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INFLUENCE OF ALKALIZATION AND COMPOSTING PROCESS OF SEWAGE SLUDGE ON CADMIUM AND NICKEL CONTENT IN PLANTS AND SOIL

WPŁYW SPOSOBU ALKALIZACJI I KOMPOSTOWANIA OSADÓW ŚCIEKOWYCH NA ZAWARTOŚĆ KADMU I NIKLU W ROŚLINACH TESTOWYCH I GLEBIE

Abstract: The influence of fertilization using fresh and composted sewage sludge (from Siedlce and Lukow), manure, as well as their mixtures with calcium oxide and brown coal ash on cadmium and nickel contents in test plants and soil was evaluated in three-year pot experiment. Cadmium and nickel contents at plants treated with sludge with CaO addition were lower than at plants fertilized with sludge without additives. Contents of studied metals in maize and sunflower amended with sludge-ash mixtures most often were lower than in plants treated with sludge without additives and higher than after applying their mixtures with CaO. Composting the sewage sludge and its mixtures with calcium oxide and brown coal ash most often did not significantly affect the cadmium and nickel contents in test plants. Cadmium and nickel levels increased the most in soils of objects fertilized with mixtures of sludge with brown coal ash. Increase of these heavy metals contents in soil after only sludge application and its mixtures with CaO was similar.

Keywords: sewage sludge, composting process, ash, cadmium, nickel

Introducing the waste materials abundant in organic matter and plant nutrients into the fertilization systems makes the improvement of physicochemical properties of soils, but on the other hand, it often leads to the increase of amounts of mineral and organic contamination [1–3]. Sewage sludges used in agriculture for fertilizing are the source, among others, of heavy metals, the content in sludge depends on the type of purified sewage as well as applied methods for its separation, concentration, and stabilization [4, 5]. Obligatory legal acts determine in details permissible levels of heavy metals in sewage sludge for agricultural purposes, their amounts introduced and existing in a soil, which excludes its excessive contamination [6]. Availability of heavy metals introduced into the soil in a form of sludge depends on many environmental factors, eg total

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content of available forms, acidity, organic matter content as well as features of plants grown [7, 8]. If physical, chemical or biological properties of sewage sludge make it difficult or impossible to be applied in agriculture, such type of sludge is subjected to processing that normalizes its improper parameters. Improvement of sanitary status, increase of dry matter content, and decreases of excessive heavy metals concentrations can be achieved by means of sewage sludge liming. Addition of calcium oxide is often replaced with other agents that alkalize sludge, eg calcium carbonate or ash from energy power plants. Ashes, besides, macronutrients and microelements important from a point of view of plant nutrition, also contain heavy metals. Mixing sewage sludge with energy power plant ashes makes quantitative changes in heavy metals contents and, due to high pH value, it may lead to their binding in compounds of low availability for plants [9–11].

The aim of present study was to evaluate the influence of CaO addition and brown coal ash to sewage sludge and composting achieved mixtures on cadmium and nickel contents in test plants and soil.

Material and methods

Sewage sludge from wastewater treatment plants in Siedlce and Lukow as well as manure as standard fertilizer was mixed with CaO and brown coal ash at 2:1 proportion, recalculated according to dry matter content. Amount of CaO and separately ash added to 1 kg of sewage from Siedlce and Lukow was 110 g and 100 g, respectively; that added to manure – 115 g. Such prepared mixtures as well as sewage and manure without additives were composted for 3 months (February till May) at ambient temperature, and then at amount of 1 kg added to pots containing 9 kg of soil so that the manure percentage was 10 % of total medium weight. At the same time sewage sludge from Siedlce and Lukow as well as manure were again prepared by adding 105, 90, and 120 g of CaO and brown coal ash to 1 kg of these materials so that the ratio of components dry matter was 2:1. Fresh mixtures and sewage sludge and manure without additions were introduced into the soil at the same amounts as composted materials (1 kg). Control objects were distinguished in the experiments; no organic fertilization was applied in them. They included plant cultivation on unfertilized soil and on soil fertilized with CaO and brown coal ash at the amount corresponded to mean weight introduced in fresh mixtures (105 g $\cdot$ pot^{-1}). Detailed scheme of the pot experiment carried out in greenhouse in 2000–2002 is presented in Table 1.

