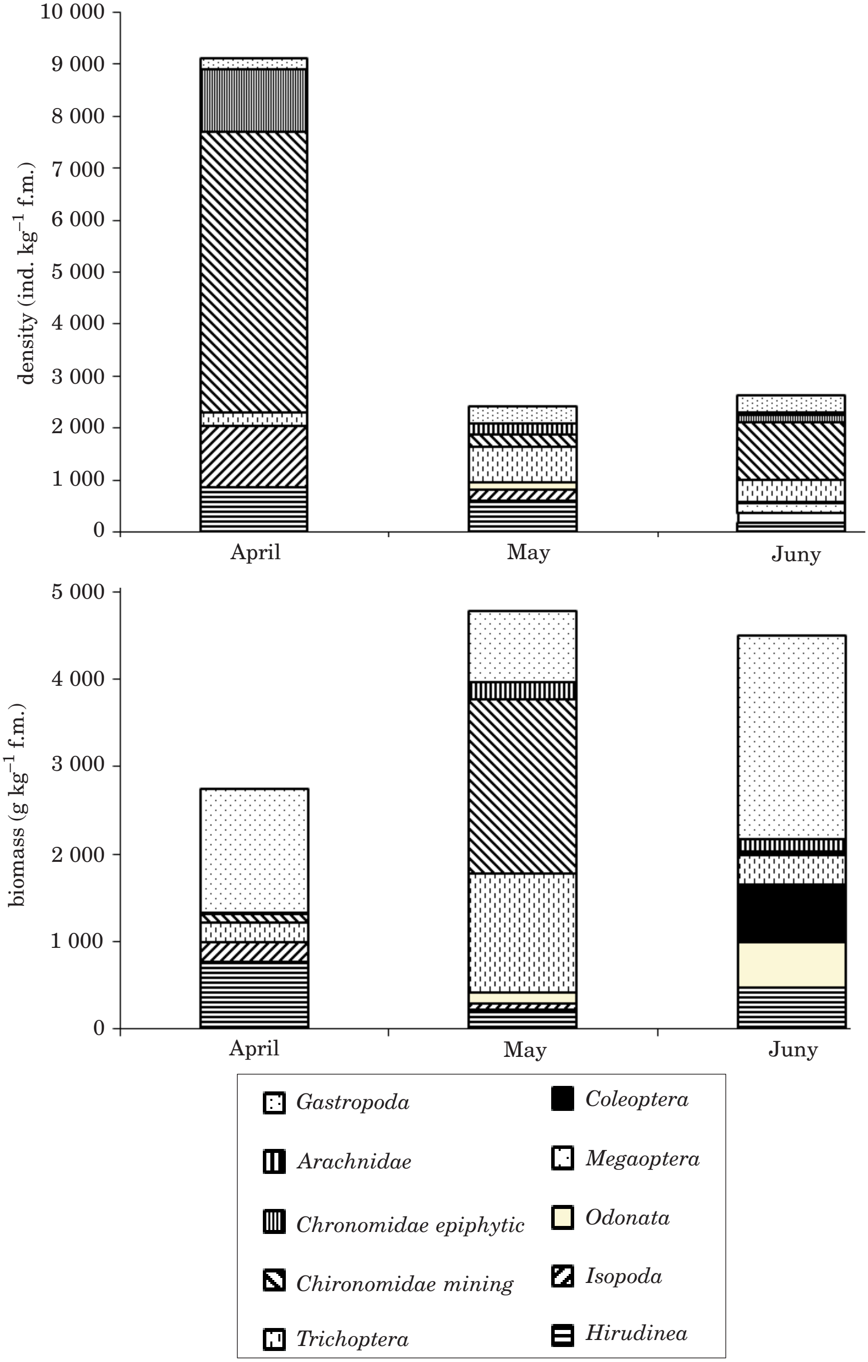

Fig. 2. Density (indiv. kg^{-1} d.m.) and biomass (g kg^{-1} d.m.) of dominant invertebrates dwelling on *S.aloides* in the oxbow lake of the Łyna River

Table 2

Dominance Index (D_A– density, D_B – biomass), frequency (F,%) and ecological importance index (Q) as well as density significance test (a=0.05) of epiphytic fauna on S.aloides in the oxbow lake of the Łyna River from April to June 2006

Taxon	April		May		June			
	DA	DB	DA	DB	DA	DB	F	Q
Total Hirudinea	9.4	27.6	24.1	6.4	6.3	10.6		
Erpobdella sp.	3.8	12.7	0.0	0.0	3.5	8.8	67	1.6
Helobdella stagnalis	2.0	5.4	23.3	2.5	0.7	0.6	100	8.7
Glossiphonia complanata	3.6	9.5	0.0	0.0	2.1	1.2	67	1.3
Hemiclepsis marginata	0.0	0.0	0.8	3.9	0.0	0.0	33	0.1
Total Crustacea (Asellus aquaticus)	13.0	8.0	8.3	1.3	0.0	0.0	67	4.7
Total Insecta	75.3	13.5	50.6	72.8	81.1	37.6		
Odonata larvae								
Lestes sp.	0.0	0.0	2.1	1.1	2.1	5.8	67	0.9
Aeshna sp.	0.0	0.0	0.5	0.3	0.0	0.0	33	0.1
other Odonata	0.0	0.0	2.5	1.0	4.9	5.5	67	1.7
Megaloptera – Sialis luteria	0.0	0.0	0.0	0.0	7.6	0.5	33	0.8
Culex sp.	0.5	0.8	0.0	0.0	0.0	0.0	33	0.1
Trichoptera larvae								
Limnephilus sp.	0.5	3.0	13.3	10.1	7.8	2.1	100	7.2
Ecnomus tenellus	0.3	2.0	3.5	2.6	5.2	1.9	100	3.0
Phryganea grandis	1.5	3.1	4.1	3.6	0.0	0.0	67	1.3
other Trichoptera	0.5	0.8	6.4	10.7	3.2	3.7	100	3.4
Chironomidae larvae – mining	59.0	3.6	9.1	39.5	42.3	0.7	100	36.8
Chironomidae larvae – epiphitic	13.0	0.2	0.0	0.0	4.9	0.1	67	4.0
Arachnida – *Argyroneta* aquatica	0.0	0.0	9.1	3.9	2.3	3.1	67	2.5
Coleoptera – *Dytiscus* sp.	0.0	0.0	0.0	0.0	0.8	14.2	33	0.1
Total Gastropoda	2.3	51.3	17.0	19.5	12.6	51.9		
Lymnaea sp.	1.5	17.1	4.0	11.9	4.2	32.7	100	3.2
Acroloxus lacustris L.	0.0	0.0	0.0	0.0	4.2	3.6	33	0.5
Planorbarius corneus L.	0.2	0.7	3.2	2.1	4.2	15.6	100	2.5
Planorbis planorbis L.	0.6	33.5	0.0	0.0	0.0	0.0	33	0.1
Anisus sp.	0.0	0.0	5.9	2.1	0.0	0.0	33	0.6
Gyraulus sp.	0.0	0.0	4.0	3.4	0.0	0.0	33	0.4
Shannon H' Log Base 10,	0.607		0.894		0.847		0.857	
Shannon index J'	0.583		0.859		0.761		0.671	
Cochran and Cox test (a=0.05)	$C=0.233 > C_a=$							
			$C=0.829 > C_a=$					
	$C=0.437 > C_a=$							

The value of Pearson's correlation coefficient implied the density of leeches was positively correlated with the water reaction but negatively related to the concentration of phosphates (Table 3).

Crustaceans were represented by *Asellus aquaticus* L., which added considerably to the density of epiphytic animals (D_A = 8.3 – 13%) but was not an ecologically important taxon (Q=4.7%). This species is common among benthos fauna in oxbow lakes (Obolewski 2005, 2006). During our study the density and biomass of *A. aquaticus* L., was steadily declining, and in June this species of *Isopoda* was not observed. As early as in May its number fell 20-fold and the biomass decreased by 3.5-fold (Figure 2). The density of *A. aqauticus* was positively correlated with the concentration of chlorides and sodium as well as the concentration of magnesium, which was correlated with the increase in the biomass of this species (Table 3). The concentration of chlorides, sodium and magnesium increased in each consecutive month, which may have been due to the fact that the water level in the Łyna River valley fell to medium high and, as water evaporated from the oxbow lake, the concentration of these ions increased.

The contribution of dragonflies to the average number of biomass of phytophilous fauna of the oxbow lake examined was small and similar to that observed in other old riverbeds (Linhart 1999, Obolewski 2005, 2006). The highest biomass and density of dragonflies occurred in June and the lowest – in May. In April, no dragonflies were noticed (Figure 2). The analysed samples of fauna contained specimens of *Ischmura* sp., *Lestes* sp., *Aeschna* sp., whose decreasing numbers were correlated with the concentration of magnesium and their smaller biomass was associated with the concentration of potassium ions (Table 3). In natural waters, most alkaline ions appear as Na^+ and much fewer are K^+. Potassium ions are intensively used by plants, including water soldier, which can then release potassium to water in the form of extracts (Van der Welle et al. 2007).

Caddisfly larvae (*Limnephilus* sp., *Ecnomus tenellus* (Rambur), *Phryganea grandis* L.) developed the best in May, when *Limnephilus* sp. constituted the group of subdominants (D_A=13.3% and D_B=10.1%) and the whole order played a principal role in shaping the density (27%) and biomass (27%) of the whole population on water soldier (Table 2, Figure 2). In April, the biomass of these larvae was small but increased several-fold in the following month. After reaching the maximum value, the density of caddisfly larvae declined 1.6-fold and their biomass went down by four-fold. Among the analysed physicochemical parameters of the oxbow lake waters, it was only the concentration of nitrites that was positively correlated with the density of caddisfly larvae.

The major group of epiphytic animals living on water pineapple plants in oxbow lakes is composed of *Chironomidae* larvae, which can either dwell on the surface of leaves or drill into them (Obolewski 2005, Obolewski et al. 2006, Prejs et al. 1997, Tarkowska-Kukuryk 2006). *Chironomidae* larvae were an absolutely permanent inhabitant of water soldier (F=100%), being evidently the principal component of epiphytic fauna (Q=41%), with the leaf-mining individual dominating (Q=36.8%) over the ones on leaf surface (Q=4%). It seems that this was a result of the larvae avoiding being eaten by predators (PREJS et al. 1997) or else the ease of obtaining plant food. *Chironomidae* larvae foraged on nitrogen rich plant tissues, thus incorporating large quantities of this element into their bodies and reaching high biomass. This is what happened in May, when a small density of mining larvae was observed alongside their large biomass, but no larvae were found on leaf surface (Figure 2). A decrease in the density of *Chironomidae* larvae on and inside leaves of water soldier may have been due to the high values of conductivity and COD in the oxbow lake waters (Table 3).

It seems that a high concentration of sulphates in the oxbow lake waters was beneficial for *Chironomidae* larvae dwelling on leaf surface. Sulphates are absorbed by aquatic plants (sulphur is assimilated in cell proteins). In turn, the plants extract substances, which may affect the consumers which dwell on these plants (TUROBOYSKI 1979).

Within the phystophilous fauna found in the oxbow lake, molluscs were represented by six species (*Lymnaea* sp., *Acroloxus lacustris* L., *Planorbarius corneus* L., *Planorbis planorbis* L., *Anisus* sp., *Gyraulus albus* O.F. Müller) typical for water bodies with stagnant waters, overgrown with aquatic plants (OBOLEWSKI et al. 2009, PIECHOCKI 2004), although their contribution to the density of epiphytic fauna was small. However, they affected significantly the biomass of the whole population, making up from D_B=16% (in May) to D_B=52% (in June) of the total value (Table 2). In May, the biomass of specimens belonging to the genera *Lymnaea* and *Planorbic planorbis* L. declined. At the same time, the mass of *Planorbis corneus* L. rose, and this is a typical for the ecology of these species (PIECHOCKI 2004). In the following month, the biomass of slugs increased as the population then comprised large representatives of *Lymneaea* sp. and *Planorbis planorbis* (Table 2). Regarding the analysed physical and chemical parameters of the water in the oxbow lake, it appears that the density of *Gastropoda* was conditioned by the amount of oxygen in the water. The identified species of molluscs breathe atmospheric oxygen, therefore poor oxygen conditions in water, which can be destructive to other epiphytic species, are not an obstacle to their development. The reduction of most of the hydrobionts on water soldier enables pulmonate molluscs to occupy empty habitats. It is interesting that there was no correlation between the structure of *Gastropoda* and the concentration of calcium in the oxbow lake water and that the dependence between these invertebrates and amounts of carbohydrates was moderate (Table 3).

The analysed samples of fauna also comprised ecologically less important (Q index) larvae of the order *Megaloptera – Sialis lutaria* (Q=0.8%), *Coleoptera – Dytiscus* sp. (Q=0.1%), whose density was proportional to the concentration of ammonia nitrogen and the biomass changed in proportion

Table 3

Pearson's correlation coefficient ($p<0.05$) between the quality of water in the oxbow lake of the Łyna River and the density (A) and biomass (B) of epiphytic fauna on *S.aloides*

	Hirudinea		Isopoda		Odonata		Megalo-ptera		Tricho-ptera		Coleoptera		Chironomidae larvae				Culex sp.		Arachnid-ae		Gastro-poda		Total	
													mining		epiphytic									
	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B
pH	+		+	+	-	- -	-	-			-	-					+	+			-			
Temp.	-		-	-	+	+	+	+			+	+	-		-		-	-			+		-	
O_2	+	+	++	+	-				-				+		+		++	++		-	- -		++	++
% O_2	+	+	++	+	- -				-				++		++		++	++		-	- -		++	++
EC		-	-	-	+				+				- -		- -		- -	- -		++	++		- -	
NO_2		--							++	+			-	+	-		-	-	+	++	+		-	
NO_3	+			+	-	- -	- -	- -			- -	- -							+			-		
NH_4	+					- -	- -	- -			- -	- -										-		
Nmin	+			+	-	- -	-	- -			-	- -										-		
Mg	++		++	++	- -	-	-	-			-	-	+		+		+	+		-	-		+	
Cl	+		++	+	-	-							+		+		+	+		-	-		+	
TDS		-							+	++				++		--						-		
PO_4	- -		-	-	+	+	+	+			+	+			-		-	-	+		+		-	
Pog	-		-	-	+	+	+	+			+	+	-		-		-	-			+		-	
SO_4	+	+	-	+	-				-				++		++		++	++		-	--		++	++
Ca		- -	-						+	+			-	+	-		-	-	-	+	+		-	
Na	+	+	++	+	-	-							+		+		+	+	+	-	-		+	
K	+			+	-	- -	-	-			-	-										-		
ChZT		-	- -	-	+								- -		- -		- -	-		+	++		- -	- -
HCO_3	- -		-	-	+	++	+	+			+	+							+			+		

Correlation coefficient
from 0.75 to 0.99 (+), 1.00 (++), from -0.75 to -0.99 (-), -1.00 (--)

to the levels of ammonia and mineral nitrogen. Larvae of the mosquitoes *Culex* sp. were sensitive to high levels of COD and their considerable density and biomass were correlated with dissolved oxygen and sulphates. The biomass of mosquitoes may also be connected with conductivity (Table 3). Among the fauna living on water soldier, a representative of arachnids, *Argyroneta aquatica* L., appeared. Its biomass was correlated with the high conductivity of the water in the oxbow lake and water dissolved nitrites.

