Original Research

Micromorphometric Characteristics of Upper Layers of Soils Contaminated by Heavy Metals in the Vicinity of a Zinc and Lead Ore Plant

K. Ciarkowska[1]*, F. Gambuś[2]

[1]Soil Science and Soil Protection Department, Agricultural University, 31-120 Kraków, Al. Mickiewicza 21, Poland,
[2]Agricultural Chemistry Department, Agricultural University, 31-120 Kraków, Al. Mickiewicza 21, Poland

Received: April 23, 2004
Accepted: December 10, 2004

Abstract

The aim of our paper was to determine selected morphometric indices of the main fabric units of humus layers in soils with different vegetation cover and contaminated by heavy metals. The study sampled soil from three sites located about 4 km NW from a zinc plant. In all humus layers decomposed organic matter occurred mainly in form of fine excrements, originated from small soil arthropods, while macrofauna excrements were the absent. The dominance of soil mesofauna over macrofauna was probably attributed to elevated heavy metal concentrations. The high concentration of heavy metals affected the major soil components, but the kind of vegetation and the degree of cover of the soil surface were as important for the development of the humus layers as heavy metal contamination.

Keywords: morphometric indices, heavy metals, soil fauna, soil biological activity

Introduction

The high concentration of heavy metals in soils in the vicinity of non-ferrous metal plants and smelters is one of the main problems in industrialized regions. Such a strong impact of heavy metals affects mostly upper soil horizons, resulting in changes of their chemical properties, structure and a decrease of their biological activity [4, 5]. The process of decomposition of soil organic matter in humus layers, as a result of biological processes, is best studied in thin sections. The most objective way of evaluating the soil microstructure is a computer-aided image analysis of photographs which enables us to classify objects seen in the thin section in different groups and then to quantify these objects [4, 7].

The aim of our paper was to determine selected morphometric indices of the main fabric units of humus layers of soils with different vegetation cover and contaminated by heavy metals.

Study Area and Soils

The investigations were carried out in the southern part of Poland near Olkusz on soils derived from Pleistocene sand deposits which cover Jurassic dolomites and limestone. The climate of the research area is humid temperate with mean annual temperature of 7.1°C, and mean annual precipitation of 832 mm.

In this region, from the beginning of the 19th century, the output and processing of zinc and lead ores has been carried out, causing contamination of the environment by heavy metals.

For the study, soil samples of surface and subsurface layers from three sites, located at about 4 km NW from the zinc plant, were sampled. Profile 1 (Table 1) represents the

*Corresponding author e-mail: rrciarko@cyf-kr.edu.pl

Table 1. Physico-chemical and chemical properties of studied soils.

Specification	Site number / depth in cm				
	1/0-10	2/0-10	2/10-30	3/0-15	3/15-30
Number of soil	1	2	3	4	5
Organic C content, $g\cdot kg^{-1}$	4.98	89.36	36.30	44.92	22.09
Total N content, $g\cdot kg^{-1}$	0.54	8.62	4.49	1.43	1.96
C:N ratio	9.2	10.4	8.1	31.4	11.3
pH_{H2O}	7.7	7.3	7.1	7.6	7.2
CEC, mmol(+)$\cdot kg^{-1}$ soil	152.8	229.9	166.9	126.1	132.4
Cd content, $mg\cdot kg^{-1}$	6.3	106.5	41.5	53.0	50.2
Pb content, $mg\cdot kg^{-1}$	320.8	2723.3	1538.3	1843.4	1803.3
Zn content, $mg\cdot kg^{-1}$	1027.3	7794.7	4919.7	4944.9	4944.8
Dehydrogenase activity, $cm^3\ H_2\cdot kg^{-1}DM\cdot d^{-1}$; mean ± SD	0.99 ±0.16	16.28 ±2.40	7.22 ±0.53	0.01 ±0.002	0.02 ±0.016

soil formed on a dump after reclamation, overgrown with 10-year-old pine greenwood cover together with undergrowth over 80% of the surface. Profile 2 represents the uncultivated soil with natural sequence of horizons which earlier was arable land. Now the vegetation, which covers 100% of the surface, is compact and characteristic of a meadow community (mainly monocotyledonous). Profile 3 represents the soil formed on a dump formed of a post flotation material, 5 years after deposition. The surface of the dump is overgrown only on 3% of the surface with pine trees. According to WRB [1], soils from sites 1 and 2 can be assigned to Anthropic Spolic Regosols while soil from site 3 belongs to Haplic Cambisols.

