5 NECROSOLS OF CEMETERIES IN MASURIAN LAKELAND

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Introduction

The soil development in the surface layer of the earth's crust is a result of soil-forming factors, such as parent material, climate, organisms (vegetation and fauna), relief and time. The advent of man on Earth and the development of civilisation added another important factor in soil formation – human activity (Jenny 1941; Dokuchaev 1949; Mulins 1991). The latter factor has led to the transformation of soils, especially in the areas of intensive settlement (Baran, Turski 1996) and deforestation of natural ecological systems (Vitousek et al. 1997). Such places may include cemeteries, where specific land use has degraded the natural soil cover.

Earlier soil science studies have led to the identification of a new type of soil formed in cemeteries as Necrosol. This is a specific type of soil that is exposed to unequal proportions of mechanical and chemical changes in the soil profile, as well as to natural soil-forming processes. Physical changes lead to the formation of specific horizons not found in soils devoid of technogenic influence (Stroganova et al. 1998; Stroganova, Prokofieva 2000; Gerasimova et al. 2003). Human activity contributes to changes in physical and chemical properties of cemetery soils.

The issue of Necrosols did not appear in the scientific literature until the second half of the 20th century. The precursors in this field were Czechoslovak researchers Smolik (1957) and Svec and Hlina (1978). Necrosols were described in detail by the Slovak researcher Sobocká (1999; 2003; 2004). The first classification was delivered by Burghardt (1994).

In Poland, cemetery soil properties have been described by Charzyński et al. (2011), as well as by Majgier and Rahmonov (2012).

Study area and soil profiles documentation

The investigation was conducted in the abandoned evangelical cemeteries in the villages of Rudówka Mała and Wejdyki. They are located in the Ryn commune in the Great Masurian Lake District, in the central part of the Masurian Lakeland (Fig. 1). Moraine deposits from the Weichselian Glaciation are the parent material for soil development in this region. They consist mostly of boulder clay, sand and gravel with a substantial contribution of limestone fragments of different sizes (Kondracki 2002).

The investigated cemeteries were founded in the 19th century by people of German and Masurian origin. They have not been used since the end of World War II (Płotek 2011) and are devastated and overgrown as a result of natural succession (Majgier, Rahmonov 2010; 2012; Rahmonov et al. 2010).

The cemeteries were surveyed by taking four soil profiles: two in Rudówka Mała (profiles 1 and 2) and two in Wejdyki (profiles 3 and 4). The profiles were divided into two groups: burial Necrosols (profiles 1 and 3) and undisturbed cemetery soils (profiles 2 and 4).

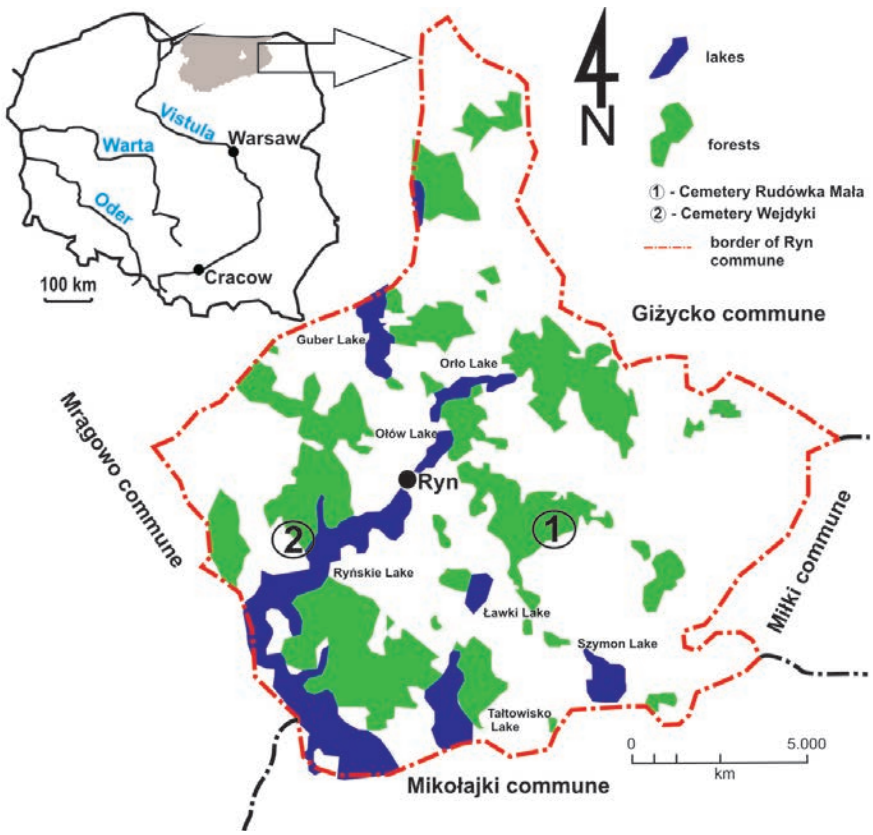
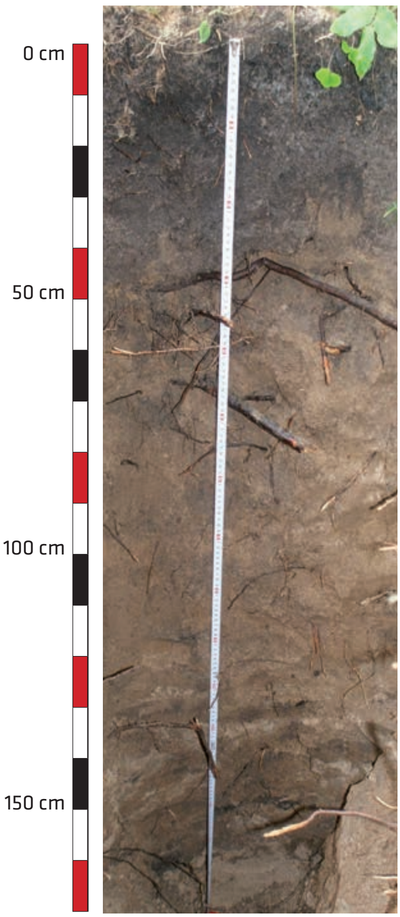


