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# Anthropogenic transformation of soils in the Barycz valley – conclusions for soil classification

*Abstract:* Large-scale river regulation, drainage and intense farming in the Barycz valley initiated in 17th century activated a transformation of the initial alluvial and swamp-alluvial soils. Soils on the Holocene flooded terraces have deep, acid humus horizons (umbric) and gleyic properties at shallow depth, but have no stratification of parent material to a depth of 100 cm. Despite the location in the floodplain, soils cannot be classified as black-earth alluvial soils (mady czarnoziemne) using the criteria of Polish soil classification (2011). The soils on the Pleistocene non-flooded terraces have a deep, base-saturated humus horizon (mollic) and gleyic properties in the lower part of soil profile, which allows to classify them as the black earths (czarne ziemie). Prominent stratification of the parent material well preserved in these soils has no influence on their classification (due to the age sediments). Almost all humus horizons of these soils meet the definition of anthric characteristics, and more than half of the studied soils can be classified as culturozemic soils – rigosols – which emphasises the important role of man in the transformation and gaining of morphological features of these soils. The lack of precise criteria for identifying soil types in the chernozemic order of the Polish soil classification (2011) causes difficulties in the classification of soils on the river terraces, in particular, in distinguishing between black-earth alluvial soils and black earths.

*Keywords:* „chernozemic alluvial soils", black earths, culturozemic soils-rigosoils

## INTRODUCTION

From the beginning of the 19th century, the soils of the river valleys, both in Poland and in other European countries were largely anthropogenically transformed as a result of intensive hydro-engineering projects. The aim of river regulation was not only to protect endangered residential areas against flood, but also to increase the agricultural area, for which was a huge demand at that time (Strzemski 1961). Hydrotechnical investments were carried out throughout Poland, both in the valleys of the biggest rivers (the Vistula and the Oder) and in a series of smaller rivers, including Barycz river. Elimination of flooding and river-flow regulation reduced the natural alluvial sedimentation, but also led to the degradation, or even the total loss of wetland and bog habitats (Klimowicz 1980; Sztyber and Pawłat 2008; Uziak et al. 2010). In the drained river valleys, the rapid increase of the biological activity and the vertical extent of soil-forming processes are observed as a result of the ground-water table lowering (Chojnicki 2002; Laskowski 1986; Rytlewski 1965).

Transformation of the morphological, physical, chemical and mineralogical soil properties causes the gradual loss of the original sediment stratification (fluvic) and enhances subsequent development of diagnostic horizons, such as mollic, umbric, and murshic, as well as cambic or sideric, which are typical for other soil types (Chojnicki 2002; Dąbkowska-Naskręt 1990; Kabała et al. 2011). Despite the fact that alluvial soils obtain features of black earths, brown earths and others (depending on site conditions and degree of human interference), the soils may still be classified as "alluvial soils", according to the Polish soil classification (PSC 2011), even if the conditions of alluvial environment disappeared. In this regard, the PSC (2011) is inconsistent, as has predicted two exceptions: (1) heavily gleyed alluvial soils may not be classified as "alluvial soils", but as gley soils, and (2) as a rule, the originally alluvial soils on the Pleistocene non-flooded terraces are not classified as alluvial soils, even if they possess stratified parent material. In addition, the systematic position of alluvial soils, which have gained the features of culturozemic soils (anthrosols), is unclear.

The aim of the study is to analyse the alluvial soils transformation in the Barycz valley, which has been taking place under long-lasting and intense human pressure. In addition, the study aimed to classify the soils according to the current version of the Polish soil classification (2011), as well as to the international soil classification (IUSS Working Group WRB 2014).

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## MATERIALS AND METHODS

The study was conducted in the Barycz valley, in the Milicz and Żmigród depressions, which were formed by huge water flow from the melting continental glacier during Warta (Riss) glaciation. High intensity fluvial processes have filled the valley bottom with sand sediments, which later, locally, underwent eolian processes that formed the numerous sand dunes.

The Barycz valley, initially dissected by many active and inactive river channels and tributaries, and regularly flooded, was in the past covered by extensive swamps (Bac 1949, Czyżewski 1949). An unique feature of this area is the numerous breeding fishponds, established since the Middle Ages. Their construction was favoured by the flat terrain, the occurrence of excavations after bog iron exploitation, small declines in the Barycz river, and a relatively mild climate that was favourable for fish farms (Ranoszek and Ranoszek 2004). The necessity of flood protection, due to expanding human settlements and the increased demand for farmland (especially meadows and pastures), caused expansion of the river artificial embankments along the river channel and large-scale drainage, which resulted in soil overdrying on large areas of the Barycz valley in the beginning of $19^{th}$ century (Drabiński and Sasik 1995). Numerous fish ponds were closed, and, together with the adjacent areas, were taken under agricultural cultivation.