Soil used in the experiment, of granulometric composition at Ap level silty light loamy sand, showed acidic reaction (pH_{KCl} 4.0). Carbon content in organic compounds, total nitrogen [g $\cdot$ kg^{-1}] as well as cadmium and nickel [mg $\cdot$ kg^{-1}] was 10.3 and 0.98, as well as 0.110 and 4.51, respectively.

Organic materials were applied only once in the 1st year (10 days before seed sowing), the after-effects were examined in the 2nd and 3rd years. Due to low content of potassium in sewage sludge and its mixtures as well as possibility to retard phosphorus on objects with CaO, complementary phosphorus and potassium fertilization at the amounts of 0.44 g P $\cdot$ pot^{-1} (granulated triple superphosphate – 20 % P) and 1.25 g

K · pot^{-1} (potassium sulfate – 49.8 % K) was applied every year on all objects before sowing.

Table 1

Scheme of experiment

Fertilizers objects	
Applied organic material	Kind of component added to waste sludge
Without organic fertilization (control object)	no additives with CaO addition with ash addition
Fresh waste sludge from Siedlce (after methane fermentation)	without additives with CaO addition with ash addition
Fresh waste sludge from Lukow (stabilized in oxygenic conditions)	without additives with CaO addition with ash addition
Fresh farmyard manure	without additives with CaO addition with ash addition
Composted waste sludge from Siedlce (after methane fermentation)	without additives with CaO addition with ash addition
Composted waste sludge from Lukow (stabilized in oxygenic conditions)	without additives with CaO addition with ash addition
Composted farmyard manure	without additives with CaO addition with ash addition

Maize ("Nimba") and sunflower sown after maize harvest in the same pots were test plants in every experimental year. Five seeds of maize or sunflower were sown in each pot, and after the emergence, only three of them were remained in every pot. Aboveground parts of plants were harvested after 75 days of vegetation at the flowering stage.

Contents of cadmium and nickel in sewage sludge, manure and their mixtures with CaO and ash as well as harvested plant material were determined by means of ICP-AES in basic solution achieved after sample dry digestion at 450 °C. Achieved ash was treated with 6 mol · dm^{-3} HCl solution to decompose carbonates and evaporated till drying on sand bath. Formed chlorides were transferred to measuring flasks in 10 % HCl and adjusted to the analyses.

Study results were statistically processes using variance analysis, in which significance of studied factors was confirmed applying F-Fisher-Snedecor's test. Values of $LSD_{0.05}$ for detailed comparison of average data were calculated using Tukey's test.

Table 2

The content of cadmium and nickel in organic materials and their mixtures with CaO or brown coal ash [mg · kg^{-1} of d.m.]

Organic material		Kind of addition to organic materials											
		without additives				CaO				ash			
		Cd		Ni		Cd		Ni		Cd (2.76)*		Ni (32.06)*	
		II	V	II	V	II	V	II	V	II	V	II	V
Sludge from Siedlce	fresh	2.406	3.420	25.52	38.43	1.507	2.153	15.63	23.31	2.460	3.236	27.93	37.30
	composted	2.433	—	26.70	—	1.531	—	16.49	—	2.536	—	29.51	—
Sludge from Lukow	fresh	1.675	1.883	20.07	18.56	1.012	1.192	12.09	11.13	1.937	2.227	25.47	22.69
	composted	1.907	—	22.50	—	1.143	—	13.73	—	2.192	—	29.02	—
Farmyard manure	fresh	0.155	0.101	23.10	13.52	0.101	0.073	14.36	8.37	1.127	1.019	27.76	21.33
	composted	0.172	—	26.03	—	0.115	—	16.16	—	1.276	—	30.72	—

Explanation: * – the content of Cd and Ni in brown coal ash; II and V – the content of Cd and Ni in organic materials and their mixtures with CaO and brown coal ash mixed in February and May, respectively.