The values of the water reaction, obtained during our study, approximated the level considered dangerous (pH>8.5), at least for some fish species (TUROBOYSKI 1979). As there were no predators in the lake, larger benthos animals could develop in the lake. Excess amounts of phosphorus compounds accelerates eutrophication processes in aquatic ecosystems, which can completely change the biological balance by increasing primary and secondary productivity as well as saprobisation of such water bodies. As for old river beds, they can disappear completely (OLSZEWSKI 1971). The lentic character of the oxbow lake we examined did not favour development of macrofauna due to the values of two life essential parameters: access to light, which was drastically limited by the thick cover of pleuston plants, associated with water soldier, on the surface of water and oxygen deficits, common in such ecosystems. Limited access to sunlight stimulating development of phytoplankton and, indirectly, oxygen production. In April, oxygen deficit appears at the depth of 1.2 m, and in the summer, it can be observed at 0.25 m. This means that anaerobic conditions are present in nearly all the water masses, which effectively limits development of all benthos organisms. Under such conditions, water pineapple creates an only remaining habitat, just under the water surface, which can be colonized by mostly aerophilous benthos organisms (OBOLEWSKI 2005, SHEFFER et al. 1984).

Studies on oxbow lakes as part of the conservation of natural habitats (Directive 92/43/EEC) should include epiphytic fauna, which the Water Directive claims can serve as a bioindicator. The qualitative and quantitative structure of epiphytic communities together with the analysis of abiotic conditions can indicate the ecological status of a given ecosystem (OBOLEWSKI 2006). This is another stage in the implementation of the EU guidelines on protection of particularly valuable natural habitats for wildlife.

CONCLUSIONS

1. The hydrochemical and hydroecological examinations carried out in an oxbow lake of the Łyna River, lacking level water exchange with river waters, showed that the major factors limiting the development of epiphytic fauna were periodic or permanent oxygen deficits in water.

2. The quantity and biomass of benthos fauna were positively correlated with aerobic conditions in lentic ecosystems. As the amount of dissolved oxygen and water oxygenation declined in late spring months (June), the number of epiphytic fauna went down.

3. Among the examined parameters, the strongest negative influence on the analysed formations was produced by high values of proper conductivity, COD, ammonia nitrogen and mineral components.

4. The highest density and biomass of epiphytic fauna were obtained by Chironomidae larvae mining water soldier leaves, which can be explained by the fact that they could successfully avoid predators and incorporate into their bodies the nitrogen accumulated in large amounts in the plant tissues.

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COMPARISON OF CHEMICAL COMPOSITION OF SELECTED WINTER WHEAT SPECIES

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Abstract

Chemical composition of common wheat – *Triticum aestivum ssp. vulgare* Vill. Host., hard wheat – *Triticum durum* Desf., and spelt – *Triticum aestivum ssp. spelta* (L.) Thell grains was investigated. Total protein, wet gluten, fiber, ash, carbohydrates, falling number, macronutrients (phosphorus, potassium, calcium, magnesium), and microelements (copper, iron, manganese, zinc) were determined. Also standard deviation, variability and correlation coefficients were calculated. Hard wheat and spelt lines were characterized by much higher contents of total protein, wet gluten, and falling number value than common wheat; however, the highest protein concentration and falling number was recorded in grains of hard wheat. Common wheat was distinguished by low ash content and the highest carbohydrates level. Higher percentage of macronutrients and microelements in grains of spelt and hard wheat, as compared to common wheat, confirms the usefulness of these species for foodstuff production. Among the qualitative traits studied, content of carbohydrates appeared to be the least variable (cv = 2.2%), while the highest variability (cv = 31.1%) was shown by fat content. Significant correlations for the following trait pairs were observed: protein–gluten, protein–carbohydrates, fat–ash, fat–falling number, carbohydrates–gluten, and ash–falling number.

Key words: hard wheat, spelt, grain quality, chemical composition, macronutrients, microelements.

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PORÓWNANIE SKŁADU CHEMICZNEGO ZIARNA WYBRANYCH GATUNKÓW PSZENICY

Abstrakt

Badano skład chemiczny ziarna pszenicy zwyczajnej – *Triticum aestivum ssp. vulgare* Vill. Host., pszenicy twardej – *Triticum durum* Desf. i orkiszu pszennego – *Triticum aestivum ssp. spelta* (L.) Thell. Określono zawartość białka ogólnego, glutenu mokrego, włókna, tłuszczu, popiołu, węglowodanów, liczby opadania, makroelementów (fosforu, potasu, wapnia, magnezu) i mikroelementów (miedzi, żelaza, manganu, cynku). Obliczono także odchylenie standardowe, współczynniki zmienności oraz współczynniki korelacji. U badanych linii pszenicy twardej i orkiszu pszennego wykazano znacznie wyższą zawartość białka ogólnego, glutenu mokrego oraz wyższą liczbę opadania niż u odmiany pszenicy zwyczajnej, przy czym najwyższą zawartość białka i liczbę opadania stwierdzono w ziarnie pszenicy twardej. Pszenica zwyczajna wyróżniała się niską zawartością popiołu i największym udziałem węglowodanów. Wyższy udział makro- i mikroelementów w ziarnie orkiszu pszennego i pszenicy twardej, w porównaniu z pszenicą zwyczajną, potwierdza dużą przydatność tych gatunków w produkcji żywności. Spośród badanych cech jakościowych zawartość węglowodanów okazała się cechą najmniej zmienną (cv = 2,2%). Największą z kolei zmiennością (cv = 31,1%) charakteryzowała się zawartość tłuszczu. Wykazano istotne korelacje dla następujących par cech: białko–gluten, białko–węglowodany, tłuszcz–popiół, tłuszcz–liczba opadania, węglowodany–gluten i popiół–liczba opadania.

Słowa kluczowe: pszenica twarda, orkisz, jakość ziarna, skład chemiczny, makroelementy, mikroelementy.

INTRODUCTION

Cereal grain is one of the oldest components of human diet. It contains numerous nutrients: proteins, carbohydrates, vitamins, minerals (iron, magnesium, potassium, phosphorus, zinc), and, next to fruits and vegetables, constitutes a source of antioxidants (Marciniak, Obuchowski 2006). Wheat is the species of cereals which, owing to its extremely varied uses and large area of cultivation, constitutes the basic food all over the world. Apart from common wheat, which is the fundamental species in cultivation, more and more importance is gained by hard wheat, an excellent material for production of pasta, and spelt, which in the form of bakery products can be consumed by persons suffering from various kinds of allergy, mainly allergies to wheat-based foods (Campbell 1997).

Hard wheat (*Triticum durum* Desf.) is a wheat species with hard and vitreous kernels, high content of proteins and gluten, and of carotenoid pigments. Due to its values, this species of wheat is frequently referred to as "pasta wheat", and the coarse-grains grits obtained from it, known as semolina, is especially recommended for the production of pasta of various kinds. It is grown mainly in countries with dry climate, where unfavourable moisture conditions restrict the cultivation of common wheat (Rachoń 2001).

In turn, the grain of spelt (*Triticum aestivum ssp. spelta* (L.) Thell), in spite of its relation with common wheat, is superior to it in terms of its nutritional and health qualities. It has a higher content of proteins and gluten, and also contains vitamins A, E, D. Moreover, the composition of vitamin E in spelt is dominated by gamma- and alpha-tocopherols (Grela 1996, Pałys, Kuraszkiewicz 2003, Waga 2003, Sulewska et al. 2005).

The objective of this study was to evaluate grain quality of new lines of hard wheat and spelt as compared to common wheat, in terms of the chemical composition and the content of macro- and microelements in the grain.

MATERIAL AND METHODS

In 2005–2007, a field experiment was conducted at the Experimental Farm at Felin, the University of Life Sciences in Lublin. The experimental field was located on soil classified as good wheat complex, with high level of nutrients: P–76, K–119 and Mg–55 (in $mg \cdot kg^{-1}$ of soil). The reaction of the soil in KCl solution was 6.3 (Rachoń 2001).

The experiment was set up in random blocks design, in four replications, on a stand after rapeseed. The experiment comprised two winter spelt lines (STH 3 and STH 715) and winter hard wheat lines (STH 716 and STH717), originating from the Plant Breeding Station at Strzelce, and a single cultivar of common wheat (Tonacja – a cultivar in quality group A acc. to the COBORU, constituting a model cultivar for technological quality of winter wheat grain). The area of the harvest plots was $10m^2$. The soil tillage was conventional, plough system. Pre-sowing fertilisation was applied as follows: phosphorus in the dose of 26.2 kg P?ha^{-1} and potassium in the dose of 66.6 kg K ?ha^{-1}. Nitrogen fertilisation was applied as top dressing, after the start of vegetative growth (N – 70 $kg \cdot ha^{-1}$) and in the phase of the third node (N – 30 $kg \cdot ha^{-1}$). A total of 5 million germinating kernels of common wheat, hard wheat and spelt (threshed from chaff) were sown per 1 ha. Plant protection treatments (herbicide, fungicide, insecticide, retardant) were applied as suggested by the relevant recommendations.

Every year of the study, chemical analyses were made on samples of grain from the plots. Following wet mineralisation (concentrated sulphuric acid + 30% solution of H_2O_2), determinations were made of the content of fibre (gravimetric method), fat (Soxhlet method) and ash (gravimetric method at 580°C). The content of proteins was determined according to the Kjeldahl method ($N\% \cdot 5.75$). The level of carbohydrates was obtained after the deduction of the remaining dry matter components. Also, determination was made of the concentration of the following macro- and microelements: N and P (flow spectrophotometry), K (emission of flame spectrometry), Ca, Mg, Cu, Fe, Mn and Zn (atomic absorption spectrometry). Wet gluten content was determined with the elution method (acc. to standard PN-A-74041:1977), and the falling number with the method of Hagberg-Perten, acc. to standard PN-ISO 3093:1996.

The results of the experiment were processed statistically with the method of analysis of variance, the significance of differences being estimated by means of Tukey test at 0.05 level of significance. The results are given as mean values for the three years of the study, with standard deviation (SD). Variability of the studied quality parameters of wheat grain was determined on the basis of coefficient of variation, while relationships between them were determined through calculation of coefficients of correlation for significance level of 0.05.

In the years of the study (2005–2007), October and April were characterised by notable deficit of precipitation and by temperatures that considerably exceeded the long-term average (Table 1). The years 2005 and 2006 had cool and wet March, and rainfall level in June below the long-term mean value. Additionally, in 2006 a considerable deficit of rainfall was recorded in July. In the final season of the study the lowest rainfall sum was recorded, and the highest air temperature, exceeding the long-term average for each month – from September 2006 to August 2007. The year 2007 was also characterised by excessive rainfalls in May and June.

RESULTS AND DISCUSSION

Analysis of the chemical composition of grain of the wheat lines and cultivars under comparison revealed significant differentiation of most of the features and traits examined (Table 2).

One of the more important quality features of wheat is the content and quality of proteins in grain. The lines of hard wheat and wheat spelt were characterised by notably higher content of total protein in grain compared to the common wheat cultivar. The highest content of protein (14.1%) was found for hard wheat line STH 716, and the lowest one (11.0%) – for common wheat cultivar Tonacja. The lines of wheat spelt attained intermediate values among all the cultivars tested (mean 12.1%). Numerous authors point out to a higher protein content in grain of hard wheat in comparison to that of common wheat. In the studies by Rachoń and Kulpa (2004) as well as Rachoń and Szumiło (2006), hard wheat contained on average 2.3-2.6% more protein, while in the research by Szwed-Urbaś (1993) and Segit and Szwed-Urbaś (2006) those differences were even higher reaching 4.6%.

Grain of spelt wheat, compared to common wheat, has a higher protein content. This is verified by our own study (spelt – 12.1%, common wheat – 11.0%) and by other authors. Bojňanská and Frančáková (2002) recorded val-

Table 1

Rainfalls and air temperatures according to the Meteorological Observatory at Felin

Year	Month												IX-VIII
	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	
Rainfalls (mm)													sum
2004/2005	14.2	19.1	58.2	17.1	41.6	26.0	48.0	18.6	98.0	55.9	109.8	108.7	615.2
2005/2006	18.0	8.6	21.7	54.5	15.7	26.7	47.0	30.3	59.5	37.9	6.8	198.3	525.0
2006/2007	11.0	14.2	41.2	18.6	51.5	22.3	30.2	17.4	81.5	87.8	87.0	37.6	500.3
Mean for 1951-2000	52.1	40.3	39.1	31.5	21.7	24.8	25.8	40.6	58.3	65.8	78.0	69.7	547.7
Temperature (°C)													mean
2004/2005	12.8	9.7	3.1	1.5	0.0	-3.9	-0.1	9.1	13.2	16.0	19.8	16.9	8.2
2005/2006	14.9	8.8	2.7	-0.8	-7.6	-4.3	-1.0	8.7	13.6	16.9	21.9	17.4	7.6
2006/2007	15.8	10.1	5.3	3.0	2.6	-1.6	6.2	8.7	15.0	18.1	19.2	18.4	10.1
Mean for 1951-2000	12.9	7.9	2.5	-1.4	-3.6	-2.8	1.0	7.5	13.0	16.5	17.9	17.3	7.4

Table 2

The chemical composition of wheat (% d.m.)

Cultivar and lines		Total protein	Fiber	Crude fat	Ash	Carbo-hydrate	Wet gluten (%)	Falling number (s)
Tonacja *T. aestivum ssp. vulgare*	M	11.0	2.4	1.9	1.6	83.1	24	215
	SD	1.02	0.13	0.84	0.07	3.44	3.5	56.4
STH 716 *T. durum*	M	14.1	2.4	1.4	2.0	80.1	30	285
	SD	1.78	0.11	0.23	0.11	3.56	8.2	72.3
STH 717 *T. durum*	M	12.9	2.2	1.5	1.8	81.6	25	276
	SD	1.82	0.08	0.37	0.14	3.57	5.3	70.5
STH 3 *T. aestivum ssp. spelta*	M	12.1	2.9	2.0	1.7	81.3	28	258
	SD	1.44	0.37	0.20	0.17	3.20	8.7	70.0
STH 715 *T. aestivum ssp. spelta*	M	12.1	2.1	2.1	1.7	82.0	27	272
	SD	1.08	0.11	0.42	0.13	3.29	8.7	54.0
$LSD_{(p=0.05)}$		1.04	0.20	0.33	0.11	1.03	4.3	40.4
CV (%)		13.9	13.1	31.1	10.3	2.2	27.0	26.0

M – mean for the years 2005-2007
SD – standard deviation
$LSD_{(p=0.05)}$ for cultivar and lines
CV – coefficient of variation

ues in the range of 12.5-19.4% in the studied genotypes. LACKO-BARTOSOVA and REDLOVA (2007) reported 14.8-18.6% protein content, and SULEWSKA et al. (2005) determined 15.5-19.7%.

According to CEGLIŃSKA et al. (2004) and SEGIT and SZWED-URBAŚ (2006), gluten of good quality should be strong, elastic and plastic, and its content should fall within the range of 30-40%. Wheat grain for processing is required to contain at least 25% of gluten in kernels. However, particular species and cultivars vary, sometimes considerably, in this properties. As GĄSIOROWSKI and OBUCHOWSKI (1978) report, hard wheat grain is characterised by gluten that is more suitable for pasta products than for bakery products, due to somewhat different structure and composition compared to common wheat. Similar conclusions were reached RACHOŃ (2001). In turn, according to SULEWSKA et al. (2005), gluten of wheat spelt is sensitive to overly intensive mechanical treatment in the course of dough formation.

In our own study, the content of gluten oscillated within a relatively low level (24-38%) compared to the results obtained by other authors (ACHREMOWICZ et al. 1999, BOJŇANSKÁ, FRANČÁKOVÁ 2002, RACHOŃ, SZUMIŁO 2002, SULEWSKA et al. 2005, SEGIT, SZWED-URBAŚ 2006). These authors, who studied various wheat genotypes, obtained results spread over a fairly broad range (30.6--50.6%). Among the tested objects, the highest content of gluten was found in hard wheat (line STH 716-30%), and the lowest one – in the common wheat (24%).

