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The effect of ash and compost on the content and bioaccumulation of selected heavy metals

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Therefore the carried out study aimed at determination of the effect of high-calcium brown coal ash and compost being produced from municipal sewage sludge on the content and bioaccumulation of heavy metals in potato tubers, wheat grains and rapeseeds during a three-year period. Rapeseeds contained most Cd whereas wheat rains less. Potato tubers, wheat grains and rapeseeds contained more Mn, Ni and Zn in the fertilization objects with municipal sewage sludge with or without coal ash and compared to those where calcium carbonate or coal ash had been introduced into the soil at a dose corresponding to 1.5 Mg CaO · ha^{-1} at the beginning of this study. Differences in the Mn, Ni and Zn contents in test plants between the fertilization objects with sewage sludge of with and without addition of ash were not significant.

Keywords: ash, compost, heavy metals, bioaccumulation, test plants.

INTRODUCTION

In recent years, Poland has seen an increase in prices of mineral fertilizers, while liming of arable land has been neglected. Changes have occurred in the crop structure which was beneficial for in favor of cereals and industrial crops. Ultimately, it leads to the imbalance in organic matter and nutrients in soils. Taking this situation into consideration, multidirectional research was conducted on the acquisition of environmentally friendly sources of organic matter and nutrients for plants.

During combustion of brown coal, process wastes are produced in the form of boiler slag, bottom ash and fly ash[1, 2]. In Poland, the amount of high-calcium ash that was produced in the process of brown coal combustion is estimated to equal 4.5 million tons per year[3].

High-calcium brown coal ash from the combustion process is characterized by different chemical composition. The alkaline reaction of brown coal fly ash and a considerable content of calcium and magnesium oxides in it has been shown in the studies[4, 5]. Moreover, high-calcium brown coal ash contains in addition: As, Ba, Cd, Cr, Cu, Mn, Mo, Pb, Se, Sr, Zn and other microelements. Municipal sewage sludge may be intended for fertilization purposes as it contains large amounts of organic matter. A factor limiting the direct use of municipal sewage sludge for fertilization purposes may be excessively caused by some heavy metals and polycyclic aromatic hydrocarbons (PAH), contamination with pathogenic microorganisms (*Salmonella* and others) and alimentary tractparasites[6–9].

As a rule, combustion ash (waste) contains a smaller quantity of heavy metals than municipal sewage sludge[10]. In ash-sludge mixtures, the pH values increases together with the increase of ash percentage. The reaction corresponding to pH 10-11contributes to a decrease in solubility of heavy metals[11]. Combustion ash is characterized by poor gravity drainage capacity and alkaline reaction and therefore may be used for the fixation of heavy metals being found in sewage sludge or composts produced from them and the same mat limit their availability to plants[12].

The study aimed at the determination of the effect of high-calcium brown coal ash and compost being produced from municipal sewage sludge by the GWDA method on the content and bioaccumulation of heavy metals in potato tubers, wheat grains, and rapeseeds during field experiment in a three-year period.

MATERIAL AND METHODS

In 2008–2010, a single-factor field experiment was carried out at the Cultivar Evaluation Stationin Szczecin--Dąbie. The soil on which this experiment was set up had been formed from light loamy sand (lls). With regard to its granulometric composition, it is classified into the category of light soils, of soil quality class IV b and good rye complex (5). The field experiment was composed of 6 fertilization objects. Examinations were carried out on 33 m^2 plots, in four replications per each experimental object. In this field experiment, a crop rotation was applied according to the following pattern: potatoes of the cultivar *Jasia* in 2008, spring wheat of the cultivar *Griva* in 2009, and winter rapeseed of the cultivar *Bazyl* in 2010. The best fertilization effects were obtained in the system with municipal sewage sludge compost being applied at a dose corresponding to 250 kg · ha^{-1}N as well as with coal ash at a dose corresponding to 1.5 Mg CaO · ha^{-1} being introduced into soil in the first year of study and at a dose corresponding to 0.75 Mg CaO·ha^{-1} in successive years. After introducing the compost with municipal sewage sludge, calcium carbonate and coal ash into the soil in spring 2008, the following mineral fertilization was applied:

– a multi-component fertilizer SuproFoska 20 was introduced into the soil at a dose of 400 kg · ha^{-1} 5.05.2008 (in the first year of experiment) prior to potatoes plantation. This dose corresponded to 28 kg · ha^{-1} P and 66.4 kg · ha^{-1} K. As far as nitrogen fertilizers are concerned, ammonium nitrate was introduced into the soil at a dose corresponding to 82 kg N. Three days later potatoes were planted. During the second ridging, 34 kg $\cdot ha^{-1}$ N was introduced into the soil as top-dressing in the form of ammonium nitrate. The harvest of potato tubers was performed on 03.10.2008. In the fertilization objects with annual application of coal ash (0.75 Mg CaO $\cdot$ ha^{-1}), it was introduced into the soil on 15.10. 2008 under spring wheat which was sowed in spring 2009;

– II year of the experiment, on 01.04.2009 a multi-component fertilizer Suprofos 25 was introduced into the soil at a dose of 400 kg $\cdot$ ha^{-1} prior to sowing spring wheat. On the same day, 150 kg $\cdot$ ha^{-1} of ammonium nitrate was introduced into the soil and on 03.04.2009 spring wheat was sowed. In the period of time between the shooting stage and the earring stage, a top dres sing fertilization was additionally applied in the form of ammonium nitrate at a dose corresponding to 34 kg N. The harvest of spring wheat grains was performed on 14.08.2009. On 16–25.08.2009 cultivation measures were performed, coal ash was introduced into the soil in the fertilization objects (0.75 Mg CaO $\cdot$ ha^{-1}) where it was applied each year, and 800 kg $\cdot ha^{-1}$ of multi-component fertilizer SuproFoska 20 was sowed and then the winter rapeseeds were sown; nitrogen fertilization was introduced into the soil as top-dressing in a dose 50 kg $\cdot$ ha^{-1}N, 26.03and 16.04 in the third year of experiment (2010) in the form of ammonium nitrate. The harvest of winter rapeseeds was performed on 25.07.2010.

After reaching maturity, tested plants, were harvested every year and yield was expressed in t $\cdot$ ha^{-1}. Average samples for each fertilization object were prepared from samples of tested plants. These average samples were used for determination of content of heavy metals. The heavy metal content of the test plants in the following years was determined in the medium samples for four replications of each fertilizers. The content of Cd, Cu, Mn, Ni, Pb and Zn was determined by atomic absorption spectrometry using a Perkin Elmer AAS 300 spectrometer. In compost, ash and the soil before the foundation experience, the contents of macroelement and heavy metals. N, Corg and S contents were determined on a Coestech CNS elemental analyzer, total K content by the method of flame photometry, and total Mg content by the method of atomic absorption spectrometry (AAS 300) and P content according to the Polish standard PN-98/C-04537-14. The stock solution was obtained after mineralization of compost, ash and soil according to standards PN–ISO 11466 and PN-ISO 11047, while soil pH value was determined by potentiometry in 1 mol $\cdot$ dm^{-3} KCl (PN-75/C-04540/05/01).

The study results were processed statistically by the analysis of variance in accordance with Statistica 8.0 PL computer software. In the case of significant differences, the Tukey's test was used at the significance level $p = 0.05$.

Bioaccumulation factors in test plants for heavy metals were calculated as a ratio of the content of a given chemical element to the doses introduced into the soil with municipal sewage sludge compost and coal ash[13]. A four-point scale was adopted when evaluating the bioaccumulation factors of Zn, Pb, Ni, Mn, Cd and Cu in the test plant[14]. The degree of accumulation was determined as: intense, average, poor and none, whereas the corresponding values of bioaccumulation factors are 1.0 to 10.0; 0.1 to 1.0; 0.1 to 0.01 and 0.001 to 0.01, respectively.