Results and discussion

In general, contents of heavy metals in sewage sludge do not exceed norms of their agricultural application [12] and they are the basic criterion of sludge qualification for fertilizing. Excessive – in a view of current norms – concentrations of these elements are most often observed in reference to chromium and zinc [2, 13], rarely to cadmium, and nickel [14, 15]. It is associated with the fact that some types of sludge are from large cities or from smaller ones but with great concentration of a given industry branch that is the source of pollution [14]. Tested sewage sludge types (except from Lukow collected in May 2000) and all mixtures met cited norms qualifying them for agriculture (Table 2).

Sewage sludge from Siedlce contained less cadmium and nickel than that from Lukow. Tested sorts of sewage sludge contained more cadmium than manure, while nickel contents was similar in those organic materials. When adding CaO to the sludge, mixtures contain lower amounts of cadmium and nickel than in native sludge, which was the effect of "dilution" (Table 2). Contents of heavy metals in sludge-ash mixtures were often higher than in native sludge types. Three-month composting of sewage sludge and its mixtures resulted in slight increase of cadmium and nickel contents due to organic matter mineralization.

Maize and sunflower harvested from objects fertilized with sludge and manure with CaO addition most often contained less cadmium and nickel than those grown on sludge and manure with no additives (Tables 3 and 4). The exception was cadmium in maize cultivated in the 1st and 2nd year, nickel in sunflower harvested in the 2nd year, and in maize from the 3rd year of experiment, which contents in plants grown on objects fertilized with only sludge and manure as well as with their mixtures with CaO did not significantly differ.

Table 3

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

Fertilizers objects		1st year		2nd year		3rd year	
		maize	sunflower	maize	sunflower	maize	sunflower
Without organic fertilization (control)	no additives	0.014	0.012	0.052	0.376	0.123	0.213
	with CaO addition	n.m.	0.023	0.016	0.166	0.109	0.200
	with ash addition	0.041	0.097	0.096	0.286	0.124	0.408
Fresh waste sludge from Siedlce	without additives	0.009	0.527	0.054	0.385	0.151	0.334
	with CaO addition	0.015	0.193	0.012	0.189	0.104	0.502
	with ash addition	0.031	n.m.	0.032	0.207	0.230	0.446
Fresh waste sludge from Lukow	without additives	n.m.	0.438	0.036	0.465	0.157	0.403
	with CaO addition	n.m.	0.427	n.m.	0.354	0.107	0.204
	with ash addition	n.m.	0.629	0.026	0.503	0.132	0.561
Fresh farmyard manure	without additives	0.016	0.346	0.056	0.326	0.171	0.421
	with CaO addition	n.m.	0.245	0.051	0.226	0.125	0.378
	with ash addition	0.051	0.308	0.079	0.203	0.243	0.736

Table 3 contd.

Fertilizers objects		1st year		2nd year		3rd year	
		maize	sunflower	maize	sunflower	maize	sunflower
Composted waste sludge from Siedlce	without additives	0.004	0.854	0.001	0.350	0.135	0.504
	with CaO addition	0.052	0.519	0.092	0.258	0.003	0.179
	with ash addition	n.m.	0.635	0.037	0.331	0.176	0.443
Composted waste sludge from Lukow	without additives	0.018	0.549	0.032	0.421	0.104	0.835
	with CaO addition	0.035	0.449	0.068	0.196	0.115	0.194
	with ash addition	n.m.	0.557	0.097	0.349	0.202	0.583
Composted farmyard manure	without additives	0.013	0.535	0.030	0.286	0.123	0.826
	with CaO addition	0.008	0.269	0.039	0.184	0.086	0.210
	with ash addition	0.053	0.527	0.041	0.271	0.191	0.388
Means values for fertilizers objects with organic materials with different additives							
Without additives		0.010	0.542	0.035	0.372	0.140	0.554
With CaO addition		0.018	0.350	0.044	0.235	0.090	0.278
With ash addition		0.023	0.443	0.052	0.311	0.196	0.526
$LSD_{0.05}$		n.s.	0.048	n.s.	0.029	0.048	0.070
Means values for kind of organic fertilizers							
Without organic fertilization		0.018	0.044	0.055	0.276	0.119	0.274
Fresh waste sludge from Siedlce		0.018	0.240	0.033	0.260	0.162	0.427
Fresh waste sludge from Lukow		0.000	0.498	0.021	0.441	0.132	0.389
Fresh farmyard manure		0.021	0.300	0.062	0.252	0.180	0.512
Composted waste sludge from Siedlce		0.019	0.669	0.043	0.313	0.105	0.375
Composted waste sludge from Lukow		0.018	0.518	0.066	0.322	0.140	0.537
Composted farmyard manure		0.025	0.444	0.037	0.247	0.133	0.475
$LSD_{0.05}$		n.s.	0.093	n.s.	0.056	n.s.	0.135

Explanation: n.m. – one does not mark (in statistical calculations it was accepted as 0); n.s. – non significant differences among average.

