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SELECTED CHEMICAL PROPERTIES OF NECROSOLS FROM THE ABANDONED CEMETERIES SŁABOWO AND SZYMONKA (GREAT MAZURIAN LAKES DISTRICT)

Abstract: The paper shows the occurrences of cemetery soils and the physico-chemical features of soils in the cemeteries Słabowo and Szymonka (Great Mazurian Lakes District). Necrosols are anthropogenic soils and belong to Urbanosols. They form only in the area of cemeteries. Four soil profiles (Necrosols) were investigated in terms of morphological description and chemical properties especially phosphorus (Pt), organic carbon (OC) and nitrogen (Nt). These profiles were compared with the reference profile (Rusty soil, according to WRB 2007 *Brunic Arenosol*) made outside the cemetery. On the basis of research Necrosol has been defined as a soil formed by special human activity in cemeteries and burial grounds with specific soil horizon sequence, and also physical and chemical properties.

Key words: Necrosol, abandoned cemetery, chemical properties (Pt, OC, Nt), Great Mazurian Lakes District

Introduction

Within cemeteries a specific type of soil, Necrosol, is formed. Changes made by humans as a result of burial make new physical and chemical properties of cemetery soils.

Research on Necrosol properties is relatively new. The first research into Necrosols was made in Czechoslovakia in 1957 (Smolik 1957). In 1994, a German researcher Burghardt (1994) first classified cemetery soils as

urban soils. Sobocka (2002, 2003, 2004) in her studies gave a reason for treating Necrosols as a new type of anthropogenic soils. According to the classification of anthropogenic soils carried out by Gerasimova and her team (2003), Necrosols are a type of urban soils. Investigation into Necrosols in Poland is rare (Bednarek et al. 2004; Charzyński et al. 2011) despite cemeteries being interesting objects for study of anthropogenic soil.

Burial and its consequences lead to changes in the soil profile, such as transformation of the original genetic system and changes in chemical properties (Bednarek et al. 2004). In diverse proportions cemetery soils are subjected to natural soil forming processes and mechanical changes in the soil profile (Stroganova et al. 1998). What is also characteristic is the presence of artefacts (bones, coffin remains, textile elements) artificially found in the profile.These changes, in place of soil horizons, lead to the formation of specific layers that do not occur outside the anthropogenic interference. The layers are cramped and their aeration is reduced, which may inhibit the encroachment of vascular plants (Majgier 2010).

The aim of this paper is to present the diversity of chemical properties, in particular total phosphorus, organic carbon and total nitrogen, in Necrosols based on the example of two abandoned cemeteries of Słabowo and Szymonka and their comparison with natural soil not changed by humans.

Materials and methods

Four soil profiles of selected abandoned cemeteries and one reference profile, outside the area of the cemetery, were described and analyzed. Obtained results from the reference profile were a background for comparison with Necrosols. On the basis of the distinguished genetic horizons and morphological description the reference profile was defined as rusty soil (according to WRB 2007 *Brunic Arenosol*) with a typical system of horizons O-A-Bv-C (Polish Soil Classification 2011).

Cemetery soils were divided in accordance with their character into burial Necrosol (with the direct influence of the burial on the profile) and non-disturbed Necrosol (soil in the area of the cemetery, not having undergone the direct influence of the burial). In all investigated profiles a morphological description was made, and from genetic horizons and layers samples were taken for laboratory analyses. Soil samples were submitted to standard physical and chemical analyses: texture by the Bouyoucose method

modified by Casagrande and Prószyński (particle size classes according to Polish Soil Classification 2011); soil colour according to Munsell; pH in water and in 1M KCl, $CaCO_3$ by the Scheibler method; organic carbon (OC) by the Tyurin method; total nitrogen (Nt) by the Kjeldahl method (Bednarek et al. 2004); total phosphorus (Pt) by the Bleck method, modified by Gebhardt (1982).

In this paper for the description of the burial Necrosol, due to the anthropogenic character of the investigated profiles we applied symbols: Wp – the plate of the tombstone, Wa – the anthropogenic layer, Wt – the anthropogenic layer artificially enriched with anthropogenic organic matter, with the participation of many artefacts (bones, coffin remnants, clothing pieces) in the profile.

Study area

The investigation was conducted on the abandoned evangelical cemeteries in Słabowo and Szymonka. They are located in the Ryn commune (Giżycko County) in the Great Mazurian Lakes District (Fig. 1), in the middle part of the Masurian Lakeland (Kondracki 2002).