Methods

In soil samples the following analyses were performed: pH potentiometrically, the level of organic carbon after wet combustion in $K_2Cr_2O_7$, total nitrogen after Kjeldahl's method, the cation exchange capacity (CEC) as a sum of hydrolytic acidity (determined using 1 M CH_3COONa) and basic exchangeable cations determined in 0.5 M NH_4Cl, the total content of Cd, Pb and Zn determined after soil digestion in aqua regia. Contents of the elements in solutions were determined with the use of an atomic emission spectrophotometer with inductively coupled argon plasma (ICP-AES) JY 238 ULTRACE. The dehydrogenase activity was measured after 24 hours of incubation of soil samples at 37°C using Beckman DU 600 spectrophotometer at a wavelength of 540 nm and TTC (chloride 2,3,5-triphenylotetrazole) used as a substrate was applied to measure the activity of the studied enzyme after Casida's method (3). The accuracy of the analytical methods was verified with the certified reference material GSS-8 (GBW 07408 — State Bureau of Metrology, Beijing, China).

Thin sections were prepared of undisturbed soil samples, impregnated with epoxy resin and examined through a Nikon Eclipse E400 POL polarizing microscope. Excrements of soil fauna were described on the basis of their morphology [2, 8]. Microphotographs were taken with a Nikon Coolpix 995 digital camera and images were subjected to morphometric analysis using the Aphelion 3.1 ADCIS S. A., AAI inc. computer program and statistically reworked with the use of Statistica 6 program. The significance of differences among mean values was estimated by Fisher's test.

Results and Discussion

Physico-chemical and chemical properties of studied soils were presented in Table 1. Total amounts of cadmium, zinc and lead indicate that the soils can be assigned to medium (profile 1), and heavily polluted (profiles 2, 3) by heavy metals [6].

Examinations of thin sections and morphometric analysis were focused on three components of the soil, namely undecomposed, well-decomposed organic matter and voids. Mineral parts of studied soils were neglected as they are susceptible to environmental changes to a small degree. All studied soils were characterized by sandy texture, alkaline reaction and elevated contents of heavy metals (Table 1) and in consequence showed a similar microstructure and mean values of shape and measure indices, confirming a poor differentiation among studied soils (Table 2). In all humus layers decomposed organic matter occurred mainly in the form of fine black excrements with dia. < 200 μm, when medium 200-800 μm were scarce and coarse (> 800 μm) excrements were absent. The fine excrements originated from soil mesofauna such as springtails, with a smaller share of oribatid mites and enchytraeid worms. The oribatid mites and enchytraeids are supposed to be more sensitive to heavy

Table 2. Results of morphometric analysis.
A) Selected characteristics of shapes and measurements of soil voids.

No. of soil	Mean indices of void shape			Mean indices of void measurement	
	elongation	compactness	circularity	% share of pores dia. < 30 µm	surface in mm^2
1	0.42 ab	0.62 a	0.65 a	4.17 ab	2.60 a
2	0.44 b	0.65 ab	0.67 ab	2.67 a	6.33 c
3	0.41 ab	0.63 a	0.66 a	1.87 a	4.35 b
4	0.43 ab	0.68 b	0.69 b	4.56 ab	3.07 ab
5	0.39 a	0.64 a	0.66 a	5.80 b	4.31 b

B) Selected characteristics of shape and amount of decomposed organic components.

No. of soil	Mean indices of shape of organic components				Mean indices of amount of organic components			
					% share of components with dia.			surface in mm^2
	elongation	compactness	circularity	intensity	< 200 µm	200-800 µm	> 800 µm	
1	0.43 a	0.53 bc	0.60 bc	24.5 a	87.4 bc	12.3 a	0.2 a	1.29 a
2	0.49 b	0.47 a	0.54 a	25.6 a	71.8 a	27.9 b	0.1 a	3.55 bc
3	0.46 ab	0.50 ab	0.56 ab	26.1 a	73.3 a	26.5 b	0.2 a	5.35 d
4	0.45 ab	0.53 bc	0.59 bc	28.8 b	79.2 ab	19.8 ab	1.0 a	4.70 cd
5	0.44 a	0.56 c	0.61 c	26.6 ab	89.1 c	10.7 a	0.2 a	2.74 ab

C) Selected characteristics of shape and amount of undecomposed organic components.

