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ZINC IN SEPARATED SEQUENTIAL FRACTIONS FROM SIX SOILS ON THE SLOPES OF THE SIEDLCE HIGH PLAIN

Abstract: The aim of the study was to evaluate the total content of zinc in the fractions separated from the soils located in two transects on the moraine slope of the Siedlecka High Plain (some situated above and some beneath the underground municipal landfill site). The highest total content of zinc was detected in the soils situated beneath the underground municipal landfill site. The sequential fractioning was performed by the Zeien-Brümmer method. The speciation analysis revealed that this metal was bound to different components of the soil solid phase. The highest percentage of zinc content was detected in the residual fraction F7 in the parent rock horizons and the lowest was noted in the bioavailability fractions, i.e. exchangeable F2 and easily-easily soluble F1. In transects A and B of the tested soils significant correlations were found between the content of zinc in the separated fractions and its total content, the total content of iron and manganese, clay fraction <0.002 mm, cation exchange capacity (CEC) as well as between the content of carbon organic compound and zinc in the F4 organic fraction.

In soils, metals are found in different states (forms, fractions) forming a variety of bindings with minerals and organic compounds and are present as ions in soil solutions [4,14]. The distribution of zinc and other metals in a soil profile is determined by natural and human-induced accumulation in the upper humus horizons, the abundance of the parent rock and the direction of the pedogenic processes [10].

Zinc is one of the most mobile elements in the soil and its desorption decreases in proportion to the increase in reaction. Its mobility depends, among others, on the redox potential, the content of organic matter, the textural

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composition and the saturation of adsorption complex with calcium and magnesium [17]. Zinc is strongly bound to iron and aluminium oxides, and clay minerals. During weathering, all zinc compounds are easily soluble, particularly in an acid environment, and the released ions form mineral or organic-mineral bindings with high mobility. In Poland, the natural content of zinc in cultivated soils ranges from 0.5 to 100.0 mg kg^{-1} [15], with a significant variation in different geological deposits.

The methods of sequential chemical extraction of metals from the soil are based on extracting a given element bound to its components by consecutive exposure to an extraction solution with different strength. They enable a quantitative determination of metals in sequenced fractions and, therefore, better qualitative evaluation of their availability and potential toxicity to biotic elements of the trophic chain [18]. The extractors in multistage sequential extractions are often used in the following order: non-buffered salt solutions, buffered solutions or weak acid solutions, reduction solutions, oxidation solutions and strong acids [5]. The sequence of stages may be used to evaluate the possibility of demobilization of a given metal due to changes in environmental conditions [1].

The studies on cultivated soils should pinpoint mainly the forms of metals which may be mobile and bioavailable under certain conditions. The methods of sequential extraction are not specific and do not allow for selective extraction of fractions in specific chemical forms from soil. The extracted fractions are defined customarily and operatively and give an approximate description of metal forms.

The aim of the study was to evaluate the content of total zinc and its fractions extracted in accordance with the Zeien-Brümmer method from the genetic horizons of six diversified types of soil from different locations on the moraine slope of mid-Polish glaciations situated on the Siedlecka High Plain near the underground municipal landfill site.

MATERIALS AND METHODS

The soil samples were taken from the selected horizons in six diversified types of soils on the slope of a frontal moraine (western exposition, 22° 43'E and 52° 13'N) of the mid-Polish glaciations of the Warta stadial located on the Siedlecka High Plain within the mid-Polish lowlands. In this region, the moraine hills are built mainly of sands with different granulation with the addition of gravels, boulders, and are frequently separated with silts and sandy boulder clay. The soil pits were carried out in two (A and B) transects, situated app. 1 km from each other, with the first arrangement of three soils located above and beneath the underground municipal landfill site in Łosice (the former gravel pit).