Cadmium content in maize harvested in the 1st and 2nd year from objects fertilized with sludge and manure without and with addition of ash did not significantly differ, whereas in sunflower it was lower after applying these substances mixtures with ash. Maize grown in the 3rd year on the objects treated with mixtures of sludge and manure with ash, contained more cadmium than after application of these substances without additive, while sunflower cultivated on the same fertilization objects contained similar levels of cadmium. Cadmium content in maize grown in the 1st and 2nd experimental years on the objects with sludge and manure with addition of CaO and ash did not significantly differ, whereas at other test plants, the heavy metal quantity was higher after applying mixtures with ash share.

Nickel content in maize in the 1st and 2nd, as well as at sunflower in the 1st and 3rd years of experiment from objects fertilized with sludge and manure with ash addition, was lower than when treated with sludge and manure without any additive (Table 4).

Table 4

The content of nickel in tested plants [mg · kg^{-1} of d.m.]

Fertilizers objects		1st year		2nd year		3rd year	
		maize	sunflower	maize	sunflower	maize	sunflower
Without organic fertilization (control)	no additives	2.64	3.63	1.66	1.86	1.93	2.25
	with CaO addition	2.29	2.81	1.69	0.90	1.66	3.77
	with ash addition	3.70	3.62	1.18	1.36	1.56	1.98
Fresh waste sludge from Siedlce	without additives	2.62	2.90	2.03	1.79	0.97	3.09
	with CaO addition	2.16	2.63	1.28	1.43	0.95	1.62
	with ash addition	2.67	3.52	2.02	1.57	0.88	1.16
Fresh waste sludge from Lukow	without additives	2.34	2.51	1.15	1.95	0.95	1.85
	with CaO addition	1.98	2.13	1.89	1.23	1.36	1.32
	with ash addition	3.93	4.01	1.41	1.41	1.18	1.02
Fresh farmyard manure	without additives	8.65	2.67	1.11	1.48	1.04	1.80
	with CaO addition	2.55	2.54	1.69	0.90	1.63	1.13
	with ash addition	2.75	2.40	1.70	1.57	1.09	3.36
Composted waste sludge from Siedlce	without additives	15.19	6.76	2.94	1.57	1.73	1.23
	with CaO addition	2.88	2.40	2.42	1.57	0.89	0.73
	with ash addition	4.61	4.02	1.96	2.00	0.64	0.80
Composted waste sludge from Lukow	without additives	2.71	13.21	26.08	1.43	1.60	3.42
	with CaO addition	2.56	2.21	1.25	1.60	0.48	3.76
	with ash addition	9.19	2.49	1.09	1.35	4.80	0.82
Composted farmyard manure	without additives	25.07	40.34	2.04	1.07	0.84	2.07
	with CaO addition	3.31	6.08	1.56	1.61	3.20	0.66
	with ash addition	3.66	10.78	0.97	2.06	1.43	0.95
Means values for fertilizers objects with organic materials with different additives							
Without additives		9.43	11.40	5.89	1.55	1.19	2.24
With CaO addition		2.57	3.00	1.68	1.39	1.42	1.54
With ash addition		4.47	4.54	1.53	1.66	1.67	1.35
$LSD_{0.05}$		3.88	3.16	3.90	n.s.	0.29	0.64
Means values for kind of organic fertilizers							
Without organic fertilization		2.88	3.35	1.51	1.37	1.72	2.67
Fresh waste sludge from Siedlce		2.48	3.02	1.78	1.60	0.93	1.96
Fresh waste sludge from Lukow		2.75	2.88	1.48	1.53	1.16	1.40
Fresh farmyard manure		4.65	2.54	1.50	1.32	1.25	2.10
Composted waste sludge from Siedlce		7.56	4.39	2.44	1.71	1.09	0.92
Composted waste sludge from Lukow		4.82	5.97	9.47	1.46	2.29	2.67
Composted farmyard manure		10.68	19.07	1.52	1.58	1.82	1.23
$LSD_{0.05}$		7.55	6.14	7.58	n.s.	0.57	1.23

Explanation: n.s. – non significant differences among average.