The present study included three soil profiles located on the Holocene flooded terraces (1.5–3 m above the river level) and three on the Pleistocene non-flooded terraces (5–10 m above the river level). The soils studied were used as meadows (profiles 1, 2 and 7), arable fields (profiles 5 and 6), or as a forest (profile 11). The field works included description of the research area and soil morphology, including stratification of the parent material. A particular emphasis was put on the morphology of the humus horizons and redoximorphic features.

The following properties were determined in the fine earth particles (<2 mm): particle-size distribution using the hydrometer and sieves; soil pH in distilled water and 1 M KCl, potentiometrically; organic carbon (TOC) using Tiurin method; the calcium carbonate ($CaCO_3$) content by the volumetric method (according to Scheibler method); total nitrogen content ($N_t$) using the Kjeldahl method, and the hydrolytic acidity (Hh) using the Kappen method. Exchangeable base cations ($Ca^{2+}$, $K^+$, $Mg^{2+}$, $Na^+$) were extracted using 1M ammonium acetate at pH=7 and analysed by atomic absorption (Mg) and emission (Ca, K, Na) spectrophotometry. Based on the sum of exchangeable cations (S) and the hydrolytic acidity (Hh), the cation exchange capacity (CEC) and base saturation (BS) were calculated.

## RESULTS

The parent material stratification, which is characteristic of alluvial soils, was not visible in the soils on the Holocene flooded terraces to a depth of 100 cm (Fig. 1), but was generally easily recognisable in the soils of the Pleistocene flooded terraces (Fig. 2). The stratification of the soil materials, in accordance with the criteria for the fluvic materials, was recognised as a vertical diversity of soil texture (profiles 5–7) followed by stronger redoximorphic features or irregular accumulation of the organic matter throughout the soil profile (profile 6). Redoximorphic features (gleyic mottles and Fe-Mn segregations) were visible in all soil profiles, but generally occurred with greater intensity and at shallower depths in the soils located on the Holocene flooded terraces. This is due to lower position occupied by these soils in the valley that resulted in shallow groundwater level.

Groundwater was not sometimes observed in soil profiles located on the Pleistocene non-flooded terraces (profile 6). A characteristic feature of all of the studied soils was deep (30–62 cm) and dark coloured humus horizons (arable) having a granular or subangular blocky structure. Humus horizons were double or triple layered in all profiles, reflecting the different frequency and vertical extent of ploughing. The deepest sub-layers of arable horizon (for example, in profiles 1 and 5) were probably formed by a single ploughing, and they have features of horizons A and B, or A and C. Furthermore, in all profiles, arable horizons were sharply cut off from the other layers.

Below this abrupt boundary, the soil structure changed rapidly, suppressing activity of macro- and mesofauna (except for profile 6). The TOC content was relatively high (up to 5.61%) in humus horizons, but it can be very diverse, both on Holocene flooded and Pleistocene non-flooded terraces (Table 2). In profiles 2, 6 and 7, the high TOC content (1.9–3.8%) was maintained throughout the arable horizon, even to a depth of 40–50 cm, although there were always slightly lower levels in bottom subhorizon. The high TOC content in other profiles occurred only in the uppermost subhorizons, and rapidly decreased in the lower-lying subhorizons (for example, from 1.7 to 0.6% in profile 1). TOC content was much smaller in subsoil (0.01–0.36%), and was related to the soil texture– in sands, the content did not exceed 0.1%, and higher values were only recorded in loamy sands and loams. All arable horizons had relatively high nitrogen content, especially in surface subhorizons