The transect A included: on the flat-topped hill (above the landfill site): podzolized soil lessive (profile I) - 186 m AMSL; two on the hill (beneath the landfill site): leached brown soil (profile II) and below humous deluvial soil (profile III) (located near the road to the landfill site). The transect B included: on the flat-topped hill - rigosol (profile IV), 178 m AMSL; on the hill: typical soil lessive (profile V) and at the foot of the hill: proper deluvial soil (profile VI) (Fig. 1).

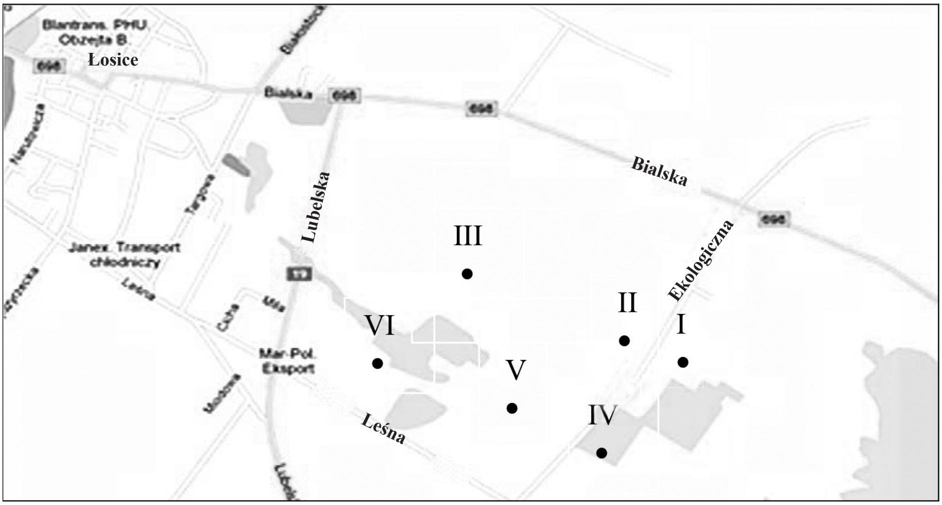

Fig1. Location of research area and soils profile.
I ... VI - number of soils profile.

The podzolized soil lessive (profile I) was wasteland and other soils were cultivated. The soil material was collected from the individual genetic horizons of the analysed soils and the following parameters were determined: the percentage of clay fraction ф < 0.002 mm with the areometric method (in accordance with PN-R-04033); pH (in 1 mol KC1 dm^{-3} with the potentiometric method; cation exchange capacity (CEC) calculated on the basis of hydrolytic acidity (Hh) and the sum of exchangeable alkaline cations (S) by Kappen's method (excluding the soils with pH > 7.5); carbon in organic compounds (C_{org}) with oxidative-volumetric method [9]; and total content of Zn_t, Fe_t and Mn_t with the ICP-AES method using an Optima 3200 RL (Perkin Elmer) with prior soil mineralization in the mixture of concentrated acids HC1+HNO_3 (3:1). The fractions of zinc were sequenced by the modified method of Zeien and Brümmer [18] (Table 1). This method enables the extraction of seven fractions of this metal with different activity in soil environment. The analysis was carried out in three replications. The value of standard deviation for individual fractions in the selected genetic horizons ranged from 0.10 to 0.56 mg kg^{-1}. In order to verify the accuracy and correctness of the measurements, the following reference materials were used:

WEPAL Soil Reference Material RTH 911 (Swiss Less Soil) by Perkin Elmer and internal Y - yttrium (wave length 371.029 nm) added to standard, control, and tested solutions so that the concentration of the solution amounted to 10 mg dm^{-3}. The values of Pearson's correlation coefficient were calculated with Statistica 9.1 software in order to determine the correlation between the content of zinc in the sequenced fractions and its total content and selected parameters of soil C_{org}, pH_{KCl}, CEC, clay fraction ɸ < 0.002 mm, Fe_t Mn_t.