Sunflower cultivated in the 2nd year on objects treated with sludge and manure without additives as well as with addition of ash, contained similar nickel amounts, while maize in the 3rd year contained significantly more that element on the objects amended with ash mixtures.

Achieved results confirmed the assumption on the lack of increasing the threat due to heavy metals as a result of energy power plant ashes addition into the sewage sludge. In a view of literature references, the quantitative and qualitative estimation of heavy metals contents indicates no considerable influence of such sanitation of a sludge on contamination of the biomass with heavy metals, and studied elements occurred in sludge-ash mixtures mostly in forms that are hardly available for plants [16]. No tendencies towards heavy metals accumulation at plants treated with sludge with CaO addition should be attributed with the soil deacidification effect and decrease of their availability as a consequence of hardly available hydroxide formation [17]. Decrease of heavy metals concentrations in plants resulting from liming was observed in many earlier studies [18, 19].

Mean contents of cadmium and nickel (for three experimental years) at test plants fertilized with sludge and manure with any additives were higher than at plants treated with these agents with CaO and ash addition (Table 5).

Table 5

The content of cadmium and nickel in plants; mean values for maize and sunflower cultivated for 3 years of experiment [mg · kg^{-1} of d.m.]

Heavy metal	Waste activated sludge and farmyard manure fertilized in fresh and composted forms		
	without additives	with CaO addition	with ash addition
Cadmium	0.275	0.169	0.258
Nickel	5.28	1.93	2.53

Less cadmium and nickel (by 38.6 % and 6.2 %, respectively) was found at plants harvested from objects amended with sludge and manure with CaO mixtures than after application of these organic materials without additives. Plants fertilized with mixtures with ash contribution contained less cadmium and nickel (by 63.4 % and 52.0 %, respectively) as compared with those harvested from objects fertilized with sludge and manure with no additives.

Analysis of cadmium and nickel contents in maize and sunflower amended with fresh sewage sludge from Siedlce and Lukow as well as manure (average for objects with no additives and after addition of CaO and ash) most often indicated lack of significant differences as compared with their contents in plants fertilized with composts prepared from these organic and mineral-organic materials (Tables 3 and 4).

Contents of cadmium and nickel (average for three years experiment for objects without additives and after CaO and ash addition) in test plants treated with sludge from Siedlce were lower than at plants fertilized with sludge from Lukow by 13.6 % and 21.1 %, respectively.

Influence of manure applied in combinations without additives and in mixtures with CaO and ash on cadmium content at maize and sunflower fertilized with manure and

sludge (mean value for three years for objects with no additives and after CaO addition) was only 6 %, while nickel amount at plants treated with sewage sludge was lower by 31.4 % than after manure application.

Besides accumulation of heavy metals in plants fertilized with sewage sludge, the soil contamination due to these metals is also worth mentioning. After application of sludge, it should be a subject of interests both in an aspect of their introduction, accumulation, detoxication, and purification. Applying recommended (moderate) rates of sewage sludge with low content of heavy metals does not make significant increase of their content in a soil [20]. An excessive accumulation of heavy metals in soil is observed in the case of large sludge doses and with their large contents [21, 22]. Sewage sludge and their mixtures with CaO and brown coal ash, in present experiment, were introduced at large rates (about 10 % of soil weight). An apparent increase of cadmium content in the soil was recorded on objects treated with fresh and composted sludge from Siedlce and Lukow as well as their mixtures with CaO and brown coal ash (Table 6).

Table 6

Cadmium and nickel content in the soil after 3 years of experiment [mg · kg^{-1} d.m.]