Fig. 1. Location of investigated cemeteries

Profile 1

Location:
Cemetery Rudówka Mała
Ryn commune
Northern Poland
Coordinates:
53°55.550' N
21°37.443' E
Soil classification (WRB 2007):
Urbic Technosol



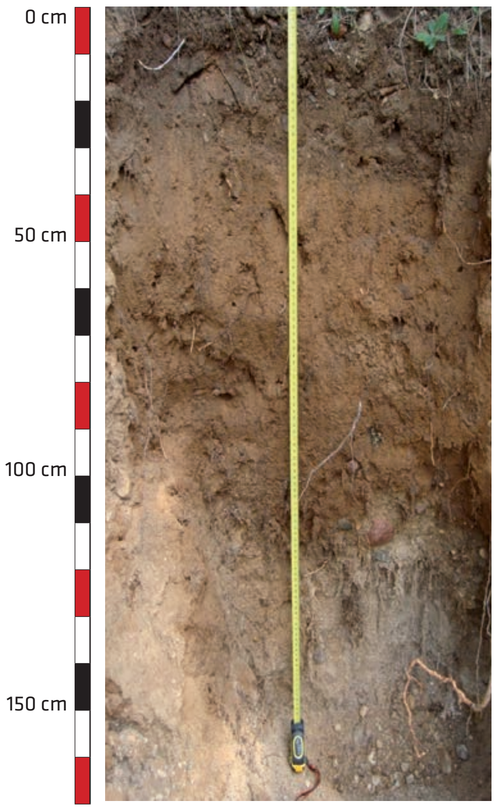
A – 0–30 cm: loose sand, dark greyish brown, fresh, penetrated by thin roots of plants, abrupt boundary.
Bu1 – 30–70 cm: large contribution of material originated from A horizon, loose sand, yellowish brown, fresh, occasionally penetrated by thin roots of plants, a few artefacts (pieces of concrete, pieces of bricks; 5%), gradual boundary.
Bu2 – 70–100 cm: slight contribution of material originated from A horizon (gravel), loose sand, yellowish brown, fresh, penetrated by large roots of plants, gradual boundary.
Bu3 – 100–125 cm: large contribution of material originated from Bu2 layer, loose sand, yellowish brown, fresh, penetrated by thin roots of plants, a few artefacts (pieces of concrete, pieces of bricks, stones; 15%), gradual boundary.
Bu4 – 125–148 cm: artificial enrichment with anthropogenic organic matter, loamy sand, yellowish brown, fresh, roots of plants absent, iron concretions, a lot of artefacts (bones, coffin remains, clothing pieces, gravel, stones; <30%), abrupt boundary.
C – below 148 cm: loose sand, pale yellow, fresh, occasionally penetrated by thin roots of plants.