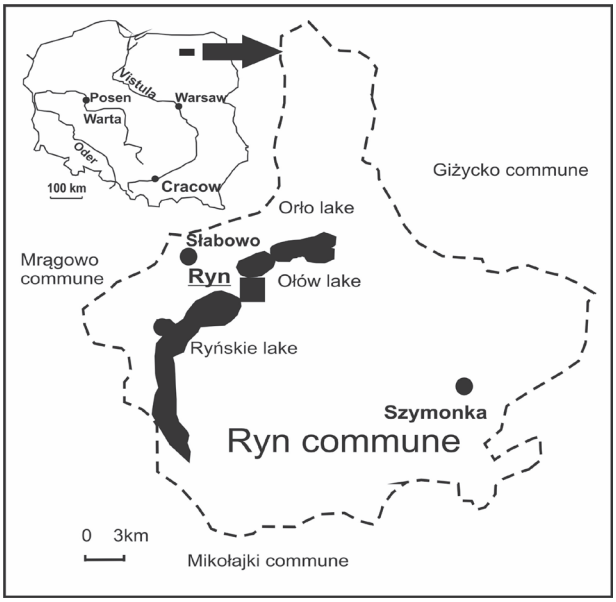

Fig. 1. Location of the study area

The evangelical cemetery Słabowo with a surface area of 0.19 ha, became established at the end of 19th century, as the cemetery for the Slabowen village. The cemetery Szymonka has the character of a mass grave of German soldiers buried in 1914 and 1945. Its surface covers 0.10 ha. The described features are placed on moraine forms, and the material of the ground is of postglacial origin which is composed of boulder clay, moraine deposition, sand and sandy loam.

Results and discussion

The detailed morphological descriptions of the tested soils are presented in Table 1 and Figure 2. In the morphological structure of burial Necrosols anthropogenic layers (Wt) were distinguished. They are the result of mixing of the material due to the burial. Additionally, the burial Necrosol of Szymonka cemetery has an anthropogenic layer, clearly defined between 90 cm and 110 cm, enriched in organic matter. A large proportion of artefacts (bones, coffin remains and textile elements) artificially introduced into the profile is characteristic for this layer. Given the mass nature of the grave in the cemetery of Szymonka, the contents of artefacts in the layer Wt of the burial Necrosol is considerable and the share of bones in relation to other artefacts is 60%.

Table 1. Morphology of investigated soils

Depth [cm]	Horizon	Description
Cemetery Słabowo – **Burial Necrosol (Fig. 2)**		
–	Wp	Tombstone
0–12	A	Humus horizon, loose coarse and medium sand, fresh, colour 10YR 4/2 in the dry state, 10YR 2/2 in the wet state, occasionally overgrown with thin roots of plants, horizon boundary abrupt
13–22	Wa	The anthropogenic layer strongly mixed, with the large share of material originated from A horizon, loose fine and medium sand, fresh, colour 10YR 4/4 in the dry state, 10YR 3/3 in the wet state, occasional iron concretions, occasionally outrgrown with thin roots of plants, horizon boundary gradual

Cemetery Słabowo **– Burial Necrosol (Fig. 2)**		
23–60	Wa2	The anthropogenic layer mixed, in short supply withdraws material from A horizon, loose fine and medium sand, fresh, colour 10YR 4/4 in the dry state, 10YR 3/3 in the wet state, occasional iron concretions, occasionally outgrown with thin roots of plants, horizon boundary gradual
61–100	Wa3	The anthropogenic layer strongly mixed, with features of the C horizon, loose fine and medium sand, fresh, appears anthropogenic material in form of unidentified plastic elements (15 %), colour 10YR 5/4 in the dry state, 10YR 3/4 in the wet state, a single large root appears, horizon boundary gradual
> 100	C	The parent rock horizon, coarse and fine silt and clay, strongly compacted, fresh, colour 2.5Y 7/4 in the dry state, 2.5Y 4/4 in the wet state, roots of plants do not appear
Cemetery Słabowo **– Non-disturbed Necrosol – Rusty soil** (*Brunic Arenosol*) (Fig. 2)		
2–0	O	The horizon built from decomposed and undecomposed litter of *Syringa vulgaris* and *Tilia platyphyllos*
0–20	A	Humus horizon, loose coarse and medium sand, fresh, colour 10YR 4/2 in the dry state, 10YR 2/2 in the wet state, outgrown with very numerous thin and thick roots of plants, horizon boundary abrupt
21–60	Bv	Enrichment horizon *sideric,* loose coarse and medium sand, fresh, colour 10YR 4/4 in the dry state, 10YR 3/3 in the wet state, outgrown with many thin and thick roots of plants, many iron concretions, horizon boundary gradual
61–150	Bv2	Enrichment horizon *sideric,* loose medium sand, fresh, colour 10YR 5/4 in the dry state, 10YR 3/6 in the wet state, occasionally outgrown with thick roots of plants, occasional iron concretions, horizon boundary abrupt
> 150	C	The parent rock, loose fine and medium sand, fresh, colour 2.5Y 7/4 in the dry state, 2.5Y 4/4 in the wet state, occasionally outgrown with thin roots of plants