TABLE 1. SEQUENTIAL EXTRACTION OF HEAVY METALS BY THE MODIFICATION ZEIEN AND BRÜMMER'S METHOD

Fraction	Name	Extraction reagent	Extraction time	pH
F1	soluble and exchangeable (mobile)	1 mol NH_4NO_3 dm^{-3}	24 hour	natural
F2	specifically sorbed	1 mol CH_3COONH_4 dm^{-3}	24 hour	6.00
F3	bound to MnO_x	1 mol $NH_2OH{\cdot}HCl$ dm^{-3}+ 1 mol CH_3COONH_4 dm^{-3}	0.5 hour	6.00
F4	organically bound	0.025 mol $C_{10}H_{22}N_4O_8$ dm^{-3}	1.5 hour	4.60
F5	bound to (oceluded in) amorphous FeO_x	0.2 mol $(NH_4)_2C_2O_4$ dm^{-3}+ 0.2 mol $H_2C_2O_4$ dm^{-3}; in the dark	4 hour	3.25
F6	bound to (oceluded in) crystalline FeO_x	0.2 mol $(NH_4)_2C_2O_4$ dm^{-3}+ 0.2 mol $H_2C_2O_4$ dm^{-3}+ 0.1 mol $C_6H_8O_6$ dm^{-3}; in the dark	0.5 hour	3.25
F7	residual (postexstraction resisue)	calculated from the difference between the total content of a certain metal and the sum of its fractions	–	–

Ratio soil : solution 1g: 10 cm^3.

RESULTS AND DISCUSSION

The selected physical and physicochemical characteristics of the six tested soils located on the moraine slope are presented in Table 2. The content of clay fraction in the humus horizon of the analyzed soils was 2–9%; with the exception of humus deluvial soil (profile III), the strong acidification (pH 3.47–4.26), the low content of organic carbon compounds (6.30–10.4 g kg^{-1}) and the low cation exchange capacity (with the exception of deluvial soils - profiles III and IV) 45.7–72.4 mmol(+) kg^{-1} were detected [7].

TABLE 2. SELECTED PROPERTIES AND TOTAL CONTENT Zn, Fe AND Mn OF THE INVESTIGATED SOILS [7]

Horizon	Depth (cm)	% fraction of clay	pH_{KCl}	CEC	Org. C	Zn_t	Fe_t	Mn_t
				(mmol(+) kg^{-1})	(g kg^{-1})	(mg kg^{-1})		
Transect A								
I Albic Luvisol (flat)								
A	0–25	9	4.05	45.7	6.30	16.8	4322	216
Eet.fe	25–40	8	4.46	28.2	1.50	13.9	5178	97.3
Bt.fe	40–60	7	4.80	85.0	0.70	18.0	10213	79.7
Bt	60–90	9	7.73	–	0.50	21.1	10113	278
C	90–120	0	8.87	–	0.30	15.4	1721	53.1
II Haplic Cambisol (slope)								
A	0–24	4	3.63	66.2	7.30	20.6	6200	122
ABbr(fe)	24–37	5	3.77	56.4	2.60	19.9	7506	260
Bbr 1	37–47	24	4.04	123	1.80	28.0	18793	248
Bbr 2	47–75	21	4.57	132	1.00	31.7	19997	274
Bbr 3	75–100	21	4.95	122	0.94	39.8	15897	397
Bbr 4	100–140	10	7.49	–	0.83	27.5	17505	262
III Mollic Fluvisol (slope)								
IA1	0–15	2	6.68	127	17.7	29.7	6296	268
IA2	15–35	2	6.61	126	6.70	23.1	7741	443
IA3	35–46	6	6.42	124	8.10	21.7	10188	417
IIA	46–68	12	6.36	213	9.90	29.3	17321	583
AC	68–78	10	6.25	167	3.90	34.8	15284	165
IC	78–100	1	6.26	128	1.60	23.5	13075	173
IICG	100–125	15	6.32	137	1.10	29.0	19606	692
Transect B								
IV Antropic Regosol (flat)								
Aan	0–25	5	4.26	54.7	7.73	30.1	5153	222
AanA	25–50	6	4.60	48.7	2.78	17.1	4687	203
Ees	50–80	4	4.18	37.5	0.78	7.05	2838	48.2
Bhfe	80–110	8	4.20	66.2	0.77	20.3	8675	147
C	110–150	17	3.87	104	0.96	27.9	15306	99.0