Table 1. Selected soil properties – profile 1

HORIZON		A	Bu1	Bu2	Bu3	Bu4	C
DEPTH [cm]		0–30	30–70	70–100	100–125	125–148	<148
PARTICLE SIZE DISTRIBUTION [%]							
>2 mm		3	8	40	19	42	<1
2 mm–50 μm		93	97	95	94	90	99
50–2 μm		7	3	3	3	7	1
<2 μm		0	0	2	3	3	0
TEXTURE CLASS (USDA)		loose sand	loose sand	loose sand	loose sand	loamy sand	loose sand
SOIL MATRIX COLOUR	**dry**	10YR 4/2	10YR 5/4	10YR 5/4	10YR 5/4	10YR 5/4	2.5Y 7/3
	moist	10YR 2/2	10YR 3/6	10YR 3/6	10YR 3/3	10YR 3/4	2.5Y 5/3
OC [%]		3.36	0.41	1.15	0.43	0.61	0.07
N_t[%]		0.170	0.017	0.121	0.017	0.026	0.007
C:N		20	24	9	25	23	10
pH	**in H_2O**	7.2	8.2	8.1	8.4	8,2	8.6
	in 1M KCl	6.5	7.6	7.5	7.9	7.6	8.1
$CaCO_3$ [%]		1.0	1.5	2.0	1.9	1.2	5.1
P_t [mg·kg^{-1}]		1560	249	2010	239	259	184

Profile 2

Location:
Cemetery Rudówka Mała,
Ryn commune,
Northern Poland
Coordinates:
53°55.550' N
21°37.434' E
Soil classification (WRB 2007):
Brunic Arenosol



A – 0–31 cm: loose sand, very dark grey, fresh, penetrated by many thin roots of plants, a few artefacts (pieces of concrete, pieces of bricks; >5%), abrupt boundary.

Bwo1 – 31–100 cm: loose sand, dark yellowish brown, fresh, penetrated by many thin roots of plants, iron concretions, gradual boundary.

Bwo2 – 100–155 cm: loose sand, brown, fresh, penetrated by many thick roots of plants, gradual boundary.

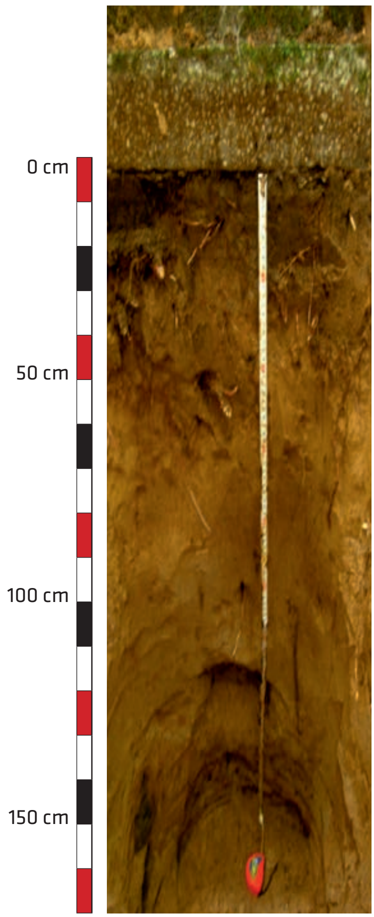
C – below 155 cm: loose sand, light yellowish, fresh, occasionally penetrated by thin roots of plants.

Table 2. Selected soil properties – profile 2

HORIZON		A	Bwo1	Bwo2	C
DEPTH [cm]		0–30	30–100	100–155	< 155
PARTICLE SIZE DISTRIBUTION [%]					
>2 mm		6	7	9	4
2 mm–50 μm		94	95	95	97
50–2 μm		6	5	5	3
<2 μm		0	0	0	0
TEXTURE CLASS (USDA)		loose sand	loose sand	loose sand	loose sand
SOIL MATRIX COLOUR	**dry**	10YR 3/1	10YR 4/4	10YR 4/3	2.5Y 6/3
	moist	10YR 2/1	10YR 3/4	10YR 3/2	2.5Y 4/3
OC [%]		3.66	0.39	1.07	0.05
N_t [%]		0.257	0.007	0.034	0.005
C:N		14	56	31	11
pH	**in H_2O**	7.4	8.0	8.0	8.4
	in 1M KCl	6.8	7.3	7.4	8.0
$CaCO_3$ [%]		0.3	0.9	1.9	5.4
P_t [mg·kg^{-1}]		323	246	468	446

Profile 3

Location:
Ryn commune,
Northern Poland
Coordinates:
53°55.140' N
21°30.080' E
Soil classification (WRB 2007):
Ekranic Technosol



Tombstone

A – 0–10 cm: loose sand, dark greyish brown, fresh, penetrated by many thin roots of plants, abrupt boundary.