The falling number enables us to conclude whether a given product originated from grain with increased enzymatic activity, frequently due to a hidden process of grain germination. In this study a considerable variation of this index was found with relation to the wheat lines under comparison (Table 2). Among the tested lines and cultivars, significantly higher values of this parameter were obtained for hard wheat (285-276 s) and wheat spelt (272-258 s) compared to common wheat (215 s). In turn, ACHREMOWICZ et al. (1999) and RACHOŃ (2001) claimed that the falling number of common wheat was higher in relation spelt lines and hard wheat they examined. However, most authors emphasize that climatic conditions have a very strongest effect on the value of the falling number, especially such weather factors as rainfall during the period of ripening and harvest of grain (RACHOŃ 2001, BOJŇANSKÁ, FRANČÁKOVÁ 2002, SEGIT, SZWED-URBAŚ 2006). Analogous relations were observed in our own study.

In a comprehensive analysis of quality parameters of wheat grain it is important to determine the content of ash and the level of mineral components, which affect technological possibilities of transforming grain into final products, i.e. pasta products. Cereal products, which constitute 40-50% of the human diet, are one of the primary sources of mineral components. In our study, the highest ash content was recorded in the grain of hard wheat (1.8-2.0%) – Table 2, significantly lower in common wheat grain (1.6%) and in spelt (1.7%). Higher ash content in hard wheat grain compared to common wheat is also indicated by GĄSIOROWSKI and OBUCHOWSKI (1978), MAKARSKA et al. (2001), and RACHOŃ (2001). PAŁYS and KURASZKIEWICZ (2003), SCHMITZ (2005) and SEIFERT (2005), on the other hand, demonstrated a higher content of that component in spelt wheat lines than in common wheat.

Among the other components we investigated, notable is the highest content of fat in wheat spelt, much higher than in common and durum wheat cultivars (Table 2), high content of fibre in one of the spelt lines (STH 3), and also the highest level of carbohydrates in common wheat. At the same time, the level of carbohydrates displayed the least variation (cv = 2.2%). The highest variation among all the examined components was shown by the content of fats (cv = 31.1%).

In the present research (Table 3), notably higher levels of such macroelements as phosphorus, potassium and calcium were determined in hard wheat as compared to common wheat, with the greatest variation being found in the case of calcium (cv = 24.5%). The grain of spelt assumed intermediate values. A less pronounced variation was demonstrated in the case of magnesium.

Table 3

The macroelements content of wheat (% d.m.)

Cultivar and lines		Phosphorus	Potassium	Calcium	Magnesium
Tonacja *T. aestivum ssp. vulgare*	M	0.38	0.42	0.034	0.13
	SD	0.042	0.017	0.002	0.014
STH 716 *T. durum*	M	0.50	0.53	0.053	0.13
	SD	0.040	0.033	0.011	0.014
STH 717 *T. durum*	M	0.42	0.52	0.055	0.11
	SD	0.043	0.027	0.014	0.006
STH 3 *T. aestivum ssp. spelta*	M	0.46	0.44	0.042	0.13
	SD	0.059	0.028	0.002	0.022
STH 715 *T. aestivum ssp. spelta*	M	0.42	0.43	0.047	0.13
	SD	0.041	0.031	0.007	0.019
$LSD_{(p=0.05)}$		0.048	0.062	0.041	0.016
CV (%)		13.2	11.6	24.5	14.5

* explanations under Table 1

Among the analysed microelements (Table 4), the significantly lowest content of all micronutrients was found in common wheat, while the highest content of copper and zinc was determined in hard wheat, and that of iron and manganese in the spelt lines. A high content of phosphorus, calcium and iron in spelt wheat lines was obtained also by Schmitz (2005) and Seifert (2005). The smallest content variation among all the microelements was found in the case of manganese (cv = 14.3%), and the greatest one – for copper (cv = 25.4%).

The suitability of a given trait of grain is determined by the degree of its correlation with other quality features which specify the technological value of grain. One such feature is the content of proteins. In this study significant correlations were demonstrated between protein content and the levels of gluten and carbohydrates (Table 5). This parameter was positively correlated with wet gluten, r = 0.78, and negatively correlated with the content of carbohydrates, r = -0.94. A strong positive correlation between the levels of proteins and gluten was also demonstrated by Szwed-Urbaś (1993) and Rachoń (2001). Significant negative correlations were found for the couples: fat–ash (r = -0.57), fat–falling number (r = -0.67) and carbohydrates–wet gluten (r = -0.81). On the other hand, there was a positive correlation between ash content and the falling number (r = 0.64).

Table 4

The microelements content of wheat ($mg \cdot kg^{-1}$ d.m.)

Cultivar and lines		Copper	Iron	Manganese	Zinc
Tonacja *T. aestivum ssp. vulgare*	M	2.84	30.9	36.9	34.9
	SD	0.61	4.62	1.57	2.37
STH 716 *T. durum*	M	3.86	33.7	41.5	43.7
	SD	1.00	4.98	6.25	6.89
STH 717 *T. durum*	M	3.18	29.0	31.1	29.7
	SD	0.73	6.99	4.72	5.17
STH 3 *T. aestivum ssp. spelta*	M	2.99	32.2	41.6	31.5
	SD	0.72	5.05	2.31	5.31
STH 715 *T. aestivum ssp. spelta*	M	2.85	33.9	37.0	37.0
	SD	0.43	4.62	2.79	2.45
$LSD_{(p=0.05)}$		0.477	3.22	3.20	4.01
CV (%)		25.4	16.9	14.3	19.1

* explanations under Table 1

Table 5

Values of correlation coefficients

Correlation coefficients	Total protein	Crude fat	Ash	Carbohydrate
Ash	0.367	-0.573 *	-	-0.311
Carbohydrate	-0.937 *	-0.157	-0.311	-
Wet gluten	0.783 *	0.301	-0.170	-0.814 *
Falling number	0.106	-0.674 *	0.639 *	0.048

* values of significant correlation coefficients at $p=0.05$

CONCLUSIONS

1. The lines of hard wheat and wheat spelt were characterised by notably higher content of total proteins and wet gluten, and higher values of falling number, compared to the common wheat cultivar, with the highest protein content and falling number being recorded for hard wheat grain.

2. Common wheat was characterised by low ash content and the highest level of carbohydrates.

3. The higher level of macro- and microelements in grain of wheat spelt and hard wheat compared to common wheat provides supporting evidence for the applicability of those wheat lines to food production.

4. Among the grain quality traits studied, the content of carbohydrates proved to be the feature with the smallest variation (cv = 2.2%). The greatest variability (cv = 31.1%), in turn, was characteristic for the fat content.

5. Significant correlations were demonstrated for the following feature couples: protein–gluten, protein–carbohydrates, fat–ash, fat–falling number, carbohydrates–gluten, and ash–falling number.

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METALS IN CHOSEN AQUATIC PLANTS IN A LOWLAND DAM RESERVOIR

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Abstract

The research involved Słup Dam Reservoir, which is used as a source of drinking water and for flood prevention. The research material was made up of aquatic plants and water collected in the littoral zone of the reservoir, in which copper, nickel, cadmium, lead and zinc contents were determined.

Ceratophyllum demersum L. turned out to be the best accumulator of nickel, cadmium and zinc, *Potamogeton crispus* L. – copper, and *Phragmites communis* Trin – zinc. The presence of plants in the backwater area of the dam reservoir definitely improves water quality, not only thanks to their metal accumulation properties but because of their ability to act as a filter of substances carried in the water.

Key words: aquatic plants, dam reservoirs, rivers, water, metals.

METALE W ROŚLINACH WODNYCH ZE ZBIORNIKA ZAPOROWEGO NA TERENIE NIZINNYM

Abstrakt

Badania prowadzono na terenie Zbiornika Zaporowego Słup, który jest rezerwuarem wody pitnej oraz stanowi rezerwę przeciwpowodziową. Materiałem badawczym były rośliny wodne oraz woda pobierane w strefie litoralu zbiornika, w których określono zawartość miedzi, niklu, kadmu, ołowiu i cynku.

Ceratophyllum demersum L. najsilniej spośród badanych roślin kumulował nikiel, kadm i cynk, *Potamogeton crispus* L. – miedź, a *Phragmites communis* Trin – ołów. Obecność roślin w rejonie tzw. cofki zbiornika zaporowego z pewnością wpływa na poprawę jakości wody nie tylko wskutek kumulacji metali, ale także działania filtracyjnego w stosunku do zawiesin wnoszonych z wodą dopływu.

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Słowa kluczowe: rośliny wodne, zbiorniki zaporowe, rzeki, woda, metale.

INTRODUCTION

Heavy metals are among the many chemical compounds regarded as harmful and present in atmospheric air, soil and water. The principal sources of heavy metals for aquatic plants are water, bottom deposits and direct dry or wet atmospheric deposition. Consequently, such plants are often used as environmental pollution indicators (KUFEL, KUFEL 1986). It is particularly important to know concentrations of metals in plants in Słup Dam Reservoir, as the facility is used for the intake of tap water for a big urban centre (SZULKOWSKA-WOJACZEK, MAREK 1984).

The reservoir is relatively poor in higher aquatic plants. Rare groups of macrophytes are only to be found in the Nysa Szalona River, its tributary, in the reservoir's backwater area and the Nysa Szalona below the reservoir. This scarcity of plants is a result of the structure of the bowl and the reservoir's functions (water storage and flood prevention). Because of constant fluctuations in water levels, the reservoir banks are not hospitable to higher aquatic vegetation.

The plants growing on the banks of the tributary and in the backwater area act as a filter for pollutants carried by the Nysa Szalona. The research described in this article sought answers to the following questions:
– Is metal accumulation in plant organisms dependent on their location?
– Is the metal concentration in aquatic plants a species characteristic?
– Is the presence of macrophytes in the upper part of the reservoir and their filtering characteristics helpful and beneficial to water quality in Słup Dam Reservoir?

MATERIALS AND METHODS

The research involved Słup Dam Reservoir and the Nysa Szalona River. The reservoir is located on the border of the Sudeten Foreland and the Silesian Lowland. The reservoir was created by constructing an earth dam across the valley of the Nysa Szalona River, 8.2 km from the river source, at the village of Słup. The facility was put into operation in 1986 and is used for flood prevention (mitigation of flood waves) and as a source of drinking and industrial water. The Nysa Szalona, classified as a grade II watercourse, is a right-bank tributary of the Kaczawa River; it collects urban and agricultural sewage from the cities of Bolków and Jawor (SZULKOWSKA-WOJACZEK, MAREK 1984).

Aquatic plant samples were collected at the following sites:

Site No. 1 – inflow into the reservoir; Site No. 2 – within the backwater area; Site No. 3 – 300 m below the reservoir. The following aquatic plant species were sampled: curly pondweed – *Potamogeton crispus* L., fennel-leaved pondweed – *Potamogeton pectinatus* L., slender-leaved pondweed – *Potamogeton filiformis* Pers., coontail – *Ceratophyllum demersum* L., narrowleaf cattail – *Typha angustifolia* L., common reed – *Phragmites communis* Trin., lakeshore bulrush – *Schoenoplectus lacustris* (L) Palla.

Five specimens of each species, without thizomes and roots, were collected for analysis. The plants were rinsed in water at the sampling site and then dried in room temperature until air-dry. The entire plants were pre-ground by crushing and then homogenized by pounding in a porcelain mortar. Mineralization was performed in concentrated nitric and perchloric acids at a ratio of 1 to 3 in a Mars 5 microwave oven. Concentrations of metals were determined by atomic absorption spectroscopy on a Varian Spectr AA-110/220 unit. The following metals were studied: copper, nickel, cadmium, lead and zinc.

Water samples were also taken at the same locations in order to establish metal accumulation rates (k) for plants. Each rate was computed as a ratio quotient of the concentration of a given metal in the plant to its concentration in water.

RESULTS

Copper contents in the specimens studied were within the limits established for plants from many lakes in various parts of Poland: Wojnowskie (Czupry-Horzela et al. 2001), Piaseczno (Kowalik et al. 1990), Łękuk (Smoleński 1999), Wadąg (Grzybowski 1996), lakes in the Suwałki region (Kwaśniak, Polechoński 2001) and other water reservoirs (Kufel, Kufel 1986, Dobicki et al. 1990, Samecka-Cymerman 1995, Samecka-Cymerman, Kempers 1996, Szymanowska et al. 1999), as well as carp ponds (Marek et al. 1986, Szulkowska-Wojaczek et al. 1992).

The lowest copper concentration (2.001 mg $Cu \cdot kg^{-1}$) was discovered in common reed at site 3 below the reservoir (Table 1). At the same site copper concentration in water was also the lowest (0.0038 mg $Cu \cdot dm^{-3}$) – Table 2. More copper was found in water samples from sites 1 and 2 (0.0045 mg $Cu \cdot dm^{-3}$); at the same sites the mean copper concentration in plants was higher than that at site 3.

The highest copper concentration (25.432 mg $Cu \cdot kg^{-1}$) was recorded for curly pondweed at site 2 in the backwater area (Table 1), where water flows more slowly. At the inflow and the outflow copper concentrations in the same plant species were lower.

Table 1

Heavy metal concentrations (mg·kg^{-1} of air-dry mass) in the aquatic plants of Słup Dam Reservoir and the Nysa Szalona River

Sampling site	Plant species	Cu			Ni			Cd			Pb			Zn		
		min max	mean	*k*	min max	mean	*k*	min max	mean	*k*	min max	mean	*k*	min max	mean	*k*
No. 1	Common reed *Phragmites communis* Trin.	3.000 7.005	5.632	1251	4.000 9.122	5.711	627	0.332 0.689	0.494	1235	2.909 7.010	4.859	1034	10.821 26.112	16.900	571
	Slender-leaved pondweed *Potamogeton filiformis* Pers.	6.014 13.980	9.738	2164	5.409 8.090	6.987	767	0.123 0.781	0.546	1365	3.776 8.010	5.586	1188	19.022 35.100	28.879	976
No. 2	Coontail *Ceratophyllum demersum* L.	6.917 18.910	10.783	2396	5.121 13.007	8.735	1432	0.992 2.997	2.154	5385	2.981 7.123	4.962	1306	35.026 80.101	59.115	2300
	Common reed *Phragmites communis* Trin.	6.132 17.000	12.380	2751	4.101 12.318	7.010	1149	0.090 0.682	0.364	910	7.021 13.010	9.996	2631	15.670 37.215	24.019	935
	Slender-leaved pondweed *Potamogeton filiformis* Pers.	5.421 16.541	10.958	2435	2.831 8.671	5.768	946	0.099 0.912	0.346	865	2.166 10.343	6.445	1696	16.110 34.090	25.899	1008
	Fennel-leaved pondweed *Potamogeton pectinatus* L.	5.999 12.440	8.695	1932	4.972 11.006	7.944	1302	0.337 1.440	0.760	1900	2.011 5.002	3.781	995	26.418 50.121	37.499	1459
	Curly pondweed *Potamogeton crispus* L.	10.799 25.432	17.489	3886	3.971 8.560	5.948	975	0.655 1.563	1.129	2823	3.001 8.439	5.379	1416	36.554 65.777	55.137	2145

cont. Table 1

No. 3	Common reed *Phragmites communis* Trin.	2.001 10.001	5.492	1445	3.541 14.002	8.065	2444	0.009 1.952	0.514	1285	0.521 7.098	2.683	706	8.000 32.015	18.119	681
	Lakeshore bulrush *Schoenoplectus lacustris* (L). Palla	5.884 10.329	7.553	1988	4.541 10.721	7.113	2155	0.995 2.153	1.655	4138	2.032 4.511	3.222	848	30.779 60.091	45.900	1726
	Narrowleaf cattail *Typha angustifolia* L.	2.898 6.488	4.645	1222	3.890 9.832	6.896	2090	0.890 3.090	1.474	3685	2.531 4.327	3.164	833	34.922 69.000	57.338	2155
	Slender-leaved pondweed *Potamogeton filiformis* Pers.	5.956 15.446	10.083	2653	5.540 9.995	7.851	2379	0.095 1.079	0.493	1233	4.365 12.959	7.934	2088	16.935 27.015	21.023	2156

k – accumulation rate = concentration in plant/concentration in water

The biggest amounts of copper had been accumulated by curly pondweed – accumulation rate k=3886, and coontail (k=2396) – Table 1 on each site. There were also large quantities of copper in slender-leaved pondweed on sites 1 (k=2164) and 3 (k=2653), and in on curly pondweed site 2 (k=3886). Also coontail contained much copper in (k=2396) – Table 1. Lower accumulation rates were discovered for the surface plants such as narrowleaf cattail, lakeshore bulrush and common reed at the inflow and outflow (Table 1). Unexpectedly, for the latter plant a very high accumulation rate of k=2751 was recorded at site 2. This resulted from nearly twice as much copper accumulated at this site as at the other sites.