Fertilizers objects	Kind of addition					
	without additives		CaO		ash	
	Cd	Ni	Cd	Ni	Cd	Ni
Control object	0.107	4.40	0.107	4.41	0.153	4.67
Fresh waste sludge from Siedlce	0.181	4.85	0.163	4.84	0.203	5.14
Fresh waste sludge from Lukow	0.136	4.77	0.131	4.59	0.164	4.82
Fresh farmyard manure	0.110	4.39	0.108	4.48	0.151	4.58
Composted waste sludge from Siedlce	0.173	4.43	0.161	4.78	0.177	4.83
Composted waste sludge from Lukow	0.137	4.26	0.127	4.45	0.178	4.73
Composted farmyard manure	0.105	4.56	0.103	4.63	0.145	4.87

Increase of cadmium concentration in soil after application of sludge and its mixtures with CaO and ash, as compared with its content before experiment, was following: 42.5 %, 32.3 %, and 64.1 % (on average for fresh, and composted sludge from Siedlce and Lukow, respectively) (Fig. 1). Quantity of nickel in the soil of objects amended only with sewage sludge was only by 1.5 % higher after the three experimental years than before its introduction, whereas higher by 3.4 % and 8.2 % after application of its mixtures with CaO and brown coal ash, respectively (Fig. 2).

The increase of heavy metals contents in soil after sewage sludge application is a phenomenon confirmed by numerous studies [11, 23]. Reducing the heavy metal contamination of the soil due to sewage sludge application can be achieved by means of addition of substances with their lower contents [4, 24]. In own research, cadmium and nickel contents in soil fertilized with sludge with no additives were most often slightly higher than after application of their mixtures with CaO (*pure* class) and apparently lower than after application of sludge-ash mixtures.

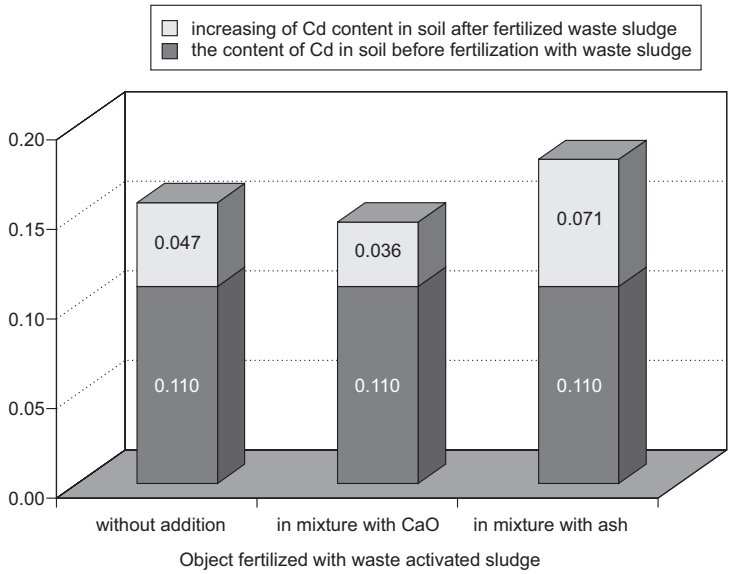

Fig. 1. The changes of cadmium content in soil after 3 years from use of waste activated sludge [mg · kg^{-1} d.m.]; $LSD_{0.05}$ = 0.013