Cemetery Szymonka – **Burial Necrosol**		
0–20	A	Humus horizon, loose coarse and medium sand with a share of fine gravel, fresh, colour 10YR 4/2 in the dry state, 10YR 2/2 in the wet state, outgrown with many thin roots of plants, horizon boundary gradual
21–40	Wa	The anthropogenic layer strongly mixed, with a large share of material from A horizon many portions of fine gravel, loose coarse and medium sand, fresh, colour 10YR 5/3 in the dry state, 10YR 3/4 in the wet state, outgrown with many thin roots of plants, horizon boundary gradual
41–60	Wa2	The anthropogenic layer strongly mixed, with a share of material from A horizon and the Wa layer (portion of fine gravel), loose coarse and medium sand, fresh, colour 10YR 4/3 in the dry state, 10YR 3/4 in the wet state, outgrown with many thick roots of plants, horizon boundary gradual
61–90	Wa3	The anthropogenic layer strongly mixed (portion of fine gravel), anthropogenic material appears in the form of glass, fragments of concrete, unidentified rusty metal elements (25%), loose coarse and medium sand, fresh, colour 10YR 5/4 in the dry state, 10YR 3/3 in the wet state, occasionally outgrown with thin roots of plants, horizon boundary gradual with the occurrence at the bottom of material from the Wt layer
91–110	Wt	The anthropogenic layer artificially enriched with anthropogenic organic matter – human remains (60%) – layer strongly mixed with a share of material from layers lying higher (a large portion of fine gravel), loose coarse and medium sand, fresh, colour 10YR 4/3 in the dry state, 10YR 3/3 in the wet state, roots of plants do not appear
Cemetery Szymonka – **Non-disturbed Necrosol – Rusty soil** (*Brunic Arenosol*)		
2–0	O	The horizon built up of decomposed and undecomposed litter of *Syringa vulgaris*
0–30	A	Humus horizon, loose medium sand, fresh, colour 10YR 4/2 in the dry state, 10YR 2/2 in the wet state, outgrown with many thin roots of plants, horizon boundary abrupt

Cemetery Szymonka **– Non-disturbed Necrosol – Rusty soil** (*Brunic Arenosol*)		
31–50	Bv	Enrichment horizon *sideric,* loose medium sand, fresh, colour 10YR 5/4 in the dry state, 10YR 3/3 in the wet state, outgrown with many thin roots of plants, iron concretions appear, horizon boundary gradual
51–90	Bv2	Enrichment horizon *sideric,* loose medium sand, fresh, colour 10YR 6/3 in the dry state, 10YR 4/3 in the wet state, occasionally outgrown with thin roots of plants, horizon boundary abrupt
91–140	C	The parent rock, loose coarse, medium and fine sand, fresh, colour 2.5Y 6/3 in the dry state, 2.5Y 4/3 in the wet state, roots of plants do not appear, horizon boundary abrupt
> 140	2C	The parent rock, coarse and fine silt and clay, strongly compacted, lithologic discontinuity, fresh, colour 2.5Y 7/4 in the dry state, 2.5Y 4/4 in the wet state, roots of plants do not appear
Reference profile **– Rusty soil (***Brunic Arenosol***)**		
2–0	O	The horizon built from decomposed and undecomposed litter of *Pinus sylvestris*
0–8	A	Humus horizon, loose medium and fine sand, fresh, colour 10YR 4/1 in the dry state, 10YR 2/1 in the wet state, outgrown with many thin and thick roots of plants, horizon boundary gradual
9–30	ABv	The transitional horizon, loose fine and medium sand, fresh, colour 10YR 4/3 in the dry state, 10YR 3/2 in the wet state, occasionally outgrown with thin roots of plants, horizon boundary gradual
31–90	Bv	Enrichment horizon *sideric,* loose coarse, medium and fine sand, fresh, colour 10YR 5/4 in the dry state, 10YR 3/6 in the wet state, occasional iron concretions, occasionally outgrown with thick roots of plants, horizon boundary abrupt
> 90	C	The parent rock, loose fine gravel, fresh, colour 2.5Y 6/3 in the dry state, 2.5Y 4/4 in the wet state, thick root of *Pinus sylvestris*