Our results confirm that cooper accumulation in aquatic plants is correlated with aquatic plant species and with ecological class.

Nickel concentrations in the plants studied varied widely, from 2.831 mg $Ni \cdot kg^{-1}$ in slender-leaved pondweed (site 2) to 14.002 mg $Ni \cdot kg^{-1}$ in common reed (site 3) – Table 1. Similarly, the minimum nickel concentrations in individual species were sometimes over two-fold smaller than the maximum ones. No special susceptibility to nickel accumulation, as opposed to copper, especially no differences between submerged and surface plants, was discovered.

The increasing accumulation rates from site 1 to site 3 were rather a result of the falling nickel concentration in water, probably for reasons other than accumulation in plants. This is confirmed by the mean nickel concentration in plants at individual sites (Table 1). In general, the nickel concentrations in the plants of Słup Dam Reservoir did not deviate from the values quoted by various authors for reservoirs throughout Poland (KOWALIK et al. 1990, SAMECKA-CYMERMAN 1995, SAMECKA-CYMERMAN, KEMPERS 1996, SZYMANOWSKA et al. 1999, KWAŚNIAK, POLECHOŃSKI 2001).

The cadmium concentrations determined for plants from Słup Dam Reservoir fell within the limits established for plants from many lakes in various parts of Poland (KOWALIK et al. 1990, ENDLER, GRZYBOWSKI 1996, SMOLEŃSKI 1999, SZYMANOWSKA et al. 1999) and other water reservoirs in the country (KUFEL, KUFEL 1986, MAREK et al. 1986, SAMECKA-CYMERMAN, STUDNICKA 1986, DOBICKI et al. 1990, SZULKOWSKA-WOJACZEK et al. 1992, KEMPERS 1996, SAMECKA-CYMERMAN 1999).

Cadmium concentrations in water at all the sites were identical, at 0.0004 mg $Cd \cdot dm^{-3}$, although there were noticeable differences in the amounts of cadmium accumulated in plants at individual sites (Tables 1 and 2). The lowest concentrations, just like the accumulation rates, were determined for common reed. The highest mean concentrations were recorded for coontail (2.154 mg $Cd \cdot kg^{-1}$), lakeshore bulrush (1.655 mg $Cd \cdot kg^{-1}$), narrowleaf cattail (1.474 mg $Cd \cdot kg^{-1}$) and curly pondweed (1.129 mg $Cd \cdot kg^{-1}$) – Table 1. The calculated accumulation rates indicate a significant affinity between the examined plants and cadmium. No perceptible differences between the amounts of cadmium accumulated by plant specimens of the same species at various sites were discovered (common reed, slender-leaved pondweed).

Table 2

Heavy metal concentrations ($mg \cdot dm^{-3}$) in water from the littoral zone in Słup Dam Reservoir and the Nysa Szalona River (mean values)

Sampling site	Cu	Ni	Cd	Pb	Zn
No. 1	0.0045	0.0091	0.0004	0.0047	0.0296
No. 2	0.0045	0.0061	0.0004	0.0038	0.0257
No. 3	0.0038	0.0033	0.0004	0.0038	0.0266

The water in Słup Dam Reservoir had very small concentrations of lead, which ranged from 0.0038 mg $Pb \cdot dm^{-3}$ at sites 2 and 3 to 0.0047 mg $Pb \cdot dm^{-3}$ at site 1 (Table 2). The examined plants had accumulated the metal in amounts comparable to those quoted by various authors for lakes (KOWALIK et al. 1990, SMOLEŃSKI 1999, KWAŚNIAK, POLECHOŃSKI 2001), carp ponds (SZULKOWSKA-WOJACZEK et al. 1992), and other reservoirs throughout Poland (KUFEL, KULEL 1986, STUDNICKA 1986, OZIMEK 1988, DOBICKI et al. 1990, SAMECKA-CYMERMAN 1995, SAMECKA-CYMERMAN, KEMPERS 1996, SZYMANOWSKA et al. 1999). Lead concentrations in the studied aquatic plants varied between 0.521 mg $Pb \cdot kg^{-1}$ in common reed at site 3 to 13.010 mg $Pb \cdot kg^{-1}$ also in common reed, but at site 2 (Table 1). The wide range between the minimum and maximum concentrations and the mean values makes it difficult to form any conclusions about the relationship between the species and lead accumulation. The mean lead concentration in common reed collected from site 2 amounted to 9.996 mg $Pb \cdot kg^{-1}$, with the accumulation rate k=2631, and in common reed from site 3 – 2.68 mg $Pb \cdot kg^{-1}$ on average, with the accumulation rate k=706. With such a minimum difference in the lead concentrations between the above sites, one can cautiously presume that the reason for the discrepancy lies in the way in which lead is absorbed by reed, i.e. not directly from water, but mainly through the roots.

Zinc concentrations, similarly to those of the other examined metals, established for the aquatic plants from Słup Dam Reservoir did not deviate from the values given by numerous authors for aquatic plants in surface waters throughout Poland (MAREK et al. 1986, OZIMEK 1988, DOBICKI et al. 1990, KOWALIK et al. 1990, SZULKOWSKA-WOJACZEK et al. 1992, SAMECKA-CYMERMAN 1995, SAMECKA-CYMERMAN, KEMPERS 1996, SMOLEŃSKI 1999, SZYMANOWSKA et al. 1999, CZUPRY-HORZELA et al. 2001, KWAŚNIAK, POLECHOŃSKI 2001). Water contained very low concentrations of the metal, which were practically identical at all the sites. Although the concentration was slightly higher at the inflow, this was true for all of the examined metals (Table 2).

Zinc concentration in the plants ranged from 8.000 mg $Zn \cdot kg^{-1}$ in common reed at site 3 to 80.101 mg $Zn \cdot kg^{-1}$ in coontail. Common reed proved to have the weakest zinc accumulation potential. Its accumulation rates at all the three sites were the lowest among all the studied plants. Coontail turned out to be the most efficient zinc accumulator; the same was true for nickel and cadmium.

CONCLUSIONS

The research results enable us to draw only some specific conclusions, as only two plant species (common reed and slender-leaved pondweed) were present at all of the sites. Common reed was found to contain minimum concentrations of all of the examined metals as well as the lowest mean concentrations of nickel, lead and zinc. It was only in the backwater area that common red had accumulated the biggest amount of lead in absolute terms. It also had the highest mean lead concentration at site 2. Simultaneously, its accumulation rate reached a very high value.

Cootail was found to be the plant with the best accumulation capability. Although it grew at one site only, in the backwater area, it proved to be the best indicator organism for nickel, cadmium and zinc, as it not only accumulated the biggest amounts of these metals but also did it in the most efficient manner. This conclusion is supported by the calculated accumulation rates. Curly pondweed may be also regarded as a good indicator organism for copper.

Comparison of the accumulation capabilities of the plants examined indicates that the mean metal accumulation levels were higher in submerged plants. This may have been due to the fact that most of them grew in the backwater area, where a slower water flow was conducive to accumulation.

It is difficult to provide unambiguous answers to the questions behind the research. For instance, common reed, which occurred at all of the sites and seems to have shown an affinity with lead, had accumulated the highest amount of lead at site 2, while at site 1, with the highest lead concentration in water, did not behave in the same way. At site 3 lead concentrations in common reed were the lowest, while its concentration in water corresponded to that at site 2 (Tables 1, 2). Similarly, slender-leaved pondweed did not display any relationship between metal concentrations in plants and their position in the reservoir.

There are grounds, however, for claiming that metal concentrations depend on the plant species. Coontail proved to be the best accumulator of nickel, cadmium and zinc, curly pondweed – copper, and common reed – lead. This is attested both by the values of the calculated accumulation rates and the plants' response (the minimum and maximum concentrations) to individual metals. The presence of plants in the backwater area of the dam reservoir definitely improves water quality, not only thanks to their metal accumulation properties, but also to their ability to act as a filter of substances carried in the water.

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UTILIZATION OF SELENIUM COMPOUNDS IN NUTRITION OF LAMBS

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Abstract

The level of mineral utilization depends on many factors related to animals as well as to the chemical form of given nutrients. It has been experimentally demonstrated that animals utilize inorganic forms of minerals less efficiently than organic ones. Hence, an attempt has been made to evaluate the bioavailability of selenium bound in different compounds to lambs. Selenium supplementation in fodder mixtures was another aspect included in our tests. Thus, an experiment was conducted on 48 growing lambs, testing the level and chemical forms of selenium in fodder mixtures for animals. In group I (the control) lambs received fodder mixture without any selenium supplement. In the experimental groups, selenium was supplemented as sodium selenite in the amount 0.2 mg Se kg^{-1} d.m. feeds (II), or selenium enriched yeast (Se-yeast) in the amounts of 0.1 and 0.2 mg Se kg^{-1} d.m. of feed groups III and IV, respectively. At the end of the experiment, when animals had reached 35 kilos of weight, blood samples were taken. The activity of glutathione peroxidase was estimated in heparinized blood samples. Eight lambs were chosen from each group and killed to collect samples of soft tissues (liver, kidney, brain, muscle). The content of selenium was determined in the tissue samples. Supplementation of feeds for lambs with selenium, both inorganic (sodium selenite) and organic (Se-yeast), increased the content of the element in soft tissues of animals. The highest level of the element was found in the liver and kidneys: 4.65 and 4.90 and 2.10 and 2.30 mg kg^{-1} fresh tissue, of the lambs receiving sodium selenine and Se-yeast in the amount 0.2 mg Se kg^{-1} D.M. of feed (groups II and IV), respectively. Selenium compounds added to feeds given to lambs significantly (PŁ0.01) increased activity of GSH-Px in blood, especially in the case of animals which received yeast enriched with selenium. In blood of the lambs which received feeds with Se-yeast in the amount 0.2 mg Se kg^{-1} d.m. of feed (group IV), the activity of glutathione peroxidase was by 129.71 U gHb^{-1} higher, and of the animals which received Se-yeast in the amount 0.1 mg kg^{-1} d.m. or sodium selenite, the activity of the enzyme was higher by 86.33 and 86.35 U gHb^{-1}, respectively, than the activity of this enzyme in blood of animals from the control group. Supplementation of lambs' rations with Se in

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the form of selenite or yeast enriched with selenium forms increased the content of Se in soft tissues and gluthatione peroxidase activity in comparison with animals which did not receive additional doses of this nutrient in fodder mixtures. The availability of Se was more profoundly affected by the amount of the element added rather than its form.

Key words: bioavailability, selenium, tissue accumulation, glutathione peroxidase.

WYKORZYSTANIE ZWIĄZKÓW SELENU W ŻYWIENIU JAGNIĄT

Abstrakt

Stopień wykorzystania składników mineralnych z paszy zależy od wielu czynników związanych zarówno ze zwierzęciem, jak i z formą chemiczną stosowanych związków. W badaniach wskazano, że związki nieorganiczne są najczęściej gorzej wykorzystywane niż ich organiczne odpowiedniki. Dlatego podjęto próbę oceny przyswajalności przez jagnięta różnych związków selenu, uwzględniając także poziom dodatku tego pierwiastka w mieszankach. W badaniach na 48 rosnących jagniętach czynnikiem różnicującym poszczególne grupy były różne poziomy i formy połączeń chemicznych selenu w mieszankach treściwych. W grupie I (kontrolnej) jagnięta otrzymywały mieszankę bez dodatku selenu. W grupach (II) doświadczalnych mieszanki uzupełniano seleninem sodu w ilości 0.2 mg Se kg^{-1} s.m. paszy, a w grupach III i IV – drożdżami wzbogaconymi w selen (drożdże-Se), odpowiednio w ilości: 0.1 i 0.2 mg Se kg^{-1} s.m. paszy. Na końcu doświadczenia, po osiągnięciu przez zwierzęta masy ciała ok. 35 kg, pobrano od nich krew. Następnie w pełnej heparynizowanej krwi oznaczono aktywność peroksydazy glutationowej (GSH-Px). Z każdej grupy wybrano losowo po 8 jagniąt, zwierzęta ubito i pobrano tkanki miękkie (wątroba, nerki, mózg, mięsień przywodziciel uda). W zliofilizowanym materiale biologicznym oznaczono zawartość selenu. Podane jagniętom w mieszankach treściwych zarówno nieorganiczne (selenin sodu), jak i organiczne (drożdże-Se) formy połączeń selenu zwiększyły zawartość tego pierwiastka w tkankach miękkich jagniąt. Najwięcej selenu znajdowało się w wątrobie i nerkach, odpowiednio 4.65 i 4.90 oraz 2.10 i 2.30 mg kg^{-1} świeżej tkanki jagniąt otrzymujących w paszy selenin sodu i drożdże–Se w ilości 0.2 mg Se kg^{-1} s.m. paszy (gr. II i IV). Stosowane w paszy jagniąt związki selenu wyraźnie ($P \leq 0.01$) zwiększyły aktywności GSH-Px we krwi owiec, zwłaszcza u zwierząt, które w mieszance otrzymywały drożdże wzbogacone w selen. U owiec otrzymujących w paszy drożdże-Se w ilości 0.2 mg Se kg^{-1} s.m. paszy (grupa IV) wykazano wyższą o 129.71 U gHb^{-1} aktywność peroksydazy glutationowej, a u zwierząt, którym w paszy podawano drożdże-Se w ilości 0.1 mg Se kg^{-1} s.m. paszy lub selenin sodu, aktywność tego enzymu we krwi była wyższa odpowiednio o 86.33 i 86.35 U gHb^{-1} w porównaniu z grupą kontrolną. Zastosowanie w dawkach dla jagniąt dodatku Se, zarówno w formie seleninu, jak i wzbogacanych drożdży, spowodowało wzrost jego zawartości w tkankach miękkich oraz wzrost aktywności peroksydazy glutationowej w porównaniu ze zwierzętami z grupy kontrolnej. Większy wpływ na dostępność Se miał jego poziom w dawce niż stosowana forma.

Słowa kluczowe: biodostępność, selen, kumulacja w tkankach, peroksydaza glutationowa.

INTRODUCTION

Proper growth and functions of plants and animals require basic nutrients as well as mineral components, including trace elements. Bioavailability of minerals depends on species of animals, their physiological condition, age and body mass, as well as the type and amount of feed given to animals; what matters too is the chemical form of minerals in animal feeds (Kirchgessner et al. 1993, Underwood, Suttle 1999). Inorganic forms of minerals are poorly absorbed by animals. Minerals are passively absorbed in the small intestine by diffusion of ions, which are only partly utilized by animals while their unused excess is excreted to the environment (Kinal et al. 1994, Rojas et al. 1995, Johanson, Velasqez 1995). In contrast, the active transport of organically bounded trace elements, by the pathway of transporting complexing groups such as amino acids, polypeptides, polysaccharides and organic acid residues, results in better absorption of organically bounded trace elements than inorganic ones. The amount of minerals that are absorbed, assimilated and used for physiological functions of an organism and stored is referred to as "the bioavailability" (Ammerman et al. 1998). As a measure of bioavailability of minerals, their absorption in animal organisms is taken. However, this process is reflected better by the accumulation of minerals in target tissues, or the activity of enzymes whose action is related to the supply of minerals (Ammerman 1995, Miles, Henry 2000).

Selenium strongly affects the growth, reproduction as well as specific and non-specific immunity of both animals and humans (Arthur et al 2003). The physiological importance of selenium for living organisms relies on its strong antioxidative activity. Selenium protects animals and people from oxidative stress, which conduces tumours and heart diseases (Grela, Sembratowicz 1997). The preventive role of selenium in the origin and growth of some tumours in humans has been emphasized for many years now (Micke et al. 2005).