RESULTS AND DISCUSSION

The chemical characteristics of as well as that of municipal sewage sludge compost being produced by the GWDA method at the Municipal Sewage Treatment Plant in Stargard, coal ash coming from the Pątnów-Adamów-Konin Power Plant Complex and being used for soil fertilization, and soil before setting up this experiment, was published in the paper by Krzywy-Gawrońska[15] (and now E. Możdżer), (Table 1, 2). Due to long descriptions of fertilization objects, acronyms were adopted for municipal Sewage Sludge Compost (SSC) and Brown Coal Ash (BCA) that were subsequently used in the discussion of research results. High content of calcium in the ash used in experiment allowed it to be classified into the group of high-calcium ashes. The total content of Cd, Mn, Cr, Zn, and Ni in the examined high-calcium ash used in experiment was higher than in municipal SSC. However, the total content of Cu and Pb was higher in compost with municipal sewage sludge when compared to high-calcium BCA. Taking into consideration the standards referring to the contents of heavy metals in fertilizers for soil de-acidification[16], high-calcium BCA may be included among the factors affecting soil deacidification without negative environmental impact. Heavy metals are absorbed by plants passively, actively or by using both these methods. Their presence in plants depends mainly

Table 1. The pH value and the content of dry matter, organic carbon, macroelements and heavy metals in municipal sewage sludge compost and brown coal ash

pH	Total content in g $\cdot$ kg^{-1}d.m.							Total content in mg $\cdot$ kg^{-1}d.m.						
	dry matter	N	P	K	Ca	Mg	Corg.	Cd	Cu	Mn	Ni	Pb	Zn	Cr
Compost with municipal sewage sludge (SSC)														
pH H_2O 8.50	340	18.0	10.2	3.58	7.0	1.0	286	1.05	47.0	259	8.61	54	140	15.5
High-calcium brown coal ash (BCA)														
pHKCl 11.0	986	lack	2.52	5.50	145	12.5	lack	2.77	27.6	265	12.6	16.2	231	20.6

Table 2. Total content of the total macroelements and heavy metals in the soil before the foundation experience

pH_{KCl}	$C_{org.}$	Total content g $\cdot$ kg^{-1}d.m.						Total content mg $\cdot$ kg^{-1} d.m.					
		N	P	K	Ca	Mg	S	Cd	Cu	Mn	Ni	Pb	Zn
5.3	8.50	0.72	0.45	0.62	0.78	0.62	0.08	0.22	9.50	205	9.50	19.2	24.0

on their soil concentration, plant species, developmental stage and plant part[17–18]. The natural content of heavy metals did not induce any negative impact on the yield quality. Potato absorbs, among other, 60–70 mg Cu, 450–500 mg Zn and 700–750 mg Mn when producing 40 Mg · ha^{-1} of tubers[19]. In the first year of experiment, the content of heavy metals in potato tubers, wheat grains, and rapeseeds differed and depended on the fertilization being applied.

Winter rapeseeds contained most Cd, from 0.06 to 0.08 mg·kg^{-1}d.m. Less Cd was found in spring wheat grains, from 0.04 to 0.06 mg · kg^{-1} d.m. and in potato tubers, from 0.03 to 0.05 mg · kg^{-1}d.m. Differences in the Cd content in potato tubers, spring wheat grains, and winter rapeseeds between respective experimental objects were not significant (Table 3). The content of Cu in potato tubers ranged from 5.65 to 6.05 mg · kg^{-1}d.m. Differences in its content in potato tubers between respective experimental objects were not significant. The highest Cu content was characteristic of spring wheat grains from the fertilization objects with municipal SSC, being introduced into the soil at a dose corresponding to 250 kg N · ha^{-1} without and with addition of high-calcium BCA applied at the beginning of the experiment and each year, i.e. from 5.09 to 5.11 mg Cu · kg^{-1} d.m. (objects C, D and F). Differences in the Cu content in test plant grains between the objects mentioned above (objects C, D and F) were not significant. Spring wheat grains in the fertilization objects C, D and F contained significantly more Cu when compared to that with calcium carbonate and high-calcium BCA being applied at a dose corresponding to 1.5 Mg CaO · ha^{-1} (objects A, B). Differences in the Cu content in spring wheat grains from fertilization objects A, B and E were not significant. The highest Cu content was characteristic of rapeseeds from the fertilization objects with municipal SSC and with annual application of high-calcium BCA, at a level of 3.36 mg · kg^{-1} d.m. Least Cu contained by rapeseeds 2.75 mg · kg^{-1} d.m. from the fertilization object with calcium carbonate being introduced into the soil at a dose corresponding to 1.5 Mg CaO · ha^{-1} (object A). No significant differences in the Cu content in rapeseeds were found. More Mn contained potato tubers, wheat grains and rapeseeds from the fertilization objects with municipal SSC with and without the addition of high-calcium BCA when compared to those where calcium carbonate or high-calcium BCA had been introduced into the soil at the beginning of this study at a dose corresponding to 1.5 Mg CaO · ha^{-1}.