TABLE 2. CONTINUATION

V Haplic Luvisol (slope)								
A	0–25	8	3.47	72.4	6.95	18.3	4974	164
Eet	25–50	6	3.95	33.7	0.66	11.8	4395	232
EB	50–80	8	4.38	146	1.21	36.8	23492	514
Bt	80–120	16	3.95	96.9	0.71	23.3	14339	97.0
C1	120–150	1	4.96	29.0	0.29	7.00	3058	39.9
C2	150–180	3	5.12	33.9	0.14	6.04	3219	52.4
VI Haplic Phaeozem (foot-slope)								
A1	0–40	6	3.47	119	10.4	24.3	5895	245
A2	40–64	10	3.95	135	8.49	10.7	4108	66.0
AC	64–74	8	4.38	75	1.05	10.3	4384	37.6
CG	74–90	6	3.95	77	0.74	15.4	5315	39.7

The total content of zinc in the analyzed soils (Table 2) was diversified between and within the profiles and amounted to: in A transect 13.9–39.8 mg kg^{-1} (on average 24.1 mg kg^{-1}) and in B transect 6.04–36.8 mg kg^{-1} (on average 17.6 mg kg^{-1}). The distribution of zinc in the soil profiles was determined by the course of soil formation processes. Depending on the type of soil, the zinc concentration zones were formed in different locations. In the surface humus layers, the content of zinc ranged from 16.8 to 29.7 mg kg^{-1} (on average 22.4 mg kg^{-1}) in A transect and from 18.3 to 30.1 mg kg^{-1} (on average 24.2 mg kg^{-1}) in B transect. Uziak *et al.* [16] and Dąbkowska-Naskręt and Różański [3] emphasize that the accumulation of zinc in the natural ecosystems depends mainly on its biological circulation and the highest concentration is detected in the epipedons with a high content of (more-or-less) converted organic matter. The highest total content of zinc was detected in the soils located below the municipal landfill site with the relatively highest content of clay fraction (profile II) and C_{org} (profile III). In the profiles of these two types of soil, the highest total content of iron and manganese was also detected. Gworek [6], Dąbkowska-Naskręt *et al.* [2] and Martyk and Niemczuk [11] reported that a significantly smaller amount of this metal, as compared to other genetic horizons, was found in the leached horizons E and the largest amount was in the enrichment horizon B where it was washed away together with the clay fraction. The content of zinc in the humus horizon did not exceed its concentration in cultivated soil [13] and stayed within the natural range.

The sequential extraction showed that in the individual genetic horizons of the tested soils, the distribution of zinc was irregular and this metal was bound to different components of soil solid phase (Table 3). The smallest percentage of

Zn (in the total content) was detected in the bioavailability fractions (Fl and F2), most mobile in the environment, where it averaged 7.56% (6.33–8.46%) for Fl fraction and 7.16% (6.68–7.65%) for the F2 fraction. The content of zinc in these fractions was lowest in the humus horizon with the exception of rigosol and the distribution in the tested profiles was similar. The higher content of zinc in Fl and F2 fractions in its total content in the genetic horizons located beneath the humus horizon indicates its mobility and the possibility of being washed away. The coefficients of a simple correlation revealed that the content of zinc in the bioavailability fractions depended on its total content, cation exchange capacity, the content of clay fraction and the total content of iron and manganese (Table 4). Moćko and Wacławek [12] concluded that the solubility of zinc and other heavy metals in soil was strongly correlated with their total content. Uziak *et al.* [16] reported that the impact of utility on the content of zinc in the soluble fractions was weak regardless of the type of soil.