Bu1 – 10–60 cm: large contribution of material originated from A horizon, loose sand, brown, fresh, penetrated by many thin roots of plants, a few artefacts (pieces of concrete; <10%), gradual boundary.

Bu2 – 60–110 cm: small contribution of material originated from A horizon and large contribution of material originated from Bu1 layer, loose sand, brown, fresh, penetrated by many thin roots of plants, a few artefacts (pieces of concrete, stones; 10%), abrupt boundary.

Bu3 – 110–140 cm: artificial enrichment with anthropogenic organic matter, loose sand, brown, fresh, penetrated by many thin roots of plants, a lot of artefacts (bones, coffin remains, pieces of concrete, gravel; <30%), gradual boundary.

Bu3C – 140–160 cm: transitional horizon mixed with Bu3 layer, loose sand, yellowish brown, fresh, penetrated by many thin roots of plants, a few artefacts (bones; 15%), gradual boundary.

C – below 160 cm: loose sand, light yellowish brown, fresh, no roots.

Table 3. Selected soil properties – profile 3

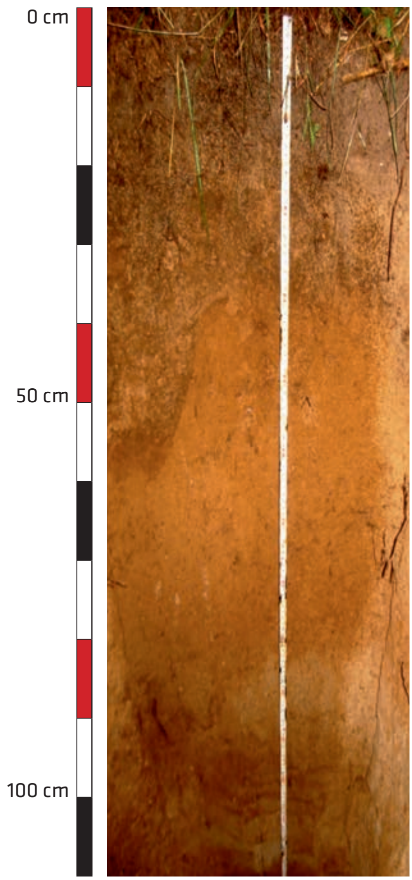
HORIZON		A	Bu1	Bu2	Bu3	Bu3C	C
DEPTH [cm]		0–10	10–60	60–110	110–140	140–160	< 160
PARTICLE SIZE DISTRIBUTION [%]							
>2 mm		9	17	18	37	25	12
2 mm–50 μm		94	94	93	95	96	93
50–2 μm		6	6	7	5	4	6
<2 μm		0	0	0	0	0	1
TEXTURE CLASS (USDA)		loose sand	loose sand	loose sand	loose sand	loose sand	loose sand
SOIL MATRIX COLOUR	**dry**	10YR 4/2	10YR 5/3	10YR 5/3	10YR 4/3	10YR 5/4	2.5Y 6/3
	moist	10YR 2/2	10YR 3/3	10YR 3/3	10YR 3/3	10YR 3/6	2.5Y 4/3
OC [%]		0.21	0.41	1.11	2.51	0.17	1.07
N_t [%]		0.006	0.034	0.027	0.064	0.024	0.020
C:N		36	12	41	39	7	53
pH	**in H_2O**	7.1	7.5	7.6	7.4	7.8	8.1
	in 1M KCl	6.4	7.0	7.0	6.7	7.3	8.0
$CaCO_3$ [%]		0.6	0.5	0.4	0.8	0.6	6.0
P_t [mg·kg^{-1}]		240	290	308	680	660	291

Profile 4

Location:
Cemetery Wejdyki,
Ryn commune,
Northern Poland

Coordinates:
53°55.141' N
21°30.100' E

Soil classification (WRB 2007):
Brunic Arenosol



A – 0–10 cm: loose sand, very dark greyish brown, fresh, penetrated by many thin roots of plants, a few artefacts (pieces of concrete; 5%), gradual boundary.