No. of soil	Mean indices of shape of organic components				Mean indices of amount of organic components			
					% share of components with surface in µm^2			surface in mm^2
	elongation	compactness	circularity	intensity	< 1000	1000-10,000	> 10,000	
1	0.44 a	0.58 b	0.62 b	102.5 a	38.8 b	29.5 ab	31.7 a	6.28 b
2	0.51 b	0.49 a	0.54 a	101.4 a	18.9 a	41.3 ab	39.8 a	0.41 a
3	0.47 ab	0.54 ab	0.60 b	104.5 a	12.1 a	26.7 a	61.2 b	0.06 a
4	0.44 a	0.56 b	0.61 b	113.3 a	39.2 b	36.6 ab	24.2 a	1.35 a
5	0.46 ab	0.58 b	0.62 b	99.8 a	33.6 b	42.4 b	24.0 a	1.18 a

D) Percentage share of studied components in the total image area.

No. of soil	Decomposed organic matter	Undecomposed organic matter	Soil voids
1	8.8 a	28.1 c	17.7 a
2	24.2 bc	2.8 ab	43.1 c
3	36.5 d	0.4 a	29.6 b
4	32.0 cd	9.2 b	20.9 ab
5	18.7 ab	8.1 b	29.4 b

The same letters indicate a lack of statistically significant differences among mean values; Elongation — 0 for a circle and 1 for an ellipse which is long and narrow; Compactness — 1 for the perfect square and smaller for shapes with irregular boundaries; Circularity — 1 for a circle and smaller for less circular objects; Intensity — differences in pixel values within an object.

metal pollution, while the springtails population was not easily affected by heavy metals [4, 5]. The absence of coarse organo-mineral excrements indicated a lack of macrofauna in studied soil layers. The dominance of small soil arthropods over macrofauna was probably attributed to elevated heavy metal concentrations.

The soil of site 1, overgrown with pine greenwood, was contaminated by heavy metals to the lowest degree. It was characterized by the highest accumulation of undecomposed organic matter (statistically significant difference — Table 2C), mainly anisotropic, composed of undecayed root fragments. In this case the development of the humus layer was determined by chemical properties of pine litter rich in lignin, a high content of which caused a slow decomposition of organic matter and consequently the accumulation of the litter on the soil sur-

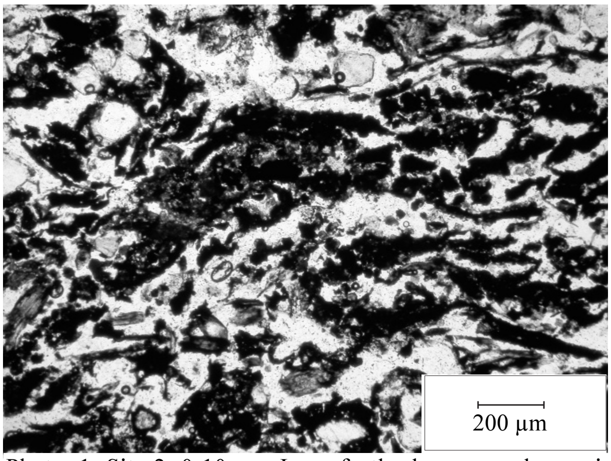

Photo. 1. Site 2, 0-10 cm. Imperfectly decomposed organic matter in forms of loosely packed, black, elongated fragments, not mixed with mineral parts of the soil. Paralell nicols.

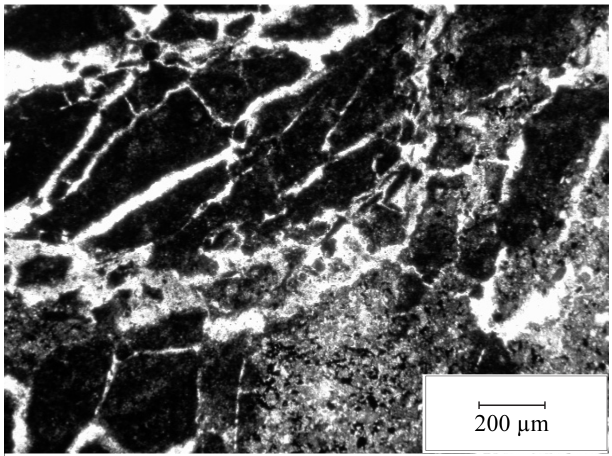

Photo. 2. Site 3, 0-15 cm. Post flotation material containing big pieces of organic carbon. Paralell nicols.

face. Moreover, the soil is characterized by rather low biological activity, indicated by a low level of estimated dehydrogenase activity, (Table 1) and the abundance of mesofauna (mostly springtails) which decomposes organic matter only to a low degree.