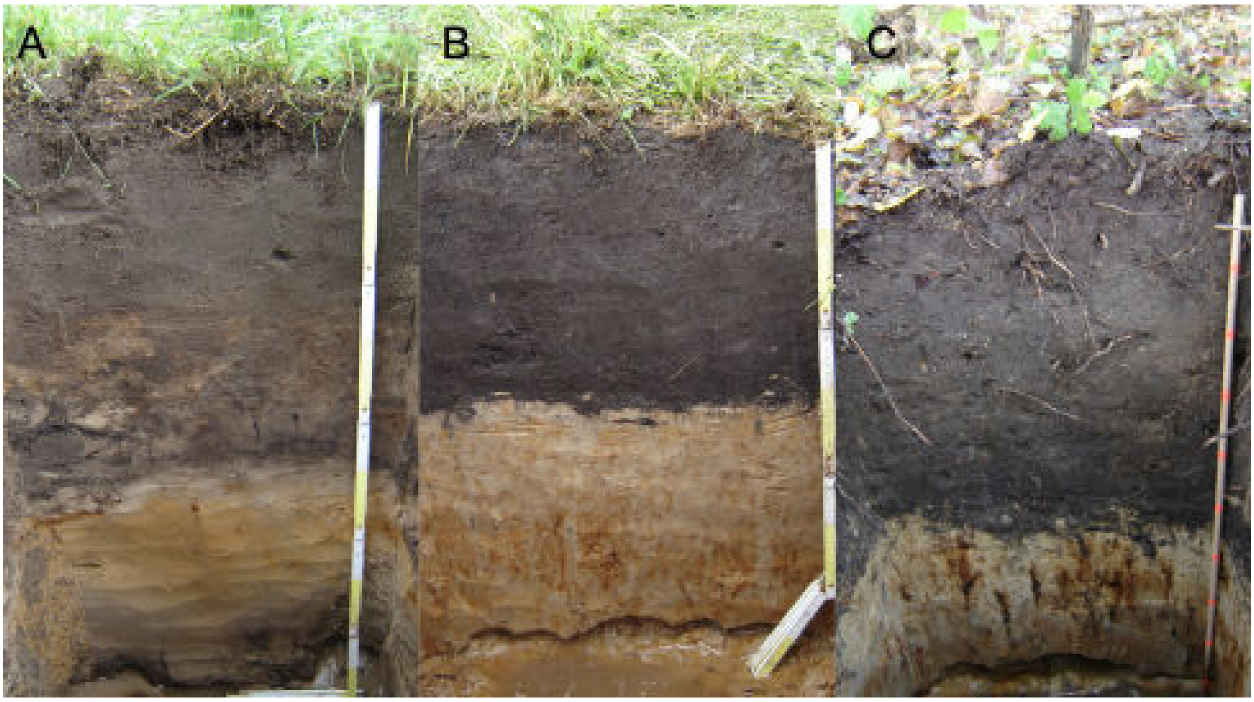


FIGURE 1. Soils on the Holocene river terraces (potentially flooded): A – Profile No. 1: Gleyic Umbrisol (Anthric, Arenic), B – Profile No. 2: Gleyic Umbrisol (Anthric, Arenic), C – Profile No. 11: Endoeutric Umbric Gleysol (Anthric, Arenic, Nechic, Pachic)


FIGURE 2. Soils on the Pleistocene river terrace (non-flooded): A – Profile No. 5: Calcaric Cambic Endogleyic Phaeozem (Anthric, Arenic), B – Profile No. 6: Greyzemic Endogleyic Phaeozem (Anthric, Arenic), C – Profile No. 7: Greyzemic Fluvic Endogleyic Phaeozem (Anthric, Arenic)

TABLE 1. Selected morphological properties and particle size distribution in soil profiles on the river Holocene and Pleistocene terraces in the Barycz valley

| Profile No. | Soil horizon | Depth [cm] | Color | Structure | Fluvic material | Diagnostic horizons and properties | Particle-size distribution [%] | | | Texture class |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | 2.0–0.05 | 0.005–0.002 | <0.002 | |
| Soils on the Holocene river terraces (potentially flooded) | | | | | | | | | | |
| Gleyic Umbrisol (Anthric, Arenic) | | | | | | | | | | |
| 1 | Ap1 | 0–10 | 10YR 3/1 | subangular | – | umbric | 96 | 3 | 1 | pl / S |
| | Ap2 | 10–30 | 10YR 3/1 | subangular | – | umbric | 91 | 8 | 1 | pl / S |
| | AB | 30–52 | 10YR 4/1 | subangular | – | – | 93 | 6 | 1 | pl / S |
| | C | 52–60 | 10YR 8/2 | loose | – | – | 98 | 1 | 1 | pl / S |
| | Cg | 60–77 | 10YR 7/6 | loose | – | gleyic | 98 | 1 | 1 | pl / S |
| | C2g | >77 | 10YR 7/4 | loose | – | gleyic | 96 | 3 | 1 | pl / S |
| Gleyic Umbrisol (Anthric, Arenic) | | | | | | | | | | |
| 2 | Ap1 | 0–8 | 10YR 2/1 | subangular | – | umbric | 73 | 23 | 4 | gp / SL |
| | Ap2 | 8–33 | 10YR 2/1 | subangular | – | umbric | 75 | 21 | 4 | pg / LS |
| | C1g | 33–50 | 10YR 6/3 | subangular | – | gleyic | 95 | 4 | 1 | pl / S |
| | C2g | >50 | 10YR 5/6 | subangular | – | gleyic | 94