ABo – 10–30 cm: loose sand, brown, fresh, calcium carbonate concretions, penetrated by many thin roots of plants, gradual boundary.

Bwo1 – 30–80 cm: loose sand, light yellowish brown, fresh, penetrated by many thin roots of plants, iron concretions, gradual boundary.

Bwo2 – 80–100 cm: loamy sand, pale brown, fresh, penetrated by many thin roots of plants, gradual boundary.

Table 4. Selected soil properties – profile 4

HORIZON		A	ABo	Bwo1	Bwo2	C	C2
DEPTH [cm]		0–10	10–30	30–80	80–100	100–120	< 120
PARTICLE SIZE DISTRIBUTION [%]							
>2 mm		7	9	5	8	0	3
2 mm–50 μm		95	94	94	86	99	95
50–2 μm		5	6	6	12	1	5
<2 μm		0	0	0	2	0	0
TEXTURE CLASS (USDA)		loose sand	loose sand	loose sand	loamy sand	loose sand	loose sand
SOIL MATRIX COLOUR	**dry**	10YR 3/2	10YR 4/3	10YR 6/4	10YR 6/3	10YR 5/4	2.5Y 6/3
	moist	10YR 2/1	10YR 2/2	10YR 4/4	10YR 4/3	10YR 4/4	2.5Y 4/3
OC [%]		3.04	0.47	0.09	0.06	0.06	0.04
N_t [%]		0.146	0.046	0.008	0.006	0.010	0.006
C:N		21	10	12	10	–	–
pH	**in H_2O**	6.9	7.7	8.1	7.8	7.5	8.5
	in 1M KCl	6.3	7.4	7.6	6.8	6.8	6.8
$CaCO_3$ [%]		0.01	0.01	0.01	0.01	0.01	0.05
P_t [mg·kg^{-1}]		572	267	152	111	188	144

Influence of the burial process and cemeteries use on soil properties

Cemetery soils were divided in accordance with their character into burial Necrosols (with the direct influence of the burial on the profile) and undisturbed cemetery soils (soil in the cemetery area, not exposed to direct influence of the burial, but exposed to indirect impact of cemetery use). Morphological descriptions were made for all investigated profiles, and samples were taken from genetic horizons and layers for laboratory analysis. Soil samples were submitted to standard physical and chemical analyses (van Reeuwijk 2006).

In the past, the soils in abandoned cemeteries were exposed to strong techno- and anthropogenic pressure, related to the nature of these sites and the consequent type of land use. As a result, they have special properties compared to soils that remain outside the influence of cemeteries. The research results also showed significant differences between soils located in individual cemeteries.

As evidenced by the research, one of the most important morphological features of burial Necrosols was the distortion of the natural sequence of genetic horizons and their replacement with the mixed human-disturbed layers (Bu). A larger number of technogenic layers was mainly connected with the contribution of material of the overlying layers and horizons (especially gravel), the presence of man-made artefacts coming from the cemetery infrastructure (concrete, brick, glass, plastic) and the presence of plant material that has entered deeper into the soil profile.

In the case of profiles 1 and 3, the technogenic layers artificially enriched with organic matter (Bu3 and Bu4) were associated with the process of grave digging, deposition of a coffin and backfilling. In this way, there was a secondary supply of technogenic material to the soil profile, which exerted further impact on the soil chemistry. The depth of this layer was determined by the nature of the burial. In the studied burial Necrosols, the depth of the technogenic layer enriched with ex situ organic matter ranged from 110 cm to 150 cm. The distinguishing feature of this layer was its peculiar brown colour, resulting from the decomposition of coffin wood. This is characteristic of burial Necrosols.

The investigated burial Necrosols were distinguished by a large contribution of skeletal particles (>2 mm) – mainly artefacts, which Sobocká (2004) considers to be typical of Necrosols. This is especially important for the technogenic layers, which in some cases of the analysed profiles contained over 30% of the skeletal particles (gravel and man-made artefacts).

All the examined soil profiles were characterised by neutral to alkaline reaction. This is due to a high content of carbonates in the parent material, and thus the presence of these compounds in other horizons and layers. In addition, a significant contribution of artefacts in Necrosols, especially elements of the cemetery infrastructure (concrete debris), affects the soil alkalisation due to their chemical composition. The increase in pH of Necrosol layers and horizons was noted (Tables 1–4). The reaction of mechanically untransformed soils (undisturbed cemetery soils) was indirectly affected by a cemetery through a secondary supply of carbonates.