Content in these fertilization objects fluctuated from 22.5 to 22.8 mg · kg^{-1}d.m. Difference in the Mn content in potato tubers, wheat grains, and rapeseeds between the fertilization objects with municipal SSC with and without the addition of high-calcium BCA were not significant. Nevertheless, an average increase in the Mn content was observed in potato tubers (by 9.40%), wheat grains (by 22.4%) and rapeseeds (by 18.2%) between fertilization objects C, D, E and object A. High-calcium BCA that was introduced into the soil at the beginning of this study and each year (objects A, E) induced a significant increase in the Mn content only in rapeseeds when compared to the object with calcium carbonate (object A). Differences in the Mn content in potato tubers and wheat grains between these fertiliza-

Table 3. Cd, Cu, Mn, Ni, Pb and Zn contents in the test plants cultivated under crop rotation

Chemical element	Plant	Fertilisationobjetcs						LSD 0.05
		A*	B	C	D	E	F	
		Total content (mg · kg^{-1})						
Cd	Potato	0.03	0.04	0.05	0.05	0.04	0.05	ns
	Wheat	0.04	0.04	0.06	0.06	0.04	0.06	ns
	Rape	0.06	0.06	0.08	0.08	0.06	0.08	ns
mean		**0.04**	**0.05**	**0.06**	**0.06**	**0.05**	**0.06**	**ns**
Cu	Potato	5.65	5.75	5.98	6.05	5.80	6.02	ns
	Wheat	4.55	4.58	5.08	5.06	4.65	5.11	0.46
	Rape	2.75	3.02	3.26	3.28	3.15	3.36	0.06
mean		**4.32**	**4.45**	**4.77**	**4.79**	**4.53**	**4.83**	**0.05**
Mn	Potato	20.6	20.8	22.5	22.3	20.5	22.8	1.77
	Wheat	20.1	20.5	24.8	24.4	20.6	24.6	3.78
	Rape	22.0	23.6	25.7	25.8	24.0	26.5	0.87
mean		**20.9**	**21.6**	**24.3**	**24.2**	**21.7**	**24.6**	**0.14**
Ni	Potato	1.15	1.20	1.30	1.32	1.17	1.32	ns
	Wheat	0.23	0.23	0.29	0.31	0.23	0.30	0.10
	Rape	2.00	2.01	2.99	3.01	2.06	3.10	0.20
mean		**1.12**	**1.14**	**1.53**	**1.55**	**1.15**	**1.58**	**0.02**
Pb	Potato	2.02	2.15	2.65	2.55	2.13	2.52	0.32
	Wheat	0.48	0.49	0.58	0.59	0.45	0.57	0.12
	Rape	1.15	1.20	1.65	1.62	1.25	1.62	0.13
mean		**1.27**	**1.28**	**1.63**	**1.59**	**1.28**	**1.57**	**0.01**
Zn	Potato	17.4	17.5	19.8	19.9	17.4	19.8	2.75
	Wheat	26.3	26.0	30.5	30.1	27.4	30.8	ns
	Rape	28.4	29.5	32.1	32.8	30.0	33.5	1.06
mean		**24.0**	**24.3**	**27.4**	**27.6**	**24.9**	**28.0**	**0.12**