The aim of the present study has been to determine bioavailability of different chemical forms of selenium. To achieve this target, it was crucial to consider levels of selenium in rations given to growing lambs. The study was made on the basis of selenium accumulation in selected tissues as well as the activity of blood gluthatione peroxidase (GSH-Px).

MATERIAL AND METHOD

The experimental material consisted of 48 lambs, a crossbreed of Polish Merino x Romanowski x Charolaise, aged *ca* 10 weeks and of average body weight of 20 kilos, which were randomly divided into 4 experimental groups (12 animals per group). The animals were kept collectively (group-pen) on deep straw, given an unlimited access to water and fed concentrated feed in the amount of 1.0-1.2 $kg^{-1}day^{-1}$ $head^{-1}$ and some hay rationed according to the body mass and feed uptake. The content of basic nutrients as well as minerals in the feeds covered the animals' requirement according to the NRC system (2001). Feeding groups were diversified with respect to the level and chemical form of selenium in the fodder mixture given to the lambs. In group I, the control, animals received mixtures without selenium supplement. In experimental group II selenium was given to animals as sodium selenite in the amount 0.2 mg Se kg^{-1} of d.m., and in groups II and III selenium was given as sodium enriched yeast in the amounts 0.1 and 0.2 mg Se kg^{-1} of d.m., respectively. At the end of the experiment, blood samples were taken from all the animals whose average body was about 35 kg. In addition, 8 lambs from each group were chosen and killed. Glutathione peroxidase activity was determined in heparinized blood samples using a Randox kit. Soft tissue samples were taken from the killed animals, such as: liver, kidney, brain and adductor femoris muscle. The tissues were lyophilized and the content of selenium was determined (AOAC, 2005). Both, the content of selenium in tissues and glutathione peroxidase activity in blood were used as indicators of the bioavailability of selenium to lambs. All the data were analyzed statistically applying two-factor variance analysis and Duncan's multiple range test with an aid of STATISTICA 7/Stat Lic.

RESULTS AND DISCUSSION

The data pertaining to the selenium concentration in selected tissues are presented in Table 1. Inorganic (sodium selenite) and organic (Se-yeast) forms of selenium added to feed mixtures for lambs had a positive influence on the concentration of this element in tissues. The highest level of selenium occurred in the liver and kidneys ($P \leq 0.01$), where it reached 4.65 and 4.90 and 2.10 and 2.30 mg of Se kg^{-1} fresh tissue, respectively for the animals which received sodium selenite and Se-yeast in the amount 0.2 mg Se kg^{-1} of d.m. (groups II and IV). In tissues of these lambs, the level of selenium was higher than in tissues of animals from the remaining groups (Table 1). Besides, in groups Ii and IV the element was also found in the brain and adductor femoris muscle. The lowest amount of selenium was determined in soft tissues of the animals which received Se-yeast in the amount 0.1 mg Se kg^{-1} of d.m. in the feed mixture. It was lower than in tissues of animals which received sodium selenite and Se-yeast in the amount 0.2 mg kg^{-1} of d.m. (groups II and IV). Yeh et al. (1997) also reported the highest level of selenium in all examined tissues of animals fed a diet with sodium selenite (0.3 mg Se kg^{-1} of feed), higher than in tissues of lambs from the negative group, without selenium supplementation. The high-

Table 1

The content of selenium in some soft tissues of lambs (in mg kg^{-1} fresh matter)

Item		Feeding groups			
		I control	II sodium selenite (0.2 mg kg^{-1}d.m.)	III Se-yeast (0.1 mg kg^{-1} d.m.)	IV Se-yeast (0.2 mg kg^{-1} d.m.)
Liver	$\overline{x}$	3.62	4.65	3.90	4.90
Kidney	$\overline{x}$	1.59^{A}	2.10^{AB}	1.86^{AB}	2.30^{B}
Adductor femoris muscle	$\overline{x}$	0.044^{A}	0.13B	0.048^{A}	0.14^{B}
Brain	$\overline{x}$	0.033	0.045	0.040	0.046

A, B – high significant differences ($P \leq 0.01$)

est level of selenium was in the liver, kidneys, brain and muscles in the order: 5.02; 3.29; 0.43 and 0.26 mg kg^{-1} d.m. of tissue. After conversion to fresh matter, these results correspond to our data (Table 1). Increased levels of selenium in selected tissues after selenium supplementation were reported also by RICHARDS and LOVEDAY (2003), who added selenium in the amount 0.3 mg Se kg^{-1} d.m. as Selplex to rations given to calves.

The data concerning the activity of glutathione peroxidase (GSH-Px) in blood are presented in Table 2. Selenium compounds added to feed mixtures for lambs significantly ($P \leq 0.01$) increased bloods GSH-Px activity, especially in blood samples form animals which received yeast enriched with selenium. Lambs which received Se-yeast in the amount 0.2 mg Se kg^{-1} d.m. of feed (group IV) had 129.71 U gHb^{-1} higher GSH-Px activity than the control animals. An analogous increase, versus the control, reached 86.33 U gHb^{-1} for animals which received Se-yeast in the amount 0.1 mg Se kg^{-1} d.m. in feed and 86.35 U gHb^{-1} in the case of lambs which were given sodium selenite as a fodder supplement (Table 2). BALDI•AROWA et al. (2005), who gave lambs fodder enriched with selenium yeast in the amount 0.3 mg Se kg^{-1} d.m., also observed increased GSH-Px blood activity. On the other hand,

Table 2

Lambs blood glutathione peroidase (GSH-Px) activity (U gHb^{-1})

Item	Feeding groups			
	I control	II sodium selenite (0.2 mg kg^{-1}d.m.)	III Se-yeast (0.1 mg kg^{-1} d.m.)	IV Se-yeast (0.2 mg kg^{-1} d.m.)
Activity of GSH-Px (U gHb^{-1})	521.57^{A}	604.58^{B}	614.5^{B}	641.43^{B}

A, B – high significant differences ($P \leq 0.01$)

there was no increase in GSH-Px in the blood of animals which received sodium selenite in feed mixture. However, Johansson et al. (1990), who supplemented lambs' feed with selenium enriched yeast and sodium selenite in the amount of 0.1 mg Se day^{-1} head^{-1}, did not find any significant increase in the GSH-Px activity in the animals' blood. Likewise, Podoll et al. (1992), who supplemented diets of lambs with inorganic selenium forms, sodium selenite and selenate (0.3 mg Se kg^{-1} of mixture), did not notice any increase in the GSH-Px blood activity.

CONCLUSION

1. Inorganic and organic selenium forms used as feed supplements are an effective way of increasing the concentration of this element in soft tissues and enhance glutathione peroxidase activity.

2. The level of selenium supplement rather than its form was more important for utilization of this nutrient by lambs.

3. Selenium supplements added to lambs' rations, which increase concentration of Se in meat, could be useful in production of nutraceutics.

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CONCENTRATION OF SELECTED MICRONUTRIENTS IN SANDY SOIL IN RELATION TO LONG-TERM DIRECT DRILLING METHOD

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Abstract

Compared to conventional tillage method, physical and chemical properties of soil treated with long-term zero-tillage method (direct drilling without ploughing) are different, especially soil porosity, moisture conditions, concentration of organic carbon and macronutrients. The aim of a three-year field study was to compare the content of micronutrients in soil under traditional and zero-tillage. The difference in micronutrient concentration in soil treated with different soil tillage method can affect quantity and quality of yields. The study was conducted using seven fields with 4-5 or 11 years period under diverse tillage method. Soil samples were colleted from three random points in every field on the beginning of June. Samples were obtained from two layers: 0-10 and 10-20 cm in depth using an Eijkelkamp soil sampler (diameter 2.5 cm). Micronutrients (Cu, Mn, Zn) in soil samples were determined by the AAS method after extraction with HCl at 1 mol dm^{-3}. The results were compared using t-Student test. The tillage methods were found to have produced differences only in Cu concentrations in soil. However, it was impossible to point clearly which method resulted in a higher Cu concentration as the actual differences depended also on the year of study and the soil layer. The zero-tillage method compared to the conventional method did not produce differences in Mn and Zn concentrations. The general level of the three microelements and the differences in their levels in relation to a tillage method were similar in both soil layers.

Keywords: soil tillage methods, zero-tillage, micronutrients, Cu, Zn, Mn.

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ZAWARTOŚĆ WYBRANYCH MIKROELEMENTÓW W GLEBIE LEKKIEJ W WARUNKACH WIELOLETNIEGO STOSOWANIA SIEWU BEZPOŚREDNIEGO

Abstrakt

Gleba pozostająca przez wiele lat w systemie uprawy zerowej (siew bezpośredni w niezaoraną glebę) charakteryzuje się, w stosunku do uprawianej tradycyjnie, zmienionymi właściwościami fizycznymi i chemicznymi, zwłaszcza warunkami powietrzno-wodnymi oraz zawartością węgla organicznego i makroelementów. Celem trzyletnich badań polowych było porównanie zawartości niektórych mikroelementów w glebie lekkiej uprawianej metodą tradycyjną oraz utrzymywanej w systemie siewu bezpośredniego. Różnice w zawartości mikroelementów w glebie w różnych systemach uprawy mogą wpływać na kształtowanie wielkości i jakości plonów. Wykorzystano ogółem 7 pól o 4-5-letnim lub 11-letnim okresie zróżnicowanej uprawy roli. Na początku czerwca pobierano próbki z trzech losowo wybranych punktów na każdym polu. Pobierano je z dwóch warstw, 0-10 i 10-20 cm, próbnikiem glebowym (firmy Eijkelkamp) o średnicy 2,5 cm. Oznaczano w nich zawartość Cu, Mn i Zn (ekstrakcja 1 mol $HCl \cdot dcm^{-3}$) metodą ASA. Wyniki opracowano statystycznie. Stwierdzono istotne różnice wyłącznie w zawartości Cu. Nie można jednak wskazać jednoznacznie, która z metod uprawowych determinowała większą jej zawartość w glebie. Różnice te były uzależnione od roku uprawy oraz głębokości warstwy gleby. Nie wykazano również wpływu uprawy zerowej na zmiany w zawartości Mn i Zn w porównaniu z uprawą tradycyjną. Ogólny poziom zawartości wszystkich badanych mikroelementów, a także różnice wynikające z metody uprawy roli były podobne w obu warstwach glebowych.

Słowa kluczowe: metody uprawy roli, metoda zerowa, mikroelementy, Cu, Zn, Mn.

INTRODUCTION

Soil maintained under a no-till farming system (direct sowing to unploughed soil) for many years is different from conventionally tilled soil in physical parameters, including density as well as water and air conditions (ARSHAD et al. 1999, PABIN et al. 2002, MCGARRY et al. 2000) Reduced or zero soil tillage continued for several years also impacts chemical properties of soil (TARKALSON et al. 2006). Changes in the chemism of soil concern mainly organic carbon accumulation (SIX ET AL. 1999) and content of micronutrients as well as their distribution in the soil horizon. No-till farming means that fertilizers cannot be mixed with soil down to a proper depth, which may result in higher concentration of nutrients in the top soil horizon (MATOWO et al. 1999). Differences in the distribution of macronutrients in soil, depending on the type of tillage, can result in a different nutritional status of crops during their vegetative growth and different yield volumes (YIN, VYN 2002, KORZENIOWSKA, STANISŁAWSKA-GLUBIAK 2006).

The purpose of this study has been to compare the abundance of soil in some micronutrients in the top horizon of sandy soil under long-term no-till farming versus conventionally ploughed soil. Different concentrations of micronutrients in soil caused by different tillage techniques, likewise those of macronutrients, may affect the volume and quality of yields.

MATERIALS AND METODS

The study, completed in 2005-2007, was carried out on fields maintained under different tillage systems at the IUNG-PIB Experimental Station in Jelcz-Laskowice near Wrocław. In 2005 and 2006 the fields selected for the tests were the ones on which different tillage methods had been applied for 4-5 years. In 2007, fields cultivated for 11 years were examined. No-till and conventional, ploughing farming were compared. In general, the soils from the experimental fields belonged to heavy loamy sand, acidic or very acidic in reaction and low in organic carbon. The soils differed in their content of phosphorus, potassium, magnesium and micronutrients (Table 1).

Table 1

Characteristics of soil from tested fields (0-20 cm)

Year	Field	Type of soil	pH (1 mol $KCl \cdot dcm^{-3}$)	C org. ($g \cdot kg^{-1}$)	*P*	K	Mg	Cu	Mn	Zn
					($mg \cdot kg^{-1}$)					
2005	1	pgm	4.3	7.0	34.7	138	29.0	2.8	163	6.0
	2	pgm	4.5	6.4	43.6	121	38.3	3.5	158	7.5
2006	1	pgmp	5.1	7,6	71.9	168	28.5	3.0	200	10.5
	2	pgmp	5.2	6.6	58.0	168	46.7	3.0	187	8.7
	3	pgm	5.2	7.3	66.2	152	29.0	2.9	175	8.5
2007	1	pgm	5.3	7.4	91.8	158	62.0	5.0	203	7.5
	2	pgm	5.3	7.6	67.9	143	62.0	6.7	120	7.3

In order to determine the concentration of selected micronutrients in soil in correlation with the type of soil tillage, soil samples were taken in early June at three random locations on each field. The soil samples were collected from two soil horizons, 0-10 and 10-20 cm, using an Eijkelkamp soil sampler of the diameter size equal 2.5 cm. Two drillings made up a single soil sample. Having been first extracted in 1 mol $HCl \cdot dm^{-3}$, the soil samples were then analysed with the AAS method to determine the content of Cu, Mn and Zn. having The results of the tests from each field were used to calculate an arithmetic mean for a given year. The statistical calculations carried out to compare means between the tillage methods relied on t-Student test and accounted for variance uniformity (Statgraphics software package).

The weather conditions from March to May, i.e. from the onset of the growth season to the soil sampling, were quite similar in each year (Table 2). Although the rainfall distribution was highly varied, the total rain-

Table 2

Temperature and precipitation for the 3-month period before sample collecting

Year	Average temperature (°C)				Sum of precipitation (mm)			
	III	IV	V	III-V	III	IV	V	III-V
2005	1.3	9.3	14.2	8.2	12.3	20.3	86.2	118.8
2006	0.0	9.4	14.1	7.8	28.9	50.2	29.9	109.0
2007	5.7	10.2	15.7	10.5	52.4	4.2	54.4	111.0

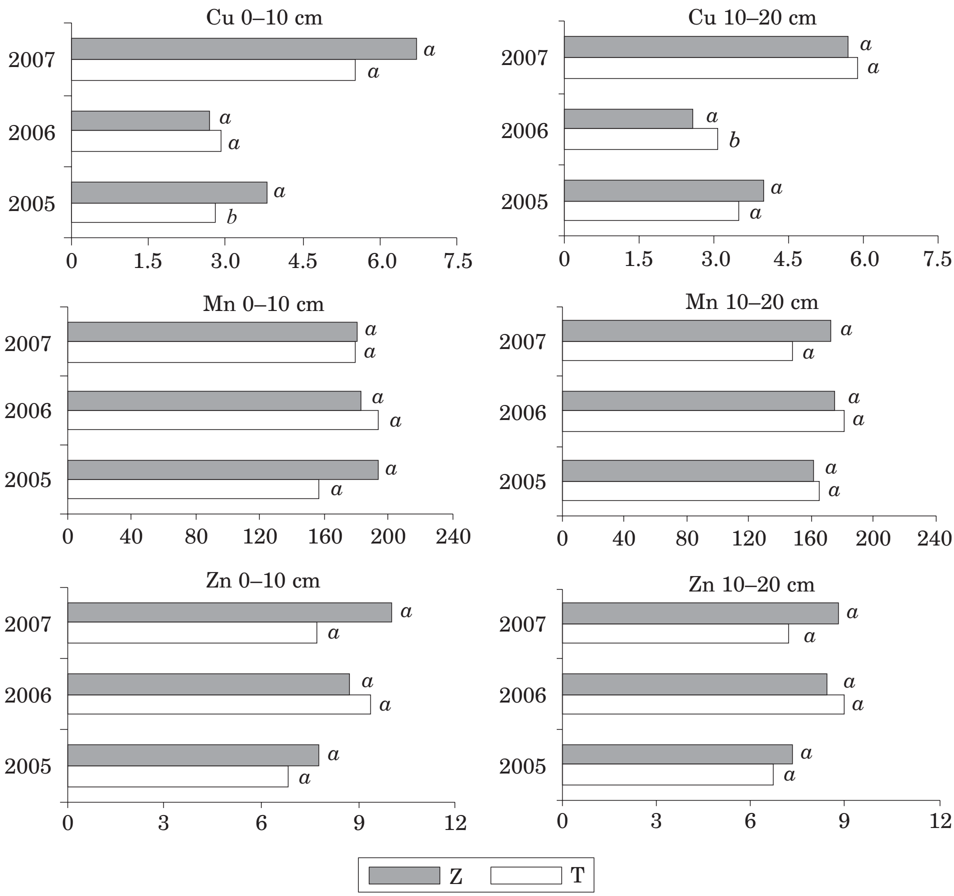

Fig. 1 Concentration of micronutrients in soil (mg·kg^{-1}) under traditional (T) and no-tillage method (Z). Different letters for the same year indicate significant differences at $p < 0.05$ acc. to Student's test

fall for the three-month period analysed was no more than 8% different. The three-month average air temperatures in 2005 and 2006 were similar, reaching about 8°C. The last year, 2007, was slightly warmer.

