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Fertilisation with ash from wood and with sewage sludge versus contents of macro-and microelements in the soil following cultivation of *Helianthus tuberosus* L.

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Abstract. The present study investigated the effects produced in the soil by municipal sewage sludge and wood ash applied during the cultivation of Jerusalem artichoke. The impact of the presence of applied the fertilizer materials on changes in soil and a macro- and microelements contents were investigated. The comparative analyses took into account 3 factors; the first factor - 4 levels of wood ash – 0; I–4.28; II–8.57; III–12.85 t ha^{-1}, the second factor – 2 levels of sewage sludge – 0; 1 – 30.3 t ha^{-1}, the third factor – 2 varieties of Jerusalem artichoke (*Helianthus tuberosus* L.) – Gigant, Albik. Application of the fertilisers did not resulted in significant change in the total contents of phosphorus, potassium and magnesium in soil examined after Jerusalem artichoke was harvested. Application of ash from coniferous trees, with high levels of calcium, resulted in increased total contents of calcium in the soil. Fertilisation of the soil with ash from coniferous trees or with sewage sludge, as well as cultivation of two varieties of Jerusalem artichoke, resulted in a significant increase in the concentrations of cadmium and lead, and produced no effects in the levels of nickel, zinc and copper identified in soil. The above findings, and in particular the fact that the limit values were not exceeded, indicate the possibility of using both sludge and biomass ash for fertilizing Jerusalem artichoke.

Key words: wood ash, sewage sludge, macro- and microelements, soil, Jerusalem artichoke.

INTRODUCTION

Owing to its composition, sewage sludge contributes to soil formation by introducing biogenic substances, into the soil. It also contains a variety of nutrients for plants, so it may be used in order to improve growing conditions before a plantation is established, and to increase the growth rate in short rotation plantations (Lazdina et al., 2011). Based on the related EU directive, the Waste Act defines detailed conditions to be followed while using municipal sewage sludge in agriculture (Official Journal L 181/6, 4.7.1986; Journal of Laws 2013 item 21; Journal of Laws 2019 item 1403). Sewage sludge may be used in the cultivation of plants, for compost production, and in the farming of crops not intended as food, or for the production of animal feed, as well as for land remediation, including the restoration of agricultural land. One such plant is the Jerusalem artichoke (*Helianthus tuberosus* L.) which may be utilised in the production of biogas and ethanol. Due to the high yielding potential and versatile utility value of biomass, Jerusalem artichoke has a chance to become an alternative source of energy. Tubers can be used for the production of bioethanol or for methane fermentation; the aboveground part can be used for the production of biomethane, (Sawicka et al., 2020).

The presence of microelements (e.g., Cu, Fe, Zn), which function as catalysts in the physiological processes occurring in plants, is an important factor affecting the development and growth of crops. On the other hand, some of these elements, i.e. Hg, Pb occurring in a dissolved form in sewage sludge, co-precipitated with metal oxides and adsorbed or associated with biological residues, are hazardous toxic substances (De la Guardia & Morales-Rubio 1996; Milik et al., 2016). Furthermore, the application of wood ash from known sources must not increase the contents of heavy metals in the soil to levels exceeding the norms (Pitman 2006; Libiete et al., 2016)

Currently based on the Decision issued by the Commission of the European Communities, on 3 May 2000 regarding the waste catalogue, sludges from the treatment of urban waste water are marked with the code 19 08 05, (Official Journal L 226, 6.9.2000). As regards the agricultural use of municipal sewage sludge the main hazards are linked with the high quantities of heavy metals; their permissible concentrations are defined in the Ordinance of the Minister of Environment dated 6 July 2015 regarding municipal sewage sludge. According to the ordinance of the Minister of the Environment on municipal sewage sludge, according to which a single dose of sewage sludge, allowed once every three years for non-food crops, may not exceed 45 Mg per hectare every 3 years (Journal of Laws 2015 item 257).