The soil of site 2 was heavily contaminated by heavy metals, but besides such high pollution, is overgrown with compact grass community, tolerant of the heavy metals which created a rich organic matter humus horizon, porous and with a high cation exchange capacity (Table 1A). This soil was more active biologically than others, which was indicated by a high level of dehydrogenase activity (Table 1B) and a higher amount of medium sized aggregates of animal origin (Table 2B). Results of morphometric analysis of aggregate shapes showed the dominance of elongated aggregates (Table 2B). These excrements are characteristic for springtails and the predominance of these animals over other mesofauna pointed to their tolerance to heavy metals. The accumulation of imperfectly decomposed organic matter, observed in thin sections of humus horizons, in the form of loosely packed, black elongated fragments, not mixed with mineral particles, indicates reduced decomposition of soil organic matter, which again could be a result of heavy metal contamination (Photo. 1).

The soil of site 3 is scarcely covered by small pine trees and is heavily polluted by heavy metals. A high content of organic carbon in this soil demonstrates that post flotation material which was recently deposited, must be spoiled with substances containing organic carbon. This supposal was confirmed by observations of thin sections (Photo. 2) and the very low level of dehydrogenase activity (Table 1B). Therefore, results of morphometric analysis regarding the shape and amount of decomposed organic matter were not related with aggregates of animal origin as the organic matter in the soil was not formed through humification of plant litter.

Although the elevated concentration of heavy metals affected major soil components, the development of humus layers indicated that the kind of vegetation, its age and degree of cover of the soil surface were as important for the development of the humus layers and organic matter accumulation as heavy metal contamination. In the case of soil which is both polluted by heavy metals and covered by plants tolerant to elevated amounts of these metals in the soil material (soil 2 — Tab. 1), content of organic matter is visibly higher in upper layers of the profile than in respective layers of other studied soil profiles. Under these conditions the accumulation of organic matter is probably a result of the reduction of the density of the soil fauna responsible for the decomposition and humification of the accumulated plant material. In spite of the neutral reaction of this soil, excrements of earthworms, enchytraeids, oribatid mites and macroarthropods have not been found, whereas springtail's fecal pellets could be easily observed. Nevertheless, springtails have a poor effect on the soil structure as they feed mainly on fungi and not on plant litter, which may accumulate despite high densities of these animals.

Conclusions

1. Total amounts of cadmium, zinc and lead indicate that the soils are polluted by heavy metals to a varying degree.
2. In all humus layers decomposed organic matter occurred mainly in the form of fine excrements, originated from small soil arthropods, while macrofauna excrements were quite absent. The dominance of soil mesofauna over macrofauna was probably attributed to higher heavy metal concentration.
3. The elevated concentration of heavy metals affected major soil components but the kind of vegetation and the degree of cover of the soil surface were as important for the development of the humus layers as heavy metal contamination itself.

References

1. World reference base for soil resources. 84 World Soil Resources Reports FAO, ISRIC and ISSS, Rome, pp. 109, **1998**.
2. BAL L. Morphological investigation in two moder humus profiles and the role of the soil fauna in their genesis. Geoderma **4**, 5, **1970**.
3. CASIDA L. E., KLEIN D. A., SANTORO T. Soil dehydrogenase activity. Soil Science **98**, 371, **1964**.
4. DIJKSTRA E. F. A micromorphological study on the development of humus profiles in heavy metal polluted and nonpolluted soils under Scots pine. Geoderma **82**, 341, **1998**.
5. GILLET S., PONGE J. F. Humus forms and metal pollution in soil. European J. Soil Science **53**, 529, **2002**.
6. KABATA-PENDIAS A., MOTOWICKA-TERELAK T., PIOTROWSKA M., TERELAK H., WITEK T. Evaluation of a degree of soil and plant pollution by heavy metals and sulphur (in Polish). IUNG, **P (53)**, 20, **1993**.
7. PROTZ R., VANDENBYGAART A. J. Towards systematic image analysis in the study of soil micromorphology. Sciences Soils **3**, 4, **1998**.
8. RUSEK J. Die bodenbilde Funktion von Collembolen und Acarina. Pedobiologia **15**, 299, **1975**.