TABLE 3. THE PERCENTAGE CONTRIBUTION OF ZINC FRACTIONS IN THE INVESTIGATED SOILS IN TRANSECT A AND B

Horizon	Depth (cm)	Fraction						
		F1	F2	F3	F4	F5	F6	F7
		(%)						
Transect A								
I Albic Luvisol (flat)								
A	0–25	5.39	5.50	8.03	24.8	9.03	11.6	35.7
Eet.fe	25–40	5.72	7.80	8.57	22.5	9.51	10.8	35.1
Bt.fe	40–60	6.25	6.94	7.68	11.8	7.50	13.5	46.1
Bt	60–90	7.03	6.75	8.50	5.14	10.2	11.7	50.6
C	90–120	7.24	7.88	9.06	4.64	7.96	7.59	55.6
Mean		6.33	6.97	8.37	13.8	8.84	11.0	44.6
II Haplic Cambisol (slope)								
A	0–24	5.34	5.59	9.26	23.6	11.7	12.7	31.8
ABbr(fe)	24–37	6.78	7.46	12.3	20.4	11.1	12.4	29.6
Bbr 1	37–47	9.01	7.85	6.55	8.39	9.03	8.76	50.4
Bbr 2	47–75	9.21	8.94	7.49	6.75	11.2	7.24	49.2
Bbr 3	75–100	7.86	7.53	5.02	3.45	10.3	10.7	55.1
Bbr 4	100–140	8.99	8.55	5.30	2.60	7.95	6.69	59.9
Mean		7.86	7.65	7.66	10.9	10.2	9.75	46.0

TABLE 3. CONTINUATION

III Mollic Fluvisol (slope)								
IA1	0–15	4.88	5.04	11.3	27.9	10.1	9.70	31.1
IA2	15–35	6.15	6.05	10.2	18.4	8.69	10.6	39.9
IA3	35–46	7.08	6.91	15.5	17.2	10.8	8.32	34.1
IIA	46–68	9.28	8.39	11.9	10.9	9.39	7.92	42.1
AC	68–78	8.48	7.99	10.3	7.82	10.5	7.77	41.3
IC	78–100	8.82	7.23	9.15	5.62	9.23	8.51	51.4
IICG	100–125	10.3	8.47	6.90	5.11	6.92	6.35	55.9
Mean		7.85	7.15	10.8	13.3	9.37	8.45	42.3
Transect B								
IV Antropic Regosol (flat)								
Aan	0–25	7.95	7.24	9.59	14.5	10.7	10.9	39.1
AanA	25–50	8.14	6.34	7.14	11.4	7.06	7.41	52.5
Ees	50–80	10.6	7.57	15.9	6.17	16.0	13.0	30.6
Bhfe	80–110	7.03	5.67	5.42	5.78	6.83	7.41	61.8
C	110–150	7.50	6.58	8.42	3.51	5.89	8.66	59.4
Mean		8.24	6.68	9.37	8.27	9.30	9.48	48.7
V Haplic Luvisol (slope)								
A	0–25	6.10	6.09	11.5	17.7	12.7	11.8	34.6
Eet	25–50	7.19	7.05	11.4	12.5	10.0	8.98	42.8
EB	50–80	7.20	6.41	9.43	7.60	10.5	8.31	50.4
Bt	80–120	10.3	8.57	8.58	4.78	11.3	11.7	44.7
C1	120–150	10.1	9.30	11.0	3.21	12.6	10.8	42.9
C2	150–180	9.88	8.16	10.1	1.66	10.6	10.7	48.8
Mean		8.46	7.60	10.3	7.90	11.2	10.4	44.0
VI Haplic Phaeozem (foot-slope)								
A1	0–40	5.97	5.75	13.9	26.4	11.7	10.4	25.8
A2	40–64	6.50	6.77	9.11	21.0	11.8	13.0	31.8
AC	64–74	7.07	7.73	10.8	8.56	12.9	14.1	38.8
CG	74–90	7.12	7.69	10.1	3.72	12.5	13.7	45.1
Mean		6.66	7.00	11.0	14.9	12.2	12.8	35.4

F1-soluble and exchangeable (mobile); F2-specifically sorbed; F3-bound to MnO_x; F4-organically bound; F5-bound to amorphous FeO_x; F6-bound to crystalline FeO_x; F7-residual.