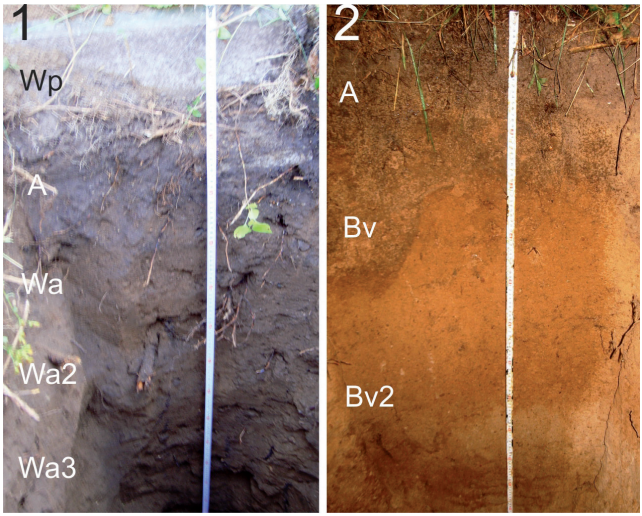

Fig. 2. Necrosol of burial (1) and Necrosol non-disturbed Rusty soil-(Brunic Arenosol) (2) from Cemetery Słabowo (photo by L. Majgier)

In terms of texture the examined soil material is dominated by medium sand (0.5 – 0.25 mm – the average contents of 45%) and fine sand (0.25–0.1 mm – the average contents of 33%). The share of skeleton grain fraction > 5 mm is 1.6% on average for burial Necrosols and 1.1% on average for non-disturbed Necrosols. Of significance is the fraction of 5–2 mm (fine gravel), whose average level is 2% higher for burial Necrosols (burial Necrosols – an average of 7.5%; non-disturbed Necrosols – an average of 5.5%). This is connected with the mixing of the soil as a result of a burial. Grain size in the reference profile is similar to that in Necrosols, which is associated with the same material building up both types of soils. The chemical and physical properties of the studied soils are shown in Table 2.

Table 2. Selected chemical and physical properties of investigated soils

Horizon	Depth	$CaCO_3$	OC	Nt	Pt	pH	
	[cm]	%			$mg \cdot kg^{-1}$	KCl	H_2O
***Cemetery Słabowo* – Burial Necrosol**							
Wp	Tombstone	–	–	–	–	–	–
A	0–12	2.0	3.50	0.214	1045	7.2	7.7

***Cemetery Słabowo* – Burial Necrosol**							
Wa	13–22	1.8	1.03	0.047	322	7.2	7.8
Wa2	23–60	2.4	0.45	0.017	644	7.1	7.4
Wa3	61–100	0.5	0.05	0.009	168	7.7	7.9
C	>100	9.0	0.46	0.019	278	7.3	8.0
		mean	1.10	0.061	491		
***Cemetery Słabowo* – Non-disturbed Necrosol – Rusty soil** (*Brunic Arenosol*)							
O	2–0	-	–	–	–	–	–
A	0–20	0.8	1.14	0.066	319	7.4	8.1
Bv1	21–60	0.7	0.89	0.033	242	7.5	8.0
Bv2	61–150	2.3	0.22	0.022	313	7.6	8.2
C	>150	1.1	0.20	0.022	278	7.2	8.0
		mean	0.61	0.036	288		
***Cemetery Szymonka* – Burial Necrosol**							
A	0–20	3.4	2.71	0.143	1553	7.5	7.9
Wa	21–40	2.7	0.59	0.029	612	7.4	7.9
Wa2	41–60	1.7	0.22	0.042	312	7.6	8.2
Wa3	61–90	1.8	0.49	0.043	332	7.8	8.2
Wt (artefacts)	91–110	1.7	0.92	0.068	644	7.5	8.1
		mean	0.98	0.065	690		
***Cemetery Szymonka*_– Non-disturbed Necrosol – Rusty soil** (*Brunic Arenosol*)							
O	2–0	–	–	–	–	–	–
A	0–30	1.7	2.29	0.236	1188	7.5	8.0
Bv1	31–50	5.2	0.21	0.019	546	8.0	8.3
Bv2	51–90	6.6	0.55	0.007	688	7.4	7.8
C	91–140	8.7	0.07	0.005	558	8.4	8.8
2C	>140	5.2	1.11	0.011	299	8.0	8.4
		mean	0.84	0.055	656		

Reference profile* –Rusty soil (Brunic Arenosol)*							
O	2–0	–	-	–	–	–	–
A	0–8	0.05	2.60	0.136	197	5.3	6.7
ABv	9–30	0.01	0.37	0.014	217	7.5	8.0
Bv	31–90	0.01	0.25	0.007	232	7.3	8.1
C	>90	5.0	0.30	0.005	234	8.1	8.6
		mean	0.88	0.040	220		

The average phosphorus content in the reference profile was 220 mg·kg^{-1}, and in individual horizons it did not exceed 240 mg · kg^{-1}; the average organic carbon content was 0.88% and of total nitrogen 0.040%.