*Description of fertilization objects: A – Carbonate lime ($CaCO_3$) at a dose corresponding to 1.5 Mg CaO · ha^{-1}, B – High-calcium brown coal ash at a dose corresponding to 1.5 Mg CaO · ha^{-1}, C – Municipal sewage sludge compost at a dose corresponding to 250 kg N · ha^{-1}N, D – Municipal sewage sludge compost at a dose corresponding to 250 kg N · ha^{-1} + high-calcium brown coal ash at a dose corresponding to 1.5 Mg CaO · ha^{-1} in the first year of experiment, E – High-calcium brown coal ash at a dose corresponding to 1.5 Mg CaO · ha^{-1} in the first year of experiment, with 0.75 Mg CaO · ha^{-1} in next years each, F – Municipal sewage sludge compost at a dose corresponding to 250 kg N · ha^{-1} + high- calcium brown coal ash at a dose corresponding to 1.5 Mg CaO · ha^{-1} in the first year of experiment, with 0.75 Mg CaO · ha^{-1} in next years each tion objects were not significant. More Ni was contained in potato tubers, wheat grains, and rapeseeds from the fertilization objects with municipal SSC with and without the addition of high-calcium BCA when compared to those in which calcium carbonate or high-calcium BCA had been applied at a dose corresponding to 1.5 Mg CaO · ha^{-1}. No significant differences in the Ni content were found in potato tubers between respective fertilization objects (Table 4). Despite the lack of significant differences in the Ni content, its average increase was found in potato tubers (by 11.5%). Significantly more Ni contained wheat grains and rapeseeds from the fertilization objects with municipal SSC with and without the addition of high-calcium BCA when compared to those in which calcium carbonate or high-calcium BCA had been applied (Table 3). More Pb was contained in potato tubers, wheat grains, and rapeseeds from the objects with municipal SSC without and with addition of high-calcium BCA (objects C, D, F) when compared to those in which calcium carbonate or high-calcium BCA had been introduced into the soil. One hand, differences in the Pb content in test plants between these groups of fertilization objects were significant. On the other hand, no significant differences in the Pb content were found in test plants between municipal SSC with and without the addition of high-calcium BCA. An average increase in the Pb content in test plants in the fertilization object with high-calcium BCA amounted to 0.78% when compared to that with exclusive calcium carbonate fertilization. The Zn content in potato tubers, wheat grains, and rapeseeds in the objects with municipal SSC with and without the addition of high-calcium BCA (objects C, D, E) was higher in the content of objects in which calcium carbonate or high-calcium BCA had been introduced into the soil (objects A, B). The one hand, differences in the Zn content in potato tubers and rapeseeds between the fertilization objects mentioned above were significant. On the other hand, differences in the Zn content in spring wheat grains between respective fertilization objects of this experiment were not significant. Nevertheless, an average increase of the zinc content was found in wheat grains, of by 16.6%, between fertilization objects C, D, F and objects A and B. No significant difference in the Zn content was found in potato tubers between fertilization objects A, B and E. To sum up, it is possible to state that most heavy metals in potato tubers, wheat grains, and rapeseeds were found after the application of municipal SSC with or without the addition of high-calcium BCA (objects C, D, F). A difference between the maximum and the minimum contents of heavy metals in potato

Table 4. Bioaccumulation index of heavy metals in potato tubers, wheat grains, and rapeseeds as affected by municipal sewage sludge compost and high-calcium brown coal ash