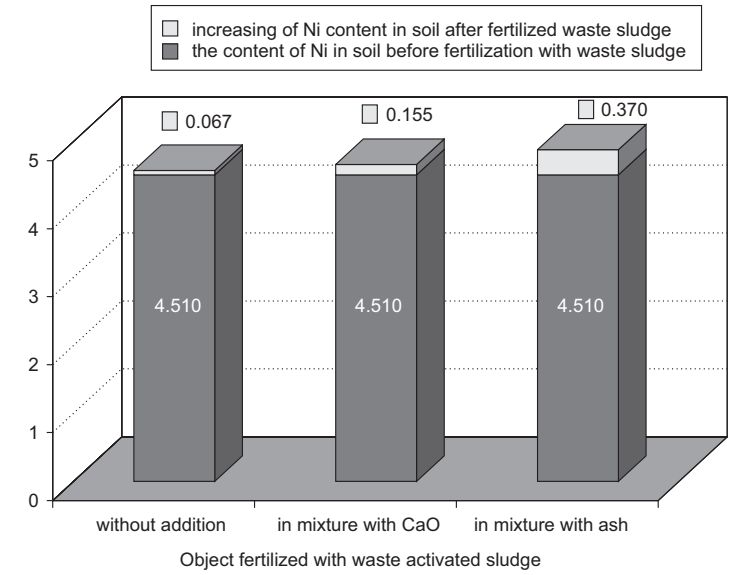

Fig. 2. The increase of nickel content in soil after 3 years from use of waste activated sludge [mg · kg^{-1} d.m.]; $LSD_{0.05}$ = 0.110

Soil treated with manure did not show heavy metals contamination symptoms. Contents of studied metals in soil after manure application was similar to their levels determined on control objects and most often lower than on objects amended with

sewage sludge (Table 6). In literature, there are frequently found information on weaker – as compared to sewage sludge – influence of manure on heavy metals contents in the soil [4].

Besides changes in heavy metals contents, the influence of fertilization on their contents in soil should be completed with the comparison to standards determining such level of soil contamination (eg with heavy metals), at which no its function is disturbed [25]. Grounds counted to arable ones (except from ground under the ponds and ditches) should contain not more than 4 mg Cd and 100 mg Ni in 1 kg of d.m. from 0–30 cm layer [26]. Contents of studied heavy metals in soil fertilized with sludge, manure, and their mixtures with CaO and brown coal ash was many times lower after three years of experiment than above cited contents.

Conclusions

1. Calcium oxide addition into the sewage sludge decreased cadmium and nickel concentration due to "dilution" effect. Mixtures of sludge with brown coal ash contained most often more cadmium and nickel as compared with sludge without additives and with CaO addition. Composting slightly increased cadmium and nickel amounts in only sludge as well as in its mixtures with these additives.

2. Cadmium and nickel contents in maize and sunflower were most often lower after application of sewage sludge with CaO and brown coal ash addition as compared with sludge fertilization without additives. Plants treated with sludge-ash mixtures contained more studied heavy metals than after application of sludge with calcium oxide addition.

3. Composting the sewage sludge and its mixtures with CaO and brown coal ash most often did not significantly affect the cadmium and nickel contents at test plants.

4. Sewage sludge applied with no additives and with addition of CaO or brown coal ash increased cadmium and nickel contents in the soil. Heavy metals contents in soil material fertilized with sludge with ash addition were higher as compared with objects treated with sludge with no additives and with CaO addition.

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WPŁYW SPOSOBU ALKALIZACJI I KOMPOSTOWANIA OSADÓW ŚCIEKOWYCH NA ZAWARTOŚĆ KADMU I NIKLU W ROŚLINACH TESTOWYCH I GLEBIE

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Abstrakt: W trzyletnim doświadczeniu wazonowym badano wpływ nawożenia świeżymi i kompostowanymi osadami ściekowymi (z Siedlec i Łukowa), obornikiem oraz ich mieszaninami z tlenkiem wapnia i popiołem z węgla brunatnego na zawartość kadmu i niklu w roślinach testowych i glebie.

Rośliny nawożone osadami z dodatkiem tlenku wapnia zawierały mniej kadmu i niklu niż rośliny nawożone osadami bez dodatków. Zawartość badanych metali ciężkich w kukurydzy i słoneczniku nawożonym mieszaninami osadowo-popiołowymi była najczęściej mniejsza niż w roślinach nawożonych osadami bez dodatków i większa niż po zastosowaniu ich mieszanin z tlenkiem wapnia. Proces kompostowania osadów ściekowych i ich mieszanin z tlenkiem wapnia i popiołem z węgla brunatnego najczęściej nie wpłynął znacząco na zawartość kadmu i niklu w roślinach testowych. Zawartość kadmu i niklu w glebie zwiększyła się najbardziej w obiektach nawożonych mieszaninami osadów z popiołem z węgla brunatnego. Wzrost zawartości tych metali ciężkich w glebie po zastosowaniu samych osadów i ich mieszanin z tlenkiem wapnia był zbliżony.

Słowa kluczowe: osady ściekowe, kompostowanie, popiół, kadm, nikiel