In the case of soils in the A transect, the content of zinc in the fractions bound to manganese oxides and hydroxides F3 (5.02–15.5%) and to amorphous (F5 5.89–12.9%) and crystal (F6 6.35–14.1%) iron oxides and hydroxides was differentiated between and within the profiles, with the lowest values generally detected in the low genetic horizons. In the soils of B transect the percentage of zinc content showed a low diversification between the soils and a larger diversification between individual horizons and reached 5.42–15.9% in F3, 5.89–16.0% in F5 and 7.41–14.1% in F6. These differences are probably due to the diversified total content of zinc and the properties of soil horizons, including the presence of metal-absorbing compounds. The statistical analysis (Table 4) revealed that the content of zinc in F3, F5 and F6 fractions in both transects (A and B) significantly correlated with the total content and cation exchange capacity. Furthermore, in the soils of A transect F3 fraction significantly correlated with the total content of carbon in organic compounds and the total content of manganese, whereas, the F5 fraction significantly correlated with the content of clay fraction and the total content of iron. In the B transect, positive correlations were found between these fractions (F3, F5 and F6) and the total content of iron and manganese.

TABLE 4. THE CORRELATION COEFFICIENTS BETWEEN THE FRACTIONS OF ZINC (mg kg^{-1}) AND SOME PROPERTIES OF INVESTIGATED SOILS

Paremeter	Fractions						
	F1	F2	F3	F4	F5	F6	F7
Transect A							
Zn_t	0.90*	0.91*	0.52*	-0.05	0.91*	0.67*	0.87*
Org C	-0.18	-0.20	0.33	0.89*	0.19	0.17	-0.31
pH_{KCl}	0.07	0.05	0.15	-0.29	-0.12	-0.30	0.17
CEC	0.59*	0.55*	0.74*	0.25	0.58*	0.57*	0.36
Ø<0.002	0.70*	0.72*	-0.05	-0.33	0.52*	0.38	0.68*
Fe_t	0.92*	0.88*	0.38	-0.37	0.57*	0.42	0.82*
Mn_t	0.54*	0.50	0.56*	0.03	0.35	0.17	0.55*
Transect B							
Zn_t	0.94*	0.96*	0.83*	0.56*	0.88*	0.91*	0.90*
Org C	0.08	0.15	0.50	0.87*	0.39	0.39	-0.08
pH_{KCl}	-0.23	-0.29	-0.46	-0.54*	-0.42	-0.50	-0.16
CEC	0.52*	0.55*	0.55*	0.45	0.61*	0.62*	0.49
Ø<0.002	0.53*	0.52*	0.14	-0.01	0.27	0.48	0.55*
Fe_t	0.81*	0.79*	0.52*	0.08	0.64*	0.63*	0.87*
Mn_t	0.63*	0.64*	0.75*	0.56*	0.72*	0.55*	0.63*

Zn_t – total content; CEC- cation exchanage capacity; Ø<0,002 – percentage fraction of clay; Fe_t; Mn_t - total content; significant α =0,05.

In the organic fraction (F4), the highest content of zinc (%) was detected in the surface humus horizons in the soils of both transects and it amounted on average to 22.5% (ranging from 14.5 to 27.9%); the highest values were measured in the deluvial soils (profile III and VI) located lowest in the transects with the highest concentration of C_{org}. In all six soils, the percentage of this fraction of zinc decreased together with the depth of the profile with the lowest values in the parent rock. Such a distribution of zinc in the profiles resulted mainly from the biological accumulation of organic matter in the humus horizon, which confirms that the organic matter formed relatively stable and solid bindings with zinc. The calculated coefficients of simple correlation (Table 4) indicate a correlation between the content of zinc in the organic fraction (F4) and the content of carbon in organic compound (transect A and B) and in the soil of B transect - a significant positive correlation with the total content of zinc and manganese and a significant negative correlation with pH values.