Fertilization objects	Chemical element					
	Cd	Cu	Mn	Ni	Pb	Zn
potato tubers						
B	0.009 none	0.138 average	0.052 poor	0.063 poor	0.089 poor	0.050 poor
C	0.190 average	0.508 average	0.347 average	0.604 average	0.196 average	0.565 average
D	0.011 poor	0.113 average	0.048 poor	0.062 poor	0.067 poor	0.052 poor
E	0.006 none	0.102 average	0.034 poor	0.041 poor	0.058 poor	0.033 poor
F	0.007 none	0.081 poor	0.035 poor	0.044 poor	0.050 poor	0.035 poor
Mean value	**0.044 poor**	**0.186 average**	**0.103 average**	**0.162 average**	**0.092 poor**	**0.147 average**
Wheat grains						
B	0.010 none	0.110 average	0.050 poor	0.012 poor	0.020 poor	0.070 poor
C	0.229 average	0.432 average	0.383 average	0.134 average	0.042 poor	0.871 average
D	0.013 poor	0.095 poor	0.052 poor	0.014 poor	0.015 poor	0.078 poor
E	0.006 none	0.074 poor	0.037 poor	0.008 none	0.012 poor	0.052 poor
F	0.009 none	0.069 poor	0.032 poor	0.010 poor	0.011 poor	0.055 poor
Mean value	**0.053 poor**	**0.156 average**	**0.111 average**	**0.035 poor**	**0.020 poor**	**0.226 average**
Rape seeds						
B	0.014 poor	0.073 poor	0.059 poor	0.106 average	0.049 poor	0.085 poor
C	0.305 average	0.277 average	0.387 average	1.390 intense	0.042 average	0.871 average
D	0.018 poor	0.061 poor	0.056 poor	0.143 average	0.043 poor	0.086 poor
E	0.009 none	0.051 poor	0.040 poor	0.073 none	0.035 poor	0.057 poor
F	0.012 none	0.046 poor	0.041 poor	0.102 average	0.032 poor	0.060 poor
Mean value	**0.072 poor**	**0.102 average**	**0.119 average**	**0.363 average**	**0.060 poor**	**0.241 average**

* Description of fertilization objects is given in Table 3

tubers in this experiment amounted to 66.7% for Cd,7.1% for Cu, 10.7% for Mn, 14.8% for Ni, 31.2% for Pb and 14.4% for Zn, while that in wheat grains amounted to 50%; 12.3%; 22.4%; 30.4%; 31.1% and 18.5% and in rapeseeds to 33.3%; 22.2%, 20.4%; 55.0%; 28.3% and 16.7%, respectively.

The test plants fertilized with municipal SSC and high-calcium BCA which was applied each year, followed by municipal SSC with and without the addition of high-calcium BCA, contained more heavy metals than those from the fertilization objects with calcium carbonate and high-calcium BCA. The content of heavy metals in test plants did not exceed the acceptable standards that do not induce their contamination. An increase in the content of heavy metals in plants after the application of municipal SSC was also observed[20–22]. The composts in which sewage sludge is the main component, may induce an increased accumulation of heavy metals in plants. According to the data published the composts in which sewage sludge is the main component, may induce an increased accumulation of heavy metals in plants[23]. High-calcium ash from the Pątnów-Adamów-Konin Power Plant Complex being applied to light soil of good rye complex do not induce changes in the chemical composition and the sowing value of wheat grains[24]. However, in the opinion of Gibczyńska et al.[25] the application of high-calcium ash induces an increase in the amount of Mn (about 25% in relation to the control object A) in spring triticale grains. In these studies, no significant differences were found in the effects of traditional calcium fertilizers and high-calcium ash on the yield quality of triticale and wheat. The application of mineral and organic fertilizers is meant to increase the yield of crop plants. Mineral fertilizers usually have an effect in the period of one year, whereas organic fertilizers need much longer time, lasting even few years.

Potato tubers, wheat grains, and rapeseeds did not contain excessive amounts of Cd, Cu, Mn, Ni, Pb and Zn because they had not been introduced into the soil in considerable quantities with municipal SSC and high-calcium BCA, while the soil itself did not contain their excess amounts. When evaluating the use fulness of potato tubers, wheat grains, and rapeseeds for utilization of heavy metals from the compost produced from municipal sewage sludge and high-calcium BCA, bioaccumulation indices for Cd, Cu, Mn, Ni, Pb and Zn were calculated.