RESULTS AND DISCUSSION

Our comparison of the content of micronutrients depending on the method of tillage showed significant differences only in the concentration of copper (Figure 1). However, it is impossible to state without any doubt which tillage method resulted in a higher level of copper as the differences depended on the year and depth of the soil horizon. In 2005 the no-till soil was more abundant in copper, but only in the 0-10 cm layer. In 2006, more copper was found at the depth of 10-20 cm of the conventionally tilled soil. Finally, in 2007, concentrations of copper were not significantly different relative to the tillage method.

The levels of zinc and manganese were not significantly diverse relative to the tillage method in either of the years. Analogously to the copper levels discussed above, we could only observe a tendency towards higher concentrations of these elements in the no-till soil in the year 2005 and a reverse trend in the following year. It needs to be added that such a tendency for zinc was observable in both soil horizons, whereas for manganese – only in the 0-10 cm layer.

There is a scarcity of studies on the effect of tillage on micronutrients in soil, and the few reports that are available contain contradictory results. It is so because changes in the chemical properties of soil which occur when ploughing is completely discontinued depend also on how long a given soil has been ploughed before, on the type of soil as well as on the climatic conditions. It can be expected that in our study the duration of no-till farming (4 to 5 years and 11 years at the most) was too short to attain stable differences in the concentration of the analysed micronutrients compared to conventional tillage. Tarkalson et al. (2006) did not discover any differences in the chemical properties of soil after 14 years of no-till faming versus conventionally tilled fields, but found out that such changes occurred after 27 years of continuous zero-tillage. In another experiment, which involved fields after 21 years of different tillage farming, it was revealed that more Cu, Mn and Zn appeared in a 0-5 cm horizon of soil under no-till faming (De Santiago et al. 2008). Lavado et al. (1999) reported that after 18 years of zero-tillage, the topmost layer of soil (0-5 cm) contained more $Zn_{(DPTA)}$ than an analogous soil layer under traditional tillage. However, in the deeper soil horizon, conventionally tilled soil was more abundant in this macronutrient. Differences in the content of $Cu_{(DPTA)}$ and $Mn_{(DPTA)}$ appeared only in the 0-5 cm soil profile, with the conventionally tilled soil being more abundant.

Carter (2005) found out that after 18 years of no-till farming the surface layer of soil (0-10 cm) contained more Mn than conventionally ploughed soil. Franzluebbers, Hons (1996), who carried out an 8-year study on loamy soil, demonstrated that the most extensive changes caused by no-till occurred in the 0-5 cm soil layer, where Zn and Mn were more abundant, whereas the content of Cu was depressed (DTPA+EDTA extraction) compared to conventionally tilled soil. At the same time, they found that the 0-30 cm soil horizon was richer in all the three elements. According to Wright et al. (2007), after just 5 years of zero-tillage on loamy soil, the content of Zn in the topmost layer of 0-15 cm was elevated in comparison to conventional tillage. Moreover, independently from the tillage method, the content of Zn tended to decline at deeper soil layers more profoundly than that of Mn or Cu. Another report (Martin-Rueda et al. 2007) concludes that a four-year zero-tillage farming has led to elevated concentrations of Mn, Zn and Cu in soil (0-15 cm) versus ploughed soil. However, it is impossible to draw any reliable conclusions on the effect of soil tillage on the content of micronutrients in soil as the few available reports dealing with this issue are based on experiments which are frequently incomparable. It seems, nevertheless, that changes in the concentration of micronutrients caused by extensive simplification of tillage appear more promptly in heavier soils and are observable not only in the topmost soil horizons but also in deeper layers, down to 30 cm depth.

CONCLUSIONS

1. No-till faming of sandy soil carried out for no more than 11 years, under the conditions encountered in our tests, did not change in any significant manner the concentration of zinc and manganese down to 20 cm depth of a soil profile as compared to conventionally ploughed soil.

2. The general abundance of the analysed micronutrients, as well as some small differences resulting from the two different tillage methods, were similar in both soil layers: 0-10 and 10-20 cm.

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INFLUENCE OF POTASSIUM DEFICIENCY IN A MEDIUM ON THE PHYSIOLOGICAL REACTION OF SEEDLINGS OF NEW RYE LINES

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Abstract

A hydroponic experiment has been conducted to determine the physiological and biochemical response of four new rye lines – S120, S76, OT1-3 and 541 – bred at the Department of Plant Genetics and Breeding, Agricultural University in Szczecin. Seeds were sown into soil and placed into a phytotrone chamber with controlled atmosphere and photoperiod. The relative humidity was 80%, the temperature maintained at 20°C and the intensity of photosynthetically active radiation (Phar) was 700 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Seed germination occurred after about 5 days. The seeds were characterised by different germination ability: 80% for S120, 100% for S76, 82% in OT1, and just 50% for 541 line. Rye seedlings, at the 2-3 leaf stage, were placed in hydroponic units and a two-factor experiment was set up, with potassium deficiency being the first factor and rye lines the second one. The control variant consisted of seedlings placed on complete Hoagland's medium, while potassium starvation was performed on a medium with 50% deficiency of this element. After seven days, fresh matter was weighed, proline content was measured according to the Bates method (1973) and amounts assimilation pigments were measured according to the method of Arnon et al. (1956). The results were processed statistically, performing a two-factor analysis of variance, while the significance of factors was tested using Tukey's test at $\alpha = 0.05$.

The study aimed at examining selected physiological and biochemical indicators of the resistance response of four rye lines to stress induced by potassium deficiency.

Application of 50% potassium deficiency in a medium induced an increase in the content of assimilation pigments in leaf fresh matter of S120 rye line. A correlation was found between proline content and that of assimilation pigments. The largest proline quantity, 27.2 $\mu g \cdot g^{-1}$ f.m., was found in 541 rye line seedlings, but its content decreased together with fresh matter yield. It was also found that the total chlorophyll content was directly

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proportional to the content of proline in S120, S76 and OT1-3 rye lines, whereas in the case of other pigments such a relationship existed only for S 120 and S76 rye lines.

Key words: rye lines, assimilation pigments, proline, fresh matter

WPŁYW NIEDOBORU POTASU NA REAKCJĘ FIZJOLOGICZNĄ SIEWEK NOWYCH LINII ŻYTA

Abstrakt

Celem doświadczenia było zbadanie reakcji fizjologicznej i biochemicznej 4 nowych linii żyta: S120, S76, OT1-3, 541, wyhodowanych w Katedrze Genetyki i Hodowli Roślin Akademii Rolniczej w Szczecinie. Nasiona wysiano do gleby i umieszczono w fitotronie z kontrolowaną atmosferą i fotoperiodem. Wilgotność względna wynosiła 80%, temperatura 20°C, a natężenie promieniowania fotosyntetycznie czynnego Phar – 700 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Kiełkowanie nasion nastąpiło po ok. 5 dniach. Nasiona charakteryzowały się różną zdolnością kiełkowania: S120 – 80%, S76 – 100% OT1 – 82%, 541 – 50%. W hydroponikach umieszczono siewki żyta w fazie 2-3 liści i założono doświadczenie dwuczynnikowe. Pierwszym czynnikiem był niedobór potasu, drugim – linie żyta. Obiektami kontrolnymi były siewki umieszczone w pożywce pełnej Hoaglanda oraz głodzone potasem (pożywka z 50% niedoborem tego pierwiastka). Po 7 dniach oznaczono świeżą masę (wagowo), zawartość proliny metodą Batesa (1973), zawartość barwników asymilacyjnych metodą Arnona i in. (1956). Wyniki opracowano statystycznie wykonując dwuczynnikową analizę wariancji, a istotność czynników testowano testem Tukeya na poziomie $\alpha = 0,05$.

Wykazano, że niedobór potasu w pożywce spowodował wzrost zawartości barwników asymilacyjnych w świeżej masie liści żyta linii S120. Stwierdzono zależność między zawartością proliny a zawartością barwników asymilacyjnych. Największą ilość proliny (27,2 $\mu g \cdot g^{-1}$ ś.m.) stwierdzono w siewkach linii 541, jednak jej zawartość malała wraz z plonem świeżej masy. Zawartość chlorofilu całkowitego była wprost proporcjonalna do zawartości proliny (S120, S76, OT1-3), natomiast pozostałych barwników tylko w przypadku linii S 120 i S76.

Słowa kluczowe: linie żyta, barwniki asymilacyjne, prolina, świeża masa, sucha masa.

INTRODUCTION

Soils contain large resources of potassium, up to 50 $t \cdot ha^{-1}$ in a horizon to 20 cm deepth, but potassium available to plants makes up only 1% of its total content. Particular cereal species show different ability to take up this chemical element from soil, with the highest activity observed in oats (100%); this activity in rye is 85% (Czuba 1998). Jarociński (2005) claims that cereals are vulnerable to potassium deficiency; even a moderate deficit of potassium in plant, visually hidden, manifests itself in increased transpiration, loss of turgor, accelerated wilting, decreased assimilation of CO_2 and retarded growth rate and in susceptibility to bacterial and fungal diseases. Deficit of chemical elements, including potassium, in a plant is a stress factor, which, according to some authors (Bandurska 1991, Claussen 2002), initiates the synthesis of proline, an amino acid which is increasingly more often used for determining the stress level. Bandurska (1991) and Hawrylak (2007) suggest that this amino acid can fulfil a function of an adaptive metabolite, although there is no simple answer to clarify the relationships between proline accumulation and plant resistance to stress. However, it should be emphasised that proline accumulation under conditions of prolonged stress is a result of irreversible and unfavourable changes such as protein or chlorophyll decomposition and can be a symptom of injuries (Bandurska 2005, 2008).

This study aimed at examining selected physiological and biochemical indicators of the immune response of four rye lines to stress induced by potassium deficit.

MATERIAL AND METHODS

In order to determine the physiological and biochemical response of four new rye lines, S120, S76, OT1-3 and 541, grown at the Department of Plant Genetics and Breeding of the Agricultural University in Szczecin, a hydroponic experiment was set up. Seeds were sowed into soil and placed in a phytotrone with controlled atmosphere and photoperiod. The relative humidity and temperature were, respectively, 80% and 20°C, while the intensity of photosynthetically active radiation Phar was 700 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Seed germination took place after about 5 days. Seeds were characterised by different germination ability, i.e. 80% for line S120, 100% for line S76, 82% for line OT1, and only 50% for line 541.

Rye seedlings were placed in hydropnic units in the 2-3 leaf stage according to a two-factor experimental design. Seedlings in Hoagland's complete medium were a control variant, while the second factor consisted of potassium-starved seedlings placed in a medium where potassium was in deficit amounts (50% of the recommended dose).

After seven days the following were determined: fresh matter yield (by weighing), proline content by the method of Bates et al. (1973) and assimilation pigment content by the method of Arnon et al. (1956). The experiment was carried out in four series and six replications.

The results were processes statistically performing a two-factor analysis of variance, while significance of factors was tested with Tukey's test at $\alpha = 0.05$ and correlations were examined between the proline content and the other analysed parameters.

RESULTS AND DISCUSSION

Potassium plays an important role in water economy of plants and activation of enzymes. It also contributes to increasing the resistance of plants to frost. Under conditions of the growing deficiency of this component, chloroses of older leaves can occur (GRZEBISZ a,b 2004). The effect of potassium deficiency on the amount of assimilation pigments, proline and fresh matter yield in four rye lines is presented in Table 1 as major effects. As far as the significance of interactions is concerned, the results are presented in Figure 1. In Table 2 are the relationships between the proline content and the content of respective pigments in the four rye lines.

Table 1

Mean content of fresh matter, assimilation pigments and proline in four rye lines

Rye lines	Fresh matter (g)	Dry matter (g)	Proline (μg · g^{-1} f.m.)	Assimilation pigments (μg · g^{-1} f.m.)			
				chlorophyll a+b	chlorophyll a	chlorophyll b	carote-noids
S120 S76 OT1-3 541	0.242 0.288 0.184 0.135	0.036 0.039 0.021 0.016	5.0 9.3 11.6 27.2	1950 1305 1017 1219	1372 908 824 882	577 396 358 336	542 383 342 392
$LSD_{0.05}$ (I)	0.094	0.015	7.00	500	253	123	98
Control deficiency of K	0.221 0.203	0.034 0.032	13.4 11.3	1149 1595	863 1131	369 465	365 464
$LSD_{0.05}$ (II)	n.s.d	n.s.d	n.s.d	263	132	64	51
$LSD_{0.05}$ (IxII)	n.s.d	n.s.d	n.s.d	860.1	431.0	209.8	167.6

n.s.d. – non-significant differences

Many authors (HERNANDEZ et al. 2000, CHEN LI 2002, SONG et al. 2005) suggest that accumulation of free proline is an indicator of stress intensity as well as a factor that decides about an organism's repair abilities. In general, it is larger in plants that are characterised by larger resistance to stress.

Based on the results of analysis of variance, significant differences were found between the fresh matter content in the rye lines examined. Its largest yield was found in lines S76 and S120, whereas the smallest one in line 541 (Table 1). However, no significant differences were observed between the mean fresh matter content in the control variant and after application of the stress factor. Significant differences were also found between the mean

Table 1

Correlations between proline content and fresh matter yield and assimilation pigments content

Character	Character	Line S120	Line S76	Line OT1-3	Line 541
*P*roline	fresh matter	-0.28	-0.72*	-0.12	-0.81*
	dry matter	0.32	0.45	0.36	0.53
	chlorphyll a +b	0.84*	0.96*	0.89*	0.32
	chlorphyll a	0.84*	0.95*	0.52	0.24
	chlorphyll b	0.85*	0.90*	-0.10	0.49
	carotenoids	0.87*	0.91*	0.30	0.06

* significant

proline content in the rye lines. Line 541 was characterised by the largest content of this osmoregulator, i.e. 27.16 $\mu g \cdot g^{-1}$ f.m. (Table 1). In the other three rye cultivars [lines], the content of proline in leaves was considerably smaller: 11.58 $\mu g\ g^{-1}$ f.m. in line OT1-3, 9.289 $\mu g\ g^{-1}$ f.m. in line S76 and 5.055 $\mu g\ g^{-1}$ f.m. in line S120 (Table 1). Also BANDURSKA (2001) found significant differences in the content of proline in leaves in four barley cultivars. These results are the evidence that the proline level in these lines is an individual trait. Similar results in cereal plants were found by BANDURSKA (2008) and NAYYAR, WALIA (2003). On the other hand, no differences were found in the mean proline content between the control and potassium-starved seedlings, which is verified by the results of other studies (BRAY et al. 1991, LEI et al. 2006), although BANDURSKA (2001) found that more proline was accumulated in leaves of plants which grew under a high potassium level. It is assumed that the role of potassium consists here in stimulating the activity of arginase, which catalyses conversion of arginine to proline (HERNANDEZ et al. 2000).