As evidenced by the research, the organic carbon (OC) content both in burial Necrosols and undisturbed cemetery soils varied. The highest OC content was recorded in humus horizons of burial and undisturbed Necrosols (from 0.21% to 3.66%) and the technogenic layers enriched with organic matter from *ex situ* (Bu4, Bu3) of the burial Necrosols (from 0.61 % to 2.51 %). A similar situation was observed for the total nitrogen (N_t) content (Tables 1–4).

Phosphorus is a crucial geochemical indicator in pedological studies of anthropogenic and technogenic soils (Goffer 1980; Gebhardt 1982; Andrzejewski, Socha 1998; Bednarek 2007, 2008; Bednarek, Markiewicz 2007; Markiewicz 2011). Its higher content in the soil may reflect the anthropogenization of the environment (Brzeziński et al. 1983; Bednarek et al. 2004; Chudecka 2009). The usefulness of the phosphorus method in the research on cemetery soils has been ascertained by other authors (Sobocká 2004; Charzyński et al. 2011; Żychowski 2011; Majgier, Rahmonov 2012), as well as by the present study.

The total phosphorus content (P_t) in the studied soils was determined by Bleck method, modified by Gebhardt (1982). The highest accumulation of P_t was found in the A horizons and layers enriched with organic matter from *ex situ* (profile 1 – Bu4 and profile 3 – Bu3) of the burial Necrosols (259–2 010 $mg \cdot kg^{-1}$), and in the humus horizons of both burial Necrosols and undisturbed soils (240–1 560 $mg \cdot kg^{-1}$).

For comparative purposes, based on the soil outside the cemeteries, the background value of phosphorus was determined for the cemeteries in the Ryn commune. The standard phosphorus content in the area was up to 300 $mg \cdot kg^{-1}$. This value is close to the average geochemical background for north-east Poland, i.e. 250 mg $P \cdot kg^{-1}$ (Geochemical Atlas of Poland 1995).

High levels of phosphorus accumulation in the humus horizons of all soils from the investigated cemeteries are associated with organic fertilisers used for soil fertilization in the areas where ornamental plants are grown. Similar values were found for other soil used for garden vegetation growing (Chudecka 2009). However, a high concentration of phosphorus in the technogenic layers (especially in the layers artificially enriched with organic matter) is closely linked with burials. It should be noted that the recorded contents of P_t were lower than the results obtained at archaeological sites (Bednarek et al. 2004; Bednarek, Markiewicz 2007; Bednarek 2008) and in mass graves (Żychowski 2011).

Summary

Due to different degrees of soil transformation within the cemeteries, it is suggested that the soils developed due to mechanical transformation, leading to disturbances in natural genetic horizons, should be classified as burial Necrosols. Other undisturbed cemetery soils have not been transformed mechanically, but they are indirectly affected by burials, especially in surface horizons.

Burial Necrosols develop due to mechanical transformation leading to disturbances in natural genetic horizons and the formation of intermingled technogenic layers with the presence of anthropogenic layers artificially enriched with organic matter. These layers have a specific brown colour, derived from decaying coffin wood and a high content of extraneous material in the form of artefacts (for example bones, coffin remains).

Undisturbed cemetery soils do not have technogenic layers, instead they preserve their natural genetic horizons. The major changes in their morphology are observed in the surface horizons, which contain technogenic material (fragments of concrete, brick and glass) from the cemetery infrastructure (especially tombstones).

Chemical changes in burial Necrosols apply to the entire soil profile and include the following parameters: increased content of organic carbon (OC) and total nitrogen (N_t), a high content of total phosphorus (P_t) and higher pH value, all in relation to untransformed soil outside the cemeteries. Similar changes of chemical properties in undisturbed cemetery soils are recorded only in the surface horizons.

Based on our research and the research by Charzyński et al. (2011), we believe that the qualifier Necric should be added to the list of qualifiers for Technosols RSG in the World Reference Base for Soil Resources (IUSS Working Group WRB 2007). This will improve the characterization of burial Necrosols. Furthermore, a suffix for technogenic subsoil layer artificially enriched with organic matter should be also added (characteristic of burial Necrosols) in FAO Guidelines for Soil Description (2006).

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