Zinc predominates in the residual fraction [8]. The highest percentage of this metal was detected in the post-extraction residues, i.e. in the residual fraction (F7), which was related to the chemical composition of the parent material and indicated a strong binding of this metal to the soil solid phase. In the A transect, the content of this fraction of zinc averaged 44.3% with the highest value in leached brown soil (46.0%), whereas, in the B transect it averaged 42.7% with the highest concentration in rigosol (48.7%). In the tested soils, zinc in the F7 fraction predominated in the parent rock horizons in all profiles (45.1–59.9%) with the exception of rigosol (profile IV). The content of zinc in the F7 fraction in both analyzed transects showed a significant positive correlation with the total content of zinc, iron and manganese and the content of the clay fraction. Kalembasa *et al.* [8] detected a lower content of zinc in the bioavailability fractions and similar in the organic fraction F4 and in the residual fraction F7 (sequenced with Zeien-Brümmer method) in the epipedons (0–25 cm) of anthropogenic soil situated near the above-surface municipal landfill site in Siedlce-Wola Suchożebrska.

CONCLUSIONS

1. The total content of zinc in the individual genetic horizons of the six tested soils located on the moraine slope on Siedlecka High Plain was diversified between and within the profiles. A higher concentration of zinc was detected in the soils in transect A than in transect B with the highest values in leached brown soil and humous deluvial soil situated beneath the underground municipal landfill site. These values did not exceed the legal permissible limits for cultivated lands (as specified in the Ministry of Environment regulations) and remained within the natural range.

2. The sequential fractioning of zinc in the genetic horizons of the tested soil by the Zeien-Brümmer method revealed the diversified concentration of this metal in the extracted fractions. In the bioavailability fractions, i.e. easily soluble Fl and exchangeable F2, the lowest content of this metal was detected, whereas the highest concentration was detected in residual fraction F7.

3. The percentage content of zinc in the separated fractions in relation to the total content in the soils was organized in the following order of decreasing values:

For A transect: F7> F4> F6 > F5> F3> Fl> F2;

For B transect: F7> F6 ~F5 > F4> F3> Fl> F2.

4. The coefficients of simple correlation for the tested characteristics showed significant positive or negative correlations between the content of zinc in separated fractions and its total content, the content of carbon in organic compounds, cation exchange capacity, clay fraction and the total content of iron and manganese.

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CYNK W WYDZIELONYCH SEKWENCYJNIE FRAKCJACH SZEŚCIU GLEB STOKU MORENOWEGO

Celem pracy była ocena zawartości ogólnej cynku oraz we frakcjach wydzielonych z gleb, położonych w dwóch transektach na stoku morenowym Wysoczyzny Siedleckiej (część z nich powyżej i poniżej podpoziomowego składowiska odpadów komunalnych). Największą ogólną zawartość cynku stwierdzono w glebach położonych poniżej podpoziomowego składowiska odpadów komunalnych. Sekwencyjne frakcjonowanie przeprowadzono metodą Zeiena i Brümmera. Analiza specjacyjna wykazała, iż metal ten był związany z różnymi składnikami fazy stałej gleby. Największy procentowy udział cynku stwierdzono we frakcji rezydualnej F7, w poziomach skały macierzystej, a najmniejszy w biodostępnych frakcjach - wymiennej F2 i łatwo rozpuszczalnej Fl. W badanych glebach, w transekcie A i B zanotowano istotne związki korelacyjne między zawartością cynku w wydzielonych frakcjach, a jej zawartością ogólną, zawartością ogólną żelaza i manganu, frakcją iłową gleby < 0,002 mm. pojemnością sorpcyjną CEC, a także między zawartością węgla związków organicznych, a cynku we frakcji organicznej F4.