Potassium deficiency contributed only slightly to degradation of assimilation pigments (Table 1, Figure 1) in line S76, which points to a small resistance of this line to deficit of this chemical element in soil. On the other hand, S120 was characterised by the significantly largest content of assimilation pigments, with their concentration increasing after application of potassium in a dose smaller by 50% than the recommended one.

The relationships between the proline concentration and the yield of fresh matter and the content of assimilation pigments were also analysed in the study (Table 1). In the case of lines S 76 and 541, the proline concentration was positively correlated with the fresh matter yield. In lines S120 and S76, the content of assimilation pigments was directly proportional to th proline concentration. Similar results were obtained by GADALLAH (1999), who examined the influence of water stress on *Vicia faba*. He found that the contents of chlorophyll a and b enlarged with an increase in the proline content.

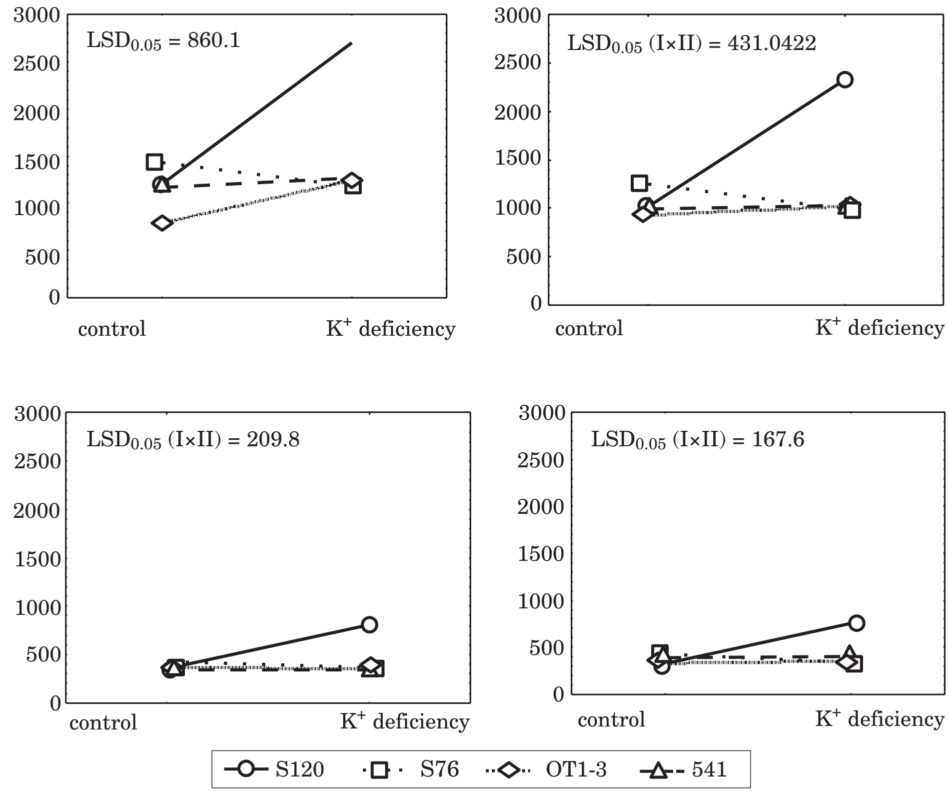

Fig. 1. Effect of potassium deficiency on assimilation pigments content

CONCLUSIONS

1. Potassium deficiency in a medium induced an increase in the content of assimilation pigments in fresh matter in rye line S120. It was also found that increase in the content of assimilation pigments occurred with a simultaneous increase of the proline content in leaf fresh matter.

2. The largest amount of proline was found in line 541 seedlings, i.e. 27.2 $\mu g \cdot g^{-1}$ f.m.; moreover, the content of proline in this line and in line S-76 increased with a simultaneous decrease in the yield of fresh matter in seedlings.

3. Line S76 proved to be most vulnerable to potassium deficiency in medium; the effect of the stress factor induced a clear decrease in the contents of assimilation pigments and of fresh matter.

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RESPONSE OF LUKASOVKA PEAR TREES TO FOLIAR ZINC SPRAYS

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Abstract

The aim of the study was to examine the efficiency of foliar zinc (Zn) application in pear culture. The experiment was carried out in 2005-2007 in a commercial orchard in central Poland, on 6-8 year-old cv. Lukasovka pear trees, grown on coarse-textured soil, moderately abundant in organic matter or available Zn and slightly acidic in reaction. The trees were sprayed with Zn as EDTA in three periods: (1) before bloom: at the stage of bud break, and green and white bud, at a rate of 80 g Zn ha^{-1} in each spray treatment; (2) after bloom: at petal fall, and 14 and 21 days after full bloom, at a rate of 50 g Zn ha^{-1} per spray or; (3) after harvest, 3-4 weeks before natural leaf fall, at a rate of 200 g Zn ha^{-1}. Trees unsprayed with Zn served as the control. The results showed, that pre-bloom Zn sprays increased status of this micronutrient in flowers, and post-bloom Zn sprays – in leaves and fruits. However, foliar Zn sprays had no effect on tree vigor, set of flowers and fruitlets, yielding, mean fruit weight, fruit russeting, and content of organic acids and soluble solids in fruit flesh. It is concluded that foliar Zn sprays of pear trees with an optimal leaf Zn status (according to the current threshold values) are not successful in improving plant growth, yielding, and fruit quality.

Key words: pear, zinc, foliar sprays.

REAKCJA GRUSZY ODMIANY LUKASÓWKA NA DOKARMIANIE DOLISTNE CYNKIEM

Abstrakt

Celem badań była ocena skuteczności dokarmiania dolistnego cynkiem (Zn) w uprawie gruszy. Doświadczenie przeprowadzono w latach 2005-2007 w prywatnym sadzie w centralnej Polsce. Obiektem doświadczalnym były 6-8-letnie grusze odmiany Lukasówka/pi-

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gwa S1, rosnące na glebie o składzie mechanicznym piasku gliniastego lekkiego, umiarkowanej zawartości materii organicznej, lekko kwaśnym odczynie oraz o średniej zawartości Zn. Grusze opryskiwano Zn w formie EDTA w trzech okresach: (1) przed kwitnieniem: w fazie pękania pąków oraz zielonego i białego pąka, w dawce 80 g Zn ha^{-1} w każdym zabiegu; (2) po kwitnieniu: w fazie opadania płatków kwiatowych oraz 14 i 21 dni później, w dawce 50 g Zn ha^{-1} w każdym zabiegu lub (3) po zbiorze owoców, 3-4 tygodnie przed naturalnym opadaniem liści, w dawce 200 g Zn ha^{-1}. Drzewa nie opryskiwane Zn stanowiły kontrolę. Wykazano, że opryskiwanie Zn przed kwitnieniem zwiększyło zawartość tego mikroskładnika w kwiatach, a opryskiwanie po kwitnieniu – w liściach i owocach. Dokarmianie dolistne Zn nie miało jednak wpływu na wigor drzew, zawiązywanie kwiatów i owoców, plonowanie, średnią masę owocu, ordzawienie owoców oraz zawartość kwasów i ekstraktu w miąższu owoców. Wnioskuje się, że dokarmianie dolistne Zn grusz o optymalnej zawartości tego mikroskładnika w liściach (wg obowiązujących liczb granicznych) nie polepsza wzrostu i plonowania roślin oraz jakości owoców.

Słowa kluczowe: gruszka, cynk, dokarmianie dolistne.

INTRODUCTION

Zinc (Zn) is an essential trace element for plants, as it conditions their good growth and development. It is involved in many enzymatic reactions, regulates the protein and carbohydrate metabolisms, affects integrity of plasmalemma and protects it against excess of O_2 free radicals. It also plays a critical role in cell elongation growth (ŚWIETLIK 1999).

Pear (*Pyrus communis* L.) is considered to be a Zn-sensitive species (SHEAR, FAUST 1980). At low soil Zn availability, plant growth is impaired, and fruit set and tree yielding are limited. Under such conditions, fruits are small, deformed, sour and early ripen. In severe cases, twig tips dry, inducing formation of lateral shoots, which after some time die. Simultaneously, bark of the trunk/branches is rough and cracked (SHEAR, FAUST 1980, ŚWIETLIK 1999, NEILSEN et al. 2005).

In Poland, orchard Zn deficiency signs are rarely observed and most frequently result from overliming; when this happens, it is recommended to spray trees with Zn both before and after bloom (ŚWIETLIK 1999). However, in recent years may fruit tree growers have been applying foliar Zn fertilizers although no tree symptoms of Zn deficiency are observed. Among growers and advisers, opinions about the efficiency of foliar Zn sprays are divided. On the other hand, no comprehensive studies on foliar Zn sprays on fruit crops have been conducted in Poland so far. Thus, it is impossible to decide whether Zn fertilization is necessary. Considering the above arguments, the present experiment has been established to test how efficiently foliar Zn sprays can improve pear tree growth, yielding and fruit quality.

MATERIAL AND METHODS

Localization, plant material and growth conditions

The experiment was conducted in 2005-2007 in a commercial orchard near Grójec. It was carried out on 6-8 year-old cv. Lukasovka pear trees (*Pyrus communis* L.)/quince S1, planted at a spacing of 4 x 2 m (1250 trees per ha), on coarse-textured soil (72% sand, 12% silt, 16% clay) moderately abundant in organic matter (12 g C kg^{-1}). Prior to the study (in autumn 2005), $pH_{(KCl)}$ of the surface soil layer was 6.2, and the levels of available phosphorus (P), potassium (K) and magnesium (Mg) were within the optimal ranges (39 mg P kg^{-1}, 76 mg K kg^{-1}, 32 mg Mg kg^{-1}) proposed by Sadowski et al. (1990) for fruit crops. Soil availability of those macronutrients was determined according to the methods recommended in Poland. Soil amount of 1M HCl-extractable Zn (4.8 mg Zn kg^{-1}) was within an optimal range proposed in Poland for agricultural crops.

The experimental trees were trained as a spindle up to a height of 3 m. In tree rows, a 1-m-wide herbicide strips were maintained and in interrows there were stripes of grass sod. From May to August, pears were irrigated (by a drip system) when shortage of water occurred in the surface soil layer (0-30 cm). Annually, pears were supplied with nitrogen and potassium; these nutrients were applied uniformly over the entire orchard soil surface, at the bud break stage, at a rate of 60 kg N ha^{-1} as ammonium nitrate, and of 80 kg K ha^{-1} as potassium chloride. During period of the study, no thinning of flowers/fruitlets was made. The trees were not sprayed with Zn-containing fungicides. Control of pathogens and pests was performed according to the standard recommendations for commercial orchards.

The treatments and experiment layout

Pears were sprayed with Zn as a chelate (EDTA, Chelat Zn 15 top, 15% Zn; Intermag, Olkusz, Poland), in three periods: (1) before bloom: at the stages of bud break, and green and white bud, at a rate of 80 g Zn ha^{-1} in each spray; (2) after bloom: at the petal fall, and 14 and 21 days after full bloom, at a dose of 50 g Zn ha^{-1} per spray or; (3) after harvest, 3-4 weeks before natural leaf fall, at a rate of 200 g Zn ha^{-1}. Sprays of Zn in the first two periods (before and after bloom) were made in 2006 and 2007, whereas in the third period – in 2005 and 2006; in this way it was possible to compare the efficiency of all the spray combinations tested. Different Zn rates in individual pear growth periods were applied so as not to damage of leaves/fruits. Sprays of Zn were made by a hand-held sprayer, using ca. 500 dm^{-3} of water per ha for pre-bloom applications, and ca. 1000 dm^{-3} water for post-bloom and post-harvest treatments. The trees unsprayed with Zn served as the control. Over the three years of the experiment, the same trees were sprayed with Zn in the above variants. The study was conducted using a randomized complete block design with 4 replications. Each experimental plot (replication) consisted of 6 trees.

Measurements and observations

(i) Tree vigor was estimated based on the total length of one-year-old shoots, calculated according to the method of JOLLY, HOLLAND (1958), on two branches from each tree, grown in a row line, at the height of 1.5-2.0 m above ground; (ii) leaf Zn status was determined 95 days after full bloom, on ca 100 leaves per plot. Leaves were taken from the mid-portion of current-season shoots, from the peripherial zone of the canopy, at the height of 1.5--2.0 m above soil surface. Leaves were rinsed with double-deionized water, dried at 75°C, ground in an agate mill, and ashed in a muffle furnace at temperature of 450°C for 12 h. Ash was dissolved in 0.5% HCl, and Zn amount in the solution was determined with an inductively-coupled plasma spectrometer (Thermo Jarrell Ash, Franklin, MA, USA); (iii) flower set was evaluated at the white bud stage, on one branch from each tree, grown in a tree row line, at the height of 1.5-2.0 m above soil surface. The results were expressed as flower number per 1 m of shoot; (iv) flower Zn concentration was determined at the full bloom stage, on 50 flowers (without the stem) per plot, taken from 2 year-old shoots, grown in the peripherial zone of the crown, at the height of 1.5-2.0 m above soil ground. Preparation of flower samples for analysis and determination of Zn were the same as for leaf samples, except that flowers were not rinsed with double-deionized water. Flower Zn concentration was expressed on a dry-mass basis; (v) fruit set was estimated immediately after "Juny drop", on the same branches as flower set. Fruit set was expressed as percentage of set fruitlets in relation to the number of flowers; (vi) fruit yield was weighted from each plot and calculated per ha; (vii) mean fruit weight was calculated on *ca* 20-kg bulk fruit sample per plot; (viii) pear skin russeting was rated on a 20-kg bulk fruit sample per plot, on a scale from 1 (no russeting) to 5 (russeting > 76% of fruit skin surface); (ix) soluble solids concentration and titratable acidity of fruits were measured/determined immediately after harvest (at commercial harvest data), on 40-fruit sample per plot. Soluble solids concentration was measured with an Abbe refractometer, and titratable acidity was determined by titrating the fruit homogenate with 0.1 N NaOH to pH 8.1 (WŁODEK et al. 1958). The results of titratable acidity represent malic acid content expressed as a percentage; (x) fruit Zn concentration was determined after harvest, on 40-fruit sample per plot. Seeds and stems of fruits were removed and two quarter-size pieces were cut out from the opposite sides of each fruit. Further preparation of fruit samples and determination of Zn were the same as the leaf analysis. The results were expressed on a dry--weight basis.

Statistical analysis

All data were subjected to the analysis of variance. Differences between combination means were evaluated separately for each growing season, using Duncan's Multiple Range Test at $P \leq 0.05$. The data of the total length of current season shoots per tree were transformed according to the equation $y = \log(x)$, and of fruit set according to $y = \arcsin(x)$.

RESULTS AND DISSCUSION

Foliar Zn sprays had no effect on pear vigor; the total length of current-season shoots per tree averaged 61.3 m in 2006 and 72.8 m in 2007.

The concentration of Zn in leaves of the control trees was within the optimal range proposed by SADOWSKI et al. 1990 (Table 1). Only post-bloom Zn sprays increased leaf status of this micronutrient (Table 1). Post-bloom Zn sprays were found to produce no effect on tree vigor, hence it can be concluded that pear Zn nutrition in this study was not a factor that limited the vegetative growth.

The flower set, expressed as a number of flowers per 1 m of shoot, did not differ significantly among combinations: 87.3 in 2006 and 112.4 in 2007, on average.