Wood ash, as an alternative to calcium fertilisers, is characterised by an alkaline reaction and therefore treatments involving the use of wood ash significantly affect soil pH. Composition of wood is rather stable, with high concentrations of calcium and silicon, and lower contents of phosphorus and potassium (Čepauskienė et al., 2018). Spruce wood ash has been reported to contain: calcium carbonate ($CaCO_3$), potassium sulphate(VI) (K_2SO_4), magnesium potassium phosphate ($K_2Mg(PO_3)_4$), manganese potassium phosphide (KMnP) and manganese sulphate(VI) ($MnSO_4$). Wood ash applied as a fertiliser produces significant changes in the physical and chemical properties of the soil (Libiete et al., 2016). Saletnik & Puchalski (2019) reported that application of wood ash may positively affect the soil, particularly in areas requiring remediation.

The present study investigated the effects on soil by municipal sewage sludge and wood ash applied during the cultivation of Jerusalem artichoke**.** The impact of the presence of applied the fertilizer materials on changes in soil and a macro- and microelements contents was investigated.

METHODOLOGY

Characteristics of the experiment

The experiment was conducted in the village of Ujkowice (49.85° N, 22.72° E), located in the commune of Przemyśl in the Podkarpackie Region of Poland. It was carried out in a field lying fallow for 8 years. The size of the plots was 35 m^2 (7 m × 5 m) at the start of the experiment, and for harvest were cut to 24 m^2 (6 m × 4 m). The comparative analyses took into account three factors; the first factor - 4 levels of fertiliser use with wood ash - 0; I – 4.28; II – 8.57; III – 12.85 t ha^{-1}, the second factor – 2 levels of fertiliser use with sewage sludge – 0; 1 – 30.3 t ha^{-1}, the third factor – 2 varieties of *Helianthus tuberosus* L. – Gigant, Albik. In English *Helianthus tuberosus* L. it is called Jerusalem artichoke.

The experiment was carried out in three replications, in accordance a with split plot – split block design.

The soil used in the experiment was classified as heavy loam, agronomic category – heavy soil (total fraction > 0.02 mm – 37.7%) and agricultural usefulness complex IV (USDA, 2006). The physicochemical and chemical parameters of the soil are shown in Table 1.

Table 1. Physicochemical and chemical parameters of the soil before the experiment

Parameter	Value	Regulation of the Minister of Environment dated September 1, 2016 on how to assess the pollution of the earth's surface, (Journal of Laws 2016 item 1395
pH (pH_{H2O})	6.10	
pH (pH_{KCl})	5.58	
Soil salinity g NaCl kg^{-1}	0.11	
Unit (mg kg^{-1})		
Available phosphorus	53.2	-
Available potassium	132.7	-
Exchangeable calcium	290.7	-
Available magnesium	124.0	-
Cd	1.30	2–15
Pb	21.5	100–600
Ni	15.4	100–500
Zn	51.9	300–2,000
Cu	14.7	100–600
Cr	22.0	150–1,000
Hg	0.0424	2–4

The soil was characterised by slightly acidic pH (ISO 10390:1997P). The contents of available phosphorus and potassium were at a medium level (Egner et al., 1960). Magnesium contents is classified as high (DIN-R-04020:1994+Azl:2004) (Table 1). The assessment of the total contents of metals in the soil showed that they did not exceed values described as medium. In the light of the applicable laws, the soil was suitable for the use of municipal sewage sludge as a fertiliser (Journal of Laws 2015 item 257). Sewage sludge obtained from the Municipal Treatment Plant in Przemyśl was subjected to fermentation, dehydration and hygienisation with lime. Metal concentrations in the sludge (Table 2) did not exceed the limits specified in the Ordinance of the Minister of Environment regarding municipal sewage sludge (Journal of Laws 2015 item 257). In terms of its chemical composition, the sewage sludge complied with the standard for organic fertilisers, as set forth in the Regulation of the Minister of Agriculture and Rural Development on the implementation of certain provisions of the act on fertilisers and fertilisation (Journal of Laws 2008 No. 119 item 765).

Ash from coniferous trees obtained from the Tartak Olczyk Sp. Z o.o. sawmill in Świdno near Krasocin, was produced from incinerated wood shavings and sawdust of coniferous trees: spruce, pine and larch. The ash was found to have an alkaline pH (9.5).

The tests took into account two varieties of Jerusalem artichoke (*Helianthus tuberosus* L.), Albik and Gigant, intended for the production of biomass for energy related purposes. Tubers of Albik Jerusalem artichoke were purchased in the Dolnośląskie Region, directly from the producer, Emilian Siemsia, and Jerusalem artichoke of the Gigant variety was acquired from Vreeken's Zaden, Voorstraat 448, 3311 CX Dordrecht (the Netherlands).

In the spring of 2013, before the seasonal works were started, and following the germination of Jerusalem artichoke, herbicidal treatments were performed with Roundup 360 SL, at the 3–4 leaf stage of couch grass, at a dose of 3 L ha^{-1} + the adjuvant AS 500 SL 1–2 L ha^{-1}, followed by Fusilade Super 125 EC (2 dm^3 ha^{-1}).

Table 2. Physicochemical and chemical parameters of the municipal sewage sludge from the Municipal Treatment Plant in Przemyśl, and ash from coniferous trees from the Tartak Olczyk Sp. Z o.o. Świdno sawmill

Parameter	Sewage sludge	Ash
pH (pH$_{H2O}$)	7.4	9.5
Dry mass (%)	23.6	-
Unit (% d.m).		
Organic matter	52.8	
N	4.24	-
P	1.60	0.60
K	0.20	2.34
Ca	2.80	20.6
Mg	0.64	1.14
Unit (mg kg^{-1} d.m)		
Cd	1.60	11.6
Pb	42.7	13.1
Ni	61.2	11.4
Zn	1053	280
Cu	171.5	134
Cr	61.2	125
Hg	1.33	0.013

In 2013, before planting, mineral and organic fertilisers were applied to the plot, taking into account the requirements of Jerusalem artichoke (N–100 kg ha^{-1}, P–70 kg ha^{-1}, K–100 kg ha^{-1}. The doses of the respective fertilisers were determined based on the contents of nitrogen and phosphorus in the sewage sludge, the contents ofcalcium and potassium and the pH value in the wood ash, and the area of the relevant plots (35 m^2). In order to balance out the dosage of sewage sludge with regard to nitrogen, 35 kg of fresh sludge was applied to the plot. The dose used once in the three years amounted to 105 kg per plot, i.e. 30 t ha^{-1}. The dosage of wood ash was determined based on the potassium content in the ash. The following doses of wood ash were applied: 0; 4.28; 8.57 and 12.85 t ha^{-1}. The potassium fertiliser, i.e. ash from wood biomass, was spread on the plots, and mixed with soil with the use of a tiller. The sewage sludge was spread into the soil in spring 2013, before the tubers of Jerusalem artichoke were planted. Only two of the above fertilizers were used in the experiment.

Methodology of chemical analyses

Samples of the soil, acquired from each plot after harvest of the Jerusalem artichokes, were collected with Egner–Riehm's sampling stick at a depth of 0–20 cm in conformity with the applicable standard (DIN-R-04031:1997). The air-dry soil samples were analysed. Soil reaction (pH$_{H2O}$ and pH$_{KCl}$) was determined with potentiometric cally (ISO 10390/1997). Available phosphorus and potassium in the soil were identified using the Egner-Riehm method based on extraction of calcium lactate and lactic acid with buffer solution characterised by a pH value of 3.55 (Egner et al., 1960). The contents of available magnesium were measured using soil extraction with a solution of calcium chloride with a concentration of 0.0125 mol $CaCl_2$ dm^{-3}, (DIN-R-04020:1994+Azl:2004).

The contents of exchangeable calcium in the soil were determined using soil extraction with barium chloride with pH = 8.1 (ISO 11260:2011). In order to measure the overall contents of elements, the soil was subjected to mineralisation in a mixture of nitric(V) acid (HNO_3) and chloric(VII) acid ($HClO_4$), subsequently a chemical assay was conducted using ICP-OES 6500 apparatus. The assessment applied Echelle-type optics with a semiconductor CID detector with a resolution of 200 nm, and an element spectrum in the range of 166–847 nm.

Statistical analysis of the findings was based on three-way analysis of variance, with a split-plot split-block design in 2013 and 2014; number of replications $n = 3$. Multiple comparison of the means was performed using Tukey's test, at a significance level $\alpha = 0.05$. The analyses were carried out using STATISTICA v.12 software.

Climatic conditions

According to the data obtained from the Institute of Meteorology and Water Management in Warsaw, mean total precipitation in the Podkarpackie Region in 2013 was lower (580 mm) than the multiannual mean (610 mm), and in 2014 it was slightly higher (640 mm). The mean air temperature during the first and second vegetation season was similar (11.2 °C and 11.3 °C, respectively), and it was slightly higher than the multiannual mean (10.6 °C). During the initial vegetation period (April – May) as well as at its peak (June – August) the mean monthly air temperatures were similar to the multiannual mean values. In June 2013 and July 2014 there was heavy rainfall (140 mm and 120 mm). During the remaining months precipitation was significantly lower. The temperatures observed from October to December were higher than the multiannual mean, on average by 2 °C. In 2014 the mean air temperature of 11.3 °C exceeded the multiannual mean by 0.7 °C. The high temperature in November and December supported continued vegetation growth, and did not pose any significant hazard for the wintering plants. During the first decade of January the high temperature promoted continued vegetation growth of the plants. Later during the same month, the increased mean diurnal temperature of the air resulted in intensified physiological processes occurring in the plants. The mellow and sunny weather in March removed excess moisture from the fields and warmed up the soil. The weather conditions in April were also favourable for agriculture. Warm and sunny weather during the month promoted rapid growth of the plants. In May the agrometeorological conditions were differently. As a result of a cold spell, the pace of plant growth and maturation was slower. The frequent and heavy rainfall during the month led to excessive hydration of the soil. The warm days in the first and second decade of June promoted plant growth and a cold spell during the third decade resulted in transient slowing down of plant maturation. The rainfall observed throughout the month of July beneficially affected the level of moisture in the surface layer of the soil as well as the growth and development of root crops.

RESULTS AND DISCUSSION

Macroelements in the soil

Owing to the ten times higher concentrations of potassium and calcium in ash, compared to sewage sludge, the former may effectively be used as an additional source of these macroelements. In 2013 the soil from the experiment was analysed and shown to have total contents of phosphorus amounting to 1 g P kg^{-1} soil (Table 3, 4, 5). Application of sewage sludge and ash from coniferous trees did a change significantly contents of the element in the soil. As an exception, the soil in which the Albik Jerusalem artichoke was grown contained significantly more phosphorus compared to the soil in which the Gigant variety was cultivated. After the experiment ended, in 2014, more uniform results were observed as regards available phosphorus concentrations in the soil; the mean value amounted to 0.60 g P kg^{-1} and no effects were produced by either of the fertilisers or the Jerusalem artichoke varieties.

Table 3. Effect of fertilisation with wood ash on the contents of total and available forms of macroelements in the soil

		Ash doses (t ha^{-1})				
Year	Element	0	4.3	8.6	12.8	LSD$_{0.05}$
		Total form (g kg^{-1} soil)				
2013	P	1.00 ± 0.095*	1.08 ± 0.089	1.22 ± 0.099	1.11 ± 0.092	n.s.
	K	2.91 ± 0.13	3.27 ± 0.14	3.17 ± 0.12	3.37 ± 0.15	n.s.
	Ca	3.01 ± 0.16	3.23 ± 0.17	4.030 ± .18	4.87 ± 0.19	1.052
	Mg	3.43 ± 0.13	3.67 ± 0.12	3.42 ± 0.13	3.57 ± 0.14	n.s.
2014	P	0.597 ± 0.076	0.658 ± 0.068	0.612 ± 0.059	0.543 ± 0.066	n.s.
	K	2.35 ± 0.12	2.24 ± 0.11	2.35 ± 0.11	2.29 ± 0.10	n.s.
	Ca	2.10 ± 0.067	2.35 ± 0.073	2.63 ± 0.069	3.04 ± 0.072	0.571
	Mg	2.47 ± 0.10	2.42 ± 0.11	2.60 ± 0.12	2.52 ± 0.11	n.s.
	Available form (mg kg^{-1} soil)					
	P	33.7 ± 2.40	47.4 ± 2.60	64.3 ± 2.70	79.52.90	11.5
2014	K	115 ± 9.00	151 ± 9.20	178 ± 10.3	222 ± 11.0	21.4
	Mg	136 ± 6.70	149 ± 6.20	147 ± 6.50	161 ± 6.80	n.s.
pH (pH$_{H2O}$)						
2014		5.58 ± 0.32	5.58 ± 0.34	5.90 ± 0.31	6.28 ± 0.36	n.s.

n.s. – no significant difference; *Standard deviation.

Analysis of the effects produced by the fertilisers shows a notable impact of sewage sludge resulting in increased contents of total potassium in the soil treated with that material at the end of the first year. Like in the case of phosphorus, the soil in which the Albik variety of Jerusalem artichoke was grown had higher total contents of potassium, with a difference of 0.68 g K kg^{-1} soil. At the end of the second year of the experiment there was no difference in the potassium contents in the soil in relation to the treatment with either sewage sludge or wood ash; the concentrations were in the range of 2.24–2.35 g K kg^{-1} soil (Table 3, 4, 5).

Ash from the wood of coniferous trees contained far less magnesium (only 1.14%) than calcium, and incorporation of the material into the soil produced no significant effects on magnesium levels in the soil during the two years of the experiment (Table 3, 4). Like in the case of total phosphorus and potassium in 2013, the soil in which the Albik variety of Jerusalem artichoke was grown contained on average 4.0 g Mg kg^{-1} soil, i.e. significantly more than the soil in which the Gigant variety was cultivated. The different levels of these macroelements in the soil, relative to the variety grown, can be explained by the higher yield of tubers in the case of the Gigant variety.

Application of the fertilisers essentially did not produce a change in the contents of the above macroelements in the soil as they were collected by the growing Jerusalem artichoke.

Table 4. Effect of fertilisation with sewage sludge on the contents of total and available forms of macroelements in the soil

Year	Element	Sludge doses (t ha^{-1})		
		0	30.3	LSD$_{0.05}$
		Total form (g kg^{-1} soil)		
2013	P	1.10 ± 0.096*	1.08 ± 0.092	n.s.
	K	2.98 ± 0.081	3.38 ± 0.090	0.127
	Ca	4.08 ± 0.17	3.49 ± 0.16	n.s.
	Mg	3.71 ± 0.12	3.33 ± 0.11	n.s.
2014	P	0.618 ± 0.72	0.587 ± 0.68	n.s.
	K	2.30 ± 0.11	2.31 ± 0.12	n.s.
	Ca	2.56 ± 0.078	2.50 ± 0.076	n.s.
	Mg	2.54 ± 0.11	2.46 ± 0.11	n.s.
	Available form (mg kg^{-1} soil)			
2014	P	49.6 ± 2.8	62.9 ± 2.6	n.s.
	K	160 ± 9.9	173 ± 10.2	n.s.
	Mg	147 ± 6.3	149 ± 6.2	n.s.
pH (pH$_{H2O}$) 6.2				
2014		5.83 ± 0.30	5.85 ± 0.31	n.s.

n.s. – no significant difference; *Standard deviation.

Owing to the 20% content of calcium in the wood ash, the soil was found with increased overall concentrations of calcium, which were maintained until the end of the experiment. In 2013 the mean concentration of calcium amounted to 3.78 g Ca kg^{-1} of soil, which shows the soil was rich in calcium (Table 3).

It should be noted that a comparative analysis of the data from the two years outlining the concentration of phosphorus, potassium, calcium and magnesium in the soil shows lower levels of these elements in the second year, which would indicate a high uptake of these elements by cultivated Jerusalem artichoke.

Available forms of the macroelements more accurately reflect their availability to plants; therefore the related literature contains far more studies investigating the impact of soil enhancements on changes in soil fertility and the contents of these elements (Kulczycki 2012; Piekarczyk, 2013; Niu & Hao 2017; Stankowski 2018).

The soil from the experiment contained 53.2 mg P kg^{-1} which means it had a moderate content of available phosphorus. The ash applied as a fertiliser contained 0.60% phosphorus, resulting in increase of the concentration of the available form of this macroelement in the soil after the experiment. Application at a dose of 12.8 t ha^{-1} resulted in a content of 79.5 mg P kg^{-1} soil, which represents a high concentration of available phosphorus in the soil (Egner et al., 1960). Cruz-Paredes et al., (2017) grew barley on loamy sand, obtained results showing that application of biomass ash as a fertiliser may be an appropriate strategy for retaining available phosphorus in agricultural soil.

Analysis of the changes in available potassium levels in the soil showed the effects of the ash from coniferous trees incorporated into the soil. At the start of the experiment the content of available potassium amounted to 133 mg K kg^{-1} soil, and at the end the soil from the plots where ash was applied at a rate of 12.8 t ha^{-1} was found with 222 mg K kg^{-1} soil (Table 3). The fact, that the ash from coniferous trees contained 2.34% potassium, as a result of which the soil, initially with a high content of potassium, after the experiment could be classified as soil with a very high concentration of potassium (Egner et al., 1960). Piekarczyk et al. (2011) assessed soil treatment involving the use of ash from rapeseed straw and reported that the material was particularly useful as a potassium fertiliser. Likewise, Saletnik & Puchalski (2019) established that by using wood ash at an adequately selected dose, it is possible to enhance the chemical characteristics of the soil, including its pH and the contents of available forms of macroelements.

Prior to the experiment, the soil was found to have available magnesium amounting to 124.0 mg Mg kg^{-1} of soil. Despite the fact that the ash from coniferous trees contained 1.14% magnesium, after two years of the experiment no effect of the fertiliser was identified in the contents of the available form of this macroelement in the soil (Table 3).

No significant effects on soil pH or contents of available forms of the above macroelements in the soil were produced in the experiment by fertilisation with sewage sludge or by the variety of Jerusalem artichoke grown (Table 4, 5). The ash from coniferous trees applied in the experiment was characterised by a pH of 9.5. This resulted in alkalisation of the soil treated with ash, proportionate to the dose of ash applied; the effect was maintained after the experiment ended (Table 3). Using a dose of 12.8 t ha^{-1} a soil pH of 6.28 was obtained, which classifies it as slightly acidic soil (ISO 10390: 1997P). The increase in soil richness in potassium and its alkalization as a result of using wood ash is a topic of research in many countries (Pels et al., 2005; Gibczyńska et al., 2007; Shen et al., 2008).

Table 5. Effect of Jerusalem artichoke cultivation on the contents of total and available forms of macroelements in the soil

Year	Element	Variety		
		Gigant	Albik	$LSD_{0.05}$
		Total form (g kg^{-1} soil)		
2013	P	1.00 ± 0.078	1.18 ± 0.076	0.142
	K	2.84 ± 0.081	3.52 ± 0.093	0.408
	Ca	3.63 ± 0.17	3.94 ± 0.18	n.s.
	Mg	3.02 ± 0.11	4.02 ± 0.14	0.412
2014	P	0.618 ± 0.70	0.5880.64	n.s.
	K	2.27 ± 0.078	2.34 ± 0.068	n.s.
	Ca	2.54 ± 0.15	2.52 ± 0.13	n.s.
	Mg	2.48 ± 0.10	2.52 ± 0.11	n.s.
	Available form (mg kg^{-1} soil)			
2014	P	54.0 ± 3.0	58.4 ± 2.9	n.s.
	K	162 ± 8.1	172 ± 7.3	n.s.
	Mg	145 ± 6.3	151 ± 6.6	n.s.
Reaction (pH)				
2014		5.77 ± 0.32	5.91 ± 0.32	n.s.

n.s. – no significant difference; *Standard deviation.

Microelements in the soil

The Ordinance of the Minister of Environment on soil quality standards and land quality standards specifies limit values for the discussed five metals (Cd, Pb, Ni, Zn, Cu) (Journal of Laws 2002 no. 165 item 1359). Cadmium is not a biologically required element. The threshold value in the case of cadmium defined as 4 mg Cd kg^{-1} of soil, (Journal of Laws 2002 nr 165 item 1359), is higher than the level of this element found in the soil at the start of the experiment. The relatively high content of cadmium (11.6 mg Cd kg^{-1}) in the ash resulted in a significant increase in cadmium levels in the soil in the plots treated with ash at the highest dose; in the consecutive years the levels amounted to 1.85 and 0.480 mg Cd kg^{-1} of soil (Table 6). Indeed, it has most frequently been reported that fertilisation with wood ash leads to an increase in cadmium concentrations in soil. Füzesi et al., (2015) investigated the combined effect of wood ash and ryegrass or mustard cultivation on soil composition and reported that cadmium was the only heavy metal whose concentrations were slightly increased. Faridullah et al., (2017), based on an experiment carried out in two types of soil, reported that charcoal introduced into the soil acted as an adsorbent and effectively reduced cadmium leachability in soil.

It is known that lead is easily absorbed by plants and accumulated in their tissues. The natural soil in which the experiment took place contained 21.5 mg Pb kg^{-1} soil. The ash from coniferous trees and the sewage sludge applied in the experiment were found with lead contents of 13.1 and 42.7 mg Pb kg^{-1}, respectively (Table 6). The findings of the experiment showed an increase in lead contents produced by all the three factors taken into account, but only in the first year of the experiment. However, the limit value defined as 100 mg Pb kg^{-1} of soil (Journal of Laws 2002 no. 165 item 1359) was not exceeded. In the second year there was a decrease in the content of lead in the soil, compared to the initial value.

Table 6. Effect of fertilisation with biomass ash in the contents of microelements in the soil

Year	Element	Ash dosage (t ha^{-1})				
		0	4.3	8.6	12.8	LSD$_{0.05}$
		mg kg^{-1} soil				
2013	Cd	1.29 ± 0.043*	1.35 ± 0.045	1.36 ± 0.046	1.85 ± 0.047	0.064
	Pb	19.1 ± 1.2	22.7 ± 1.3	21.0 ± 1.2	23.3 ± 1.2	1.069
	Ni	17.9 ± 0.82	18.7 ± 0.87	16.8 ± 0.78	17.5 ± 0.80	n.s.
	Zn	64.5 ± 3.3	67.7 ± 3.4	69.4 ± 3.3	58.0 ± 3.5	n.s.
	Cu	15.91.0	16.0 ± 1.1	15.9 ± 0.9	15.8 ± 1.1	n.s.
2014	Cd	0.411 ± 0.026	0.443 ± 0.028	0.462 ± 0.027	0.480 ± 0.021	0.039
	Pb	12.9 ± 1.2	13.7 ± 1.0	13.3 ± 1.2	12.9 ± 1.1	n.s.
	Ni	13.3 ± 0.72	13.3 ± 0.76	14.3 ± 0.81	14.3 ± 0.80	n.s.
	Zn	50.7 ± 3.5	50.4 ± 3.3	53.7 ± 3.2	49.8 ± 3.0	n.s.
	Cu	14.9 ± 1.1	15.0 ± 1.2	15.8 ± 1.1	15.4 ± 1.4	n.s.

n.s. – no significant difference; *Standard deviation.

Table 7. Effects of fertilisation with sewage sludge and Jerusalem artichoke variety on the contents of general and available forms of microelements in the soil

Year	Element	Sludge dosage (t ha^{-1})			Varieties		
		0	30.3	LSD$_{0.05}$	Gigant	Albik	LSD$_{0.05}$
		mg kg^{-1} soil					
2013	Cd	1.28 ± 0.048*	1.59 ± 0.050	n.s.	1.47 ± 0.047	1.51 ± 0.05	n.s.
	Pb	20.0 ± 1.2	23.0 ± 1.2	1.32	20.5 ± 1.2	22.5 ± 1.2	0.24
	Ni	17.6 ± 0.78	17.9 ± 0.76	n.s.	15.8 ± 0.80	19.7 ± 0.78	1.64
	Zn	64.7 ± 3.4	65.2 ± 3.3	n.s.	64.1 ± 3.5	65.7 ± 3.5	n.s.
	Cu	16.1 ± 1.2	15.7 ± 1.3	n.s.	15.8 ± 1.3	16.0 ± 1.4	n.s.
2014	Cd	0.460 ± 0.26	0.439 ± 0.22	n.s.	0.450 ± 0.23	0.449 ± 0.21	n.s.
	Pb	13.2 ± 0.98	13.3 ± 0.96	n.s.	13.3 ± 0.90	13.1 ± 0.93	n.s.
	Ni	14.1 ± 0.76	13.5 ± 0.73	n.s.	13.7 ± 0.74	13.9 ± 0.72	n.s.
	Zn	51.4 ± 3.1	50.8 ± 3.0	n.s.	52.7 ± 3.1	49.6 ± 3.2	n.s.
	Cu	15.5 ± 1.1	15.0 ± 1.2	n.s.	15.2 ± 1.2	15.3 ± 1.1	n.s.

n.s. – no significant difference; *Standard deviation.

Nickel plays an important role in regulating the processes in which free nitrogen is assimilated by soil bacteria. The maximum levels of nickel in the soil from the experiment amounted to 19.7 Ni mg kg^{-1} soil in 2013, and to 14.7 mg Ni kg^{-1} soil in 2014 (Table 6, 7). The permissible maximum content of nickel in heavy soils is defined as

100 mg Ni kg^{-1} soil (Journal of Laws 2002 no. 165 item 1359), while the levels in the soil from the experiment were much lower.

Generally, zinc contents in heavy soils are in the range of 35–75 mg Zn kg^{-1} soil (Kabata-Pendias 2011). In the experiment, the contents of zinc in the soil were in a narrower range, from 49.6 to 69.4 mg Zn kg^{-1}, and did not exceed the values typically observed in soils in Poland (Table 6 and 7).

The permissible concentration of copper in heavy soils amounts to 150 mg Cu·kg^{-1} of soil (Journal of Laws 2002 no. 165 item 1359). Throughout the duration of the experiment, copper levels in the soil were ten times lower, amounting to 15 mg Cu kg^{-1}.

While analysing the effects of the factors taken into account in the experiment it should be emphasised that the microelements were very stable in the soil. The three factors, i.e. fertilisation with ash from coniferous trees, or with sewage sludge, as well as the different varieties of Jerusalem artichoke grown in the experiment, did not produce a significant change in the concentrations of the three microelements: nickel, zinc and copper, in the soils. Besides the chemical contents of the fertilisers, the above analogy may be explained by the fact that these elements are located in the same period and they occur in the second oxidation state.

A comparison of the data collected during the two years, i.e. the levels of the five microelements in the soil, shows their lower concentrations in the second year, which may suggest that these elements are absorbed in large quantities by growing Jerusalem artichoke, and this is a similar trend to that observed in the case of the macroelements.

CONCLUSIONS

1. Application of the fertilisers essentially did not produce a change in the total contents of phosphorus, potassium and magnesium in the soil examined after Jerusalem artichoke was harvested.
2. Application of ash from coniferous trees, with high levels of calcium, resulted in increased total contents of calcium in the soil. The soil can be classified as rich in this macroelement.
3. The lower contents of the relevant macroelements and microelements in the soil in the second year of the experiment may reflect the fact that growing Jerusalem artichoke absorbs these elements in large quantities.
4. Out of the three factors in question, only fertilisation with ash from coniferous trees produced a significant increase in the concentration of available phosphorus and potassium in the soil.
5. Fertilisation of the soil with ash from coniferous trees or with sewage sludge, as well as cultivation of different varieties of Jerusalem artichoke, resulted in a significant increase in the concentrations of cadmium and lead, and produced no effects in the levels of nickel, zinc and copper identified in the soil.
6. The above findings, and in particular the fact that the limit values were not exceeded, indicate the possibility of using both sludge and biomass ash for fertilizing Jerusalem artichoke.

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