The most important diagnostic element in the case of Necrosols is phosphorus. Its content in the soil indicates the type and intensity of human activity on the site (Brzeziński et al. 1983). The sectional diversification in the phosphorus content in the burial Necrosol in Słabowo cemetery clearly shows that this place was used for a burial. The highest value is presented by the horizon A (1,045 mg · kg^{-1}) and the layer Wa2, where the total phosphorus content exceeds 600 mg · kg^{-1}. The average phosphorus content in the whole profile is 491 mg · kg^{-1} and it indicates its eminently anthropogenic origin.

The average content of organic carbon (1.10%) and total nitrogen (0.061%) in the burial Necrosol of Słabowo cemetery is twice as high as the average contents in the non-disturbed Necrosol (OC – 0.61%, Nt – 0.036%). In the case of the non-disturbed Necrosol it is connected with the natural decomposition of organic matter.

What deserves attention in the cemetery of Szymonka is a similar average content of phosphorus in both burial Necrosol and non-disturbed Necrosol, amounting to over 600 mg·kg^{-1}. It is closely related to the character of the cemetery, which consists of two mass graves from World War I and II. The high content of total phosphorus in the case of the non-disturbed Necrosol is related to the fact that the current cemetery boundary (delimitation based on the location of private premises) does not coincide with the original cemetery boundary and in reality it used to be larger. The profile of the non-disturbed Necrosol was made in the cemetery, near the present boundary. In the layer Wt of the burial Necrosol (90–100 cm), the phosphorus content

was 644 mg · kg^{-1}. The phosphorus contents in the horizons Bv2 and C (50–140 cm) of the non-disturbed Necrosol amounted to 688 mg·kg^{-1} and 558 mg·kg^{-1}, respectively.

As regards the content of organic carbon and nitrogen, the difference in average values both in the individual layers and horizons of the burial Necrosol and non-disturbed Necrosol is not as evident as in the case of Słabowo cemetery. The difference in the average content of organic carbon in the burial Necrosol is +0.14% if compared to the non-disturbed Necrosol, and total nitrogen is +0.10%.

Comparing Necrosols from the cemeteries of Słabowo and Szymonka with the reference profile, we observed that the phosphorus content in the reference profile is more than twice as low as in the burial Necrosol from Słabowo cemetery and three times lower than in the Necrosols of Szymonka cemetery. This comparison emphasizes the impact of a burial on the chemical properties of cemetery soils.

For organic carbon and total nitrogen, the respective values in the reference profile are only slightly different from the data obtained from non-disturbed Necrosols. A larger disproportion is recorded in relation to burial Necrosols of both cemeteries, indicating the increase in organic carbon and nitrogen in relation to the natural soil, which may be a direct consequence of the burial.

Comparing the results regarding the chemical properties of Necrosols transformed by burial obtained in other cemeteries (Sobocka 2004; Żołnowska 2006; Charzyński et al. 2011), the Necrosols of Słabowo and Szymonka cemeteries showed similar features, where the content of phosphorus and organic carbon in the Necrosols transformed by a burial is much higher than in non-disturbed Necrosols and in soils outside cemeteries.

Conclusion

The results showed significant differences in physical and chemical properties of Necrosols, particularly in relation to the reference soil from outside the cemetery. The most important are as follows:

– disturbance of primary genetic horizons of the soil,
– presence of intermixed layers in place of soil horizons,
– presence of artefacts (bones, coffin remains and textile elements).

The analysis of total phosphorus (Pt) content in soils demonstrated a higher content of Pt in Necrosols in relation to an untransformed profile, which confirms the remarkably anthropogenic origin of Necrosols. The increased content of this element provides the basis for recognizing it as a valuable diagnostic element in the research of Necrosols. Another characteristic feature of burial Necrosols is a higher content of organic carbon (OC) and nitrogen (Nt).

Furthermore, in the case of Szymonka cemetery, the analysis of the content of OC, Nt, Pt in soils and field interviews indicated that the current cemetery boundary does not coincide with the original one (the modern cemetery is smaller).

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