Only pre-bloom Zn sprays enhanced flower Zn status (Table 1). Lack of influence of post-harvest Zn sprays on flower Zn concentration indicates limited mobility of Zn in the plant. Limited movement of Zn^{68} from pear leaves, sprayed with this isotope in the autumn, to woody organs (shoots, branches) and next to developing tissues/organs in the spring was also found by SANCHEZ and RIGHETTI (2002).

Foliar Zn sprays did not affect fruit set, which on average was 7.8% in 2006, and 2.3% in 2007. Low fruit set in 2007 resulted from a spring frost (-5°C), which occurred at the white bud stage. Regardless of this fact, fruit yields among combinations, within each growing season, were comparable (Table 1). This indicates that pear Zn nutrition did not limit the reproductive processes.

The mean fruit weight was not influenced by foliar Zn sprays (Table 1). Fruit skin russeting depended on growing season: in 2006 fruit skin was less damaged than in 2007 (Table 1). Stronger fruit russeting in 2007 probably resulted from flower cell injuries by the spring frost. However, foliar Zn sprays did not affect fruit russeting (Table 1).

The soluble solids concentration and titratable acidity of fruits were not affected by Zn sprays, averaging 14.0% and 0.31% in 2006, and 14.2% and 0.28% in 2007, respectively.

Table 1

Effect of foliar zinc sprays on cv. Lukasovka pear zinc nutrition, yielding, and fruit quality

Treatment	Leaf Zn conc. (mg kg^{-1} d.m.)		Flower Zn conc. (mg kg^{-1} d.m.)		Fruit yield (t ha^{-1})		Mean fruit weight (g)		Fruit russeting (1-5)*		Fruit Zn conc. (mg kg^{-1} d.m.)	
	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007	2006	2007
Three pre-bloom Zn sprays at a rate of 240 g Zn ha^{-1} year^{-1}	32.1a	38.7a	58.7b	63.2b	36.7a	16.4a	280a	365a	1.5a	2.3a	4.1a	5.1a
Three post-bloom Zn sprays at a rate of 150 g Zn ha^{-1} year^{-1}	43.7b	48.7b	39.7a	37.3a	32.8a	19.2a	266a	354a	1.7a	2.5a	10.4b	12.4b
Post-harvest Zn spray at a r^{ate} of 200 g Zn ha^{-1}	33.4a	35.2a	38.5a	38.7a	32.4a	17.2a	276a	349a	1.1a	2.8a	5.3a	6.5a
No Zn sprays	35.1a	36.7a	41.7a	35.7a	35.6a	15.7a	281a	355a	1.4a	2.7a	4.3a	5.4a

* the higher value, the stronger fruit skin russeting
Means within the column with the same letter are not significantly different by Duncan's Multiple Range Test at $P \le 0.05$.

Only fruits of post-bloom Zn-sprayed trees contained more Zn than those of the control trees (Table 1).

CONCLUSIONS

1. Foliar Zn sprays of cv. Lukasovka pear trees/quince S1 with an optimal leaf Zn status (according to the current threshold values) did not affect the tree growth, yielding, and fruit quality.

2. Post-harvest Zn sprays failed to improve pear Zn nutrition in the following season.

3. Pre-bloom Zn sprays increased flower Zn level, and post-bloom Zn sprays – in leaves and fruits.

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IMPACT OF INSECTICIDES ON MAGNESIUM AND CALCIUM CONTENTS IN POTATO TUBERS

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Abstract

A study has been carried out on the basis of a field experiment set up on soil of very good rye complex. The experiment was designed as randomized sub-blocks with three replications. Experimental factors included three cultivars of edible potato – Wiking, Mors, and Żagiel, and six Colorado potato beetle control methods using the following insecticides: Actara 25 WG at the rate of 80 g ha^{-1}, Regent 200 SC at the rate of 0.1 dm^3 ha^{-1}, Calypso 480 SC at three rates: 0.05; 0.075 and 0.1 dm^3 ha^{-1}, and a control treatment without chemical protection. Magnesium and calcium contents in potato tubers were determined by the ASA method. The content of the elements depended on the cultivars, Colorado potato beetle control methods and weather conditions throughout the growing season. The insecticides applied significantly increased magnesium and calcium contents compared with the tubers harvested from the control treatment where no chemical protection was applied. Tubers of Żagiel and Wiking cultivars had the highest magnesium content and calcium content, respectively.

Key words: potato, Colorado potato beetle, insecticides, magnesium, calcium.

ODDZIAŁYWANIE INSEKTYCYDÓW NA ZAWARTOŚĆ MAGNEZU I WAPNIA W BULWACH ZIEMNIAKA

Abstrakt

Badania oparto na doświadczeniu polowym założonym na glebie kompleksu żytniego bardzo dobrego metodą losowanych podbloków w trzech powtórzeniach. Czynnikami eksperymentu były: 3 odmiany ziemniaka jadalnego: Wiking, Mors, Żagiel i 6 sposobów zwal-

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czania stonki ziemniaczanej z udziałem insektycydów – Actara 25 WG w dawce 80 g ha^{-1}, Regent 200 SC w dawce 0,1 dm^{3} ha^{-1}, Calypso 480 SC w dawkach 0,05; 0,075 i 0,1 dm^{3} ha^{-1} oraz obiekt kontrolny bez ochrony chemicznej. Zawartość magnezu i wapnia w bulwach ziemniaka oznaczono metodą ASA. Zawartość pierwiastków zależała istotnie od uprawianych odmian, sposobów zwalczania stonki ziemniaczanej i warunków pogodowych w okresie wegetacji. Aplikowane insektycydy wpłynęły na wzrost zawartości magnezu i wapnia, w porównaniu z bulwami pochodzącymi z obiektu kontrolnego, na którym nie stosowano ochrony chemicznej. W bulwach odmiany Żagiel stwierdzono największą zawartość magnezu, a w bulwach odmiany Wiking największą zawartość wapnia.

Słowa kluczowe: ziemniak, stonka ziemniaczana, insektycydy, magnez, wapń.

INTRODUCTION

Potato plays a very significant role in human diet. As a result, an impact of plant protection agents, including insecticides, on potato quality is an important issue (Leszczyński 2002). According to many authors, the content of particular macroelements in potato tubers is conditioned by cultivar properties (Mazurczyk 1994, Kołodziejczyk, Szmigiel 2005, Tekalign, Hammes 2005), agronomic factors (Roztropowicz 1989, Rykaczewska 2000, Zarzeckam, Gąsiorowska 2000) and weather conditions during the potato growing period (Leszczyński 1994, Kołodziejczyk, Szmigiel 2005). There is little available data on the impact of insecticides on the content of minerals in potato tubers. The information pertaining to an unfavourable effect of application of chemicals in agriculture on potato yield quality has provided a stimulus for determination of content of magnesium and calcium, two most important minerals. The study aimed at determining an impact of the newest generation insecticides (Actara 80 WG, Regent 200 SC, Calypso 480 SC) on magnesium and calcium concentrations in tubers of three potato varieties.

MATERIAL AND METHODS

A study was carried out on potato tubers obtained from a field experiment conducted in 2004-2006 at the Zawady Experimental Farm owned by the University of Podlasie in Siedlce. The soil belonged to very good rye complex. The experiment was established in a randomized sub-block design including two factors: factor I – three edible potato varieties: Wiking, Mors and Żagiel, and factor II – six methods of Colorado potato beetle control including the newest generation insecticides: 1) control treatment with no chemical protection, 2) Actara 80 WG (thiametoxam) at the rate of 80 g ha^{-1}, 3) Regent 200 SC (fipronil) 0.1 dm^{3} ha^{-1}, 4) Calypso 480 SC (thiacloprid) 0.05 dm^{3} ha^{-1}, 5) Calypso 480 SC (thiacloprid) 0.075 dm^{3} ha^{-1}, 6) Calypso 480 SC (thiacloprid) 0.1 dm^{3} ha^{-1}. At the beginning of the experiment, there was no recommendation regarding the rate of Calypso 480 SC, thus the amount applied was 0.05-0.1 dm^3 ha^{-1}. At present the recommended rate is 0.075-0.1 dm^3 ha^{-1}. The plot area was 15 m^2.

Potato was cultivated after winter wheat. Each year the same organic and mineral fertilization was applied. The amount of farmyard manure was 25.0 t ha^{-1}, and the respective rates of N, P and K were as follows: 100, 44.0 (100 $P_2O_5 \cdot 0.44$) and 124.5 kg ha^{-1} (150 $K_2O \cdot 0.83$). Chemical analyses were performed using dry material in three replications. Magnesium and calcium contents were determined after mineralization by atomic absorption spectrophotometry (AAS) (Ostrowska et al. 1991). Results of the study were statistically analysed by means of variance analysis and the means were compared by Tukey test at the significance level of p=0.05. Climatic conditions varied over the growing periods of potato cultivation (Table 1).

Table 1

Weather conditions during potato vegetation season in 2004-2006 according to the Zawady Meteorological Station

Months	Sielianinow's hydrothermic coefficient *		
	2004	2005	2006
April	1.50	0.47	1.18
May	2.69	1.60	0.99
June	1.14	0.92	0.47
July	0.90	1.51	0.24
August	1.14	0.84	4.18
September	0.50	0.35	0.45
April-September	1.24	1.00	1.26
Rainfalls in the vegetation period, mm	320.9	268.8	358.6
Deviation from many-year average	-22.8	-74.9	+14.9
Mean air temperature, °C	14.1	15.0	15.8
Deviation from many-year average	+0.1	+1.0	+1.8

* up till 0.5 – strong mild drought
0.51-0.69 – mild drought
0.70-0.99 – weak mild drought
≤1– fault mild drought

RESULTS AND DISCUSSION

The average magnesium content in tuber dry mater for the three-year study period amounted to 1.381 g (Table 2) and was similar to the values reported by Rogana et al. (2000), Rykaczewska (2000), Wyszkowski, Ciećko (2001). The insecticides applied to control the Colorado potato beetle caused

Table 2

Content of magnesium in potato tubers ($g \cdot kg^{-1}$ d.m.)

Objects	Cultivars			Mean
	Wiking	Mors	Żagiel	
1. Control object	1.171	1.431	1.456	1.353
2. Actara 80 WG 80 $g \cdot ha^{-1}$	1.198	1.464	1.472	1.378
3. Regent 200 SC 0.1 $dm^3 \cdot ha^{-1}$	1.195	1.480	1.494	1.390
4. Calypso 480 SC 0.05 $dm^3 \cdot ha^{-1}$	1.195	1.478	1.477	1.383
5. Calypso 480 SC 0.075 $dm^3 \cdot ha^{-1}$	1.220	1.473	1.483	1.392
6. Calypso 480 SC 0.1 $dm^3 \cdot ha^{-1}$	1.212	1.471	1.489	1.391
Mean	1.199	1.466	1.479	1.381
Mean for objects 2-6	1.204	1.473	1.483	1.387
$LSD_{0.05}$				
between cultivars (I)				0.019
between insecticides (II)				0.016
in interaction (I x II)				n.s.

n.s. – not significant

unidirectional changes in magnesium content in the examined potato varieties. An average increase in the content of this element was significant and amounted to 0.034 g kg^{-1}. The available literature lacks information on the impact of insecticides on accumulation of macroelements in potatoes. Kraska, Pałys (2005) applied the following insecticides: deltametrine, bensultap and acetamipride, and recorded an increase of 0.010 g kg^{-1} in the magnesium content in potato root dry matter. Having applied herbicides, Zarzecka, Gąsiorowska (2000) found an increase in magnesium amount in tubers. In the studies by Wyszkowski, Ciećko (2001) fungicides applied to potato fields significantly influenced neither magnesium and calcium nor phosphorus concentrations in the tubers.

The cultivars studied contained different magnesium amounts, the largest amount accumulated by Żagiel – on average 1.479 g kg^{-1}, and the lowest amount accumulated by Wiking – on average 1.199 g kg^{-1}. The differences between Mors and Żagiel were not statistically confirmed. Many authors (Mazurczyk 1994, Rykaczewska 2000, Tekalign, Hammes 2005) found that potato tuber chemical composition was primarily affected by the cultivar.

Potato tubers harvested in the individual years differed in respect of magnesium content (Table 3). The weather conditions in 2004 favoured magnesium accumulation because temperature and rainfall were evenly distributed, which is reflected in the calculated values of hydrothermal coefficient. The lowest magnesium content was in 2006, when there was a spell of drought in June and July (which is the period of intensive yield accumulation). An impact of weather conditions on this characteristic has also been confirmed in the works by Roztropowicz (1989), Kołodziejczyka, Szmigla (2005).

Table 3

Effect of weather conditions on the content magnesium and calcium in potato tubers (mean for three cultivars)

Years	Content in dry matter	
	magnesium	calcium
2004	1.644	0.808
2005	1.409	0.835
2006	1.091	0.870
$LSD_{0.05}$	0.019	0.016

Calcium content in potato tubers averaged 0.837 g kg^{-1} (Table 4). Similar values for this element have been reported by Wyszkowski, Ciećko (2001), as well as Yildrim, Tokusodlu (2005). Statistical analysis confirmed that calcium content was significantly conditioned by the methods of Colorado potato beetle control, cultivars selected for cultivation and weather conditions over the study years. Insecticides increased the concentration of this element, on average by 0.022 g kg^{-1}, compared with the control treatment, which was not chemically protected. No significant effect on calcium content was found after Calypso 480 SC had been applied at the lowest rate (0.05 dm^3 ha^{-1}). Wyszkowski, Ciećko (2001) as well as Prośba-Białczyk et al. (2002) reported that plant protection agents – fungicides – had no significant effect on the calcium content in potato tubers. However, there are no literature data pertaining to changes in the calcium amount in tubers as influenced by insecticides. Genetic properties of the grown cultivates significantly deter-

Table 4

Content of calcium in potato tubers (g · kg^{-1} d.m.)

Objects	Cultivars			Mean
	Wiking	Mors	Żagiel	
1. Control object	0.866	0.779	0.814	0.819
2. Actara 80 WG 80 g · ha^{-1}	0.884	0.800	0.828	0.837
3. Regent 200 SC 0.1 dm^3 · ha^{-1}	0.893	0.804	0.832	0.843
4. Calypso 480 SC 0.05 dm^3 · ha^{-1}	0.895	0.704	0.818	0.832
5. Calypso 480 SC 0.075 dm^3 · ha^{-1}	0.898	0.800	0.826	0.841
6. Calypso 480 SC 0.1 dm^3 · ha^{-1}	0.907	0.810	0.839	0.852
Mean	0.889	0.798	0.826	0.837
Mean for objects 2-6	0.893	0.802	0.829	0.841
$LSD_{0.05}$				
between cultivars (I)				0.016
between insecticides (II)				0.015
in interaction (I x II)				n.s.

n.s. – not significant

mined calcium content. The highest and the lowest calcium accumulations were found for Wiking (on average 0.889 g kg^{-1}) and Mors (on average 0.798 g kg^{-1}), respectively.

All the cultivars had an increased calcium content in tubers following an application of insecticides. However, there was no proven interaction between the factors studied. The impact of cultivar properties on calcium concentration is confirmed by the findings of WYSZKOWSKI, CIEĆKO (2001), as well as TEKALIGN, HAMMES (2005). Calcium concentration depended on weather conditions over the growing period and was the highest in 2006, when the temperature and rainfall exceeded multi-year means. Similar potato response under wet conditions has been observed by KOŁODZIEJCZYK, SZMIGIEL (2005).

CONCLUSIONS

1. Insecticides applied to control the Colorado potato beetle increased magnesium and calcium contents in tubers compared with the non-insecticide treatment, excluding the lowest rate of Calypso 480 SC.

2. Genetic properties of cultivars determined an accumulation of the elements in potato tubers. Mors and Żagiel accumulated significantly more magnesium than Wiking. Most calcium was accumulated by Wiking, significantly less by Żagiel and the least by Mors.

3. The concentration of magnesium and calcium in potato tubers was significantly affected by weather conditions over the growing periods.

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