The degree of bioaccumulation of the chemical elements under analysis in potato tubers, wheat grains, and rapeseeds differed, depending on the fertilization applied. When calculating the bioaccumulation index, fertilization object A was ignored, where no municipal SSC or high-calcium BCA had been applied (Table 4). The degree of Cd, Cu, Mn, Ni, Pb and Zn accumulation in potato tubers in the first years of this study was average in the fertilization object with municipal SSC being applied at a dose corresponding to 250 kg $\cdot$ ha^{-1} N (Table 4). The objects with high-calcium BCA which were introduced into the soil (objects B, E), were characterized by poor accumulation degree in case of Mn, Ni, Pb average one for Cu and the lack of bioaccumulation for Cd.

The average degree of accumulation in potato tubers characterized copper (0.103) in the object of municipal SSC introduced into the soil with high-calcium BCA (object D),whereas other heavy metals reached a poor degree. In the object of municipal SSC introduced into the soil at a dose corresponding to 250 kg N $\cdot$ ha^{-1} and high-calcium BCA at a dose corresponding to 1.5 Mg CaO $\cdot$ ha^{-1} (object F), the degree of accumulation in potato tubers for all examined chemical elements was poor, while there was a lack of Cd accumulation.

Zn, Pb, Mn and Ni bioaccumulation in wheat grains in the object with high-calcium BCA introduced into the soil at a dose corresponding to 1.5 Mg CaO $\cdot$ ha^{-1} was poor, while that of Cu was at the average level. The municipal SSC applied at a dose corresponding to 250 kg N $\cdot$ ha^{-1} induced an average degree of Mn, Ni, Cd, Zn and Cu bioaccumulation, while in the case of Pb a poor. In the objects with municipal SSC introduced into the soil with addition of high-calcium BCA (objects D and F), the degree of Cu, Mn, Ni, Pb and Zn bioaccumulation in wheat grains was poor, while there was no Cd accumulation. Whereas, in the objects with high-calcium BCA applied at a dose corresponding to 1.5 Mg CaO $\cdot$ ha^{-1} in the first year of this study and to 0.75 Mg CaO $\cdot$ ha^{-1} in the second year (object F), the degree of Cu, Mn, Pb and Zn bioaccumulation in wheat grains was poor, while there was lack in Cd and Ni bioaccumulation. The degree of Cd, Cu, Mn, Zn and Pb accumulation in rapeseeds was poor, while that of Ni was average in the objects with exclusive introduction of high-calcium BCA into the soil at a dose corresponding to 1.5 Mg CaO $\cdot$ ha^{-1} (object B) and municipal SSC being applied with the addition of high-calcium BCA (object D). An intense degree of accumulation in rapeseeds characterized Ni in the object with municipal SSC introduced into the soil at a dose corresponding to 250 kg N $\cdot$ ha^{-1} (object C), whereas other heavy metals reached an average degree (Table 4).

In the object with high-calcium BCA introduced into the soil (object E), a poor degree of accumulation in rapeseeds was observed in case of Zn, Mn, Cu, Ni and Pb while there was a lack Cd bioaccumulation. When it comes to the degree of Ni accumulation in rapeseeds, it was average and amounted. On the basis of the above up, it was found that the higher content of a given heavy metal introduced into the soil with municipal SSC with and without the addition of high-calcium BCA was the smaller bioaccumulation index in the test plants. After three years of study, the degree of heavy metals accumulation in potato tubers, wheat grains, and rapeseeds remained at a poor and an average level. The studies conducted by Baran et al. and Flus-Bujak et al. show that the complexing properties increase in the soil beding fertilized with composts, produced with municipal sewage sludge through which stable metal-organic combinations are being formed that limit the availability of heavy metals to, plants which finds ist confirmation in the experiment being just performed[26–27]. The reason of an average bioaccumulation of heavy metals in test plants was alkaline reaction of municipal SSC (pH 8.50) and high-calcium BCA (pHKCL 11.0), which influenced a weak mobility of these chemical elements and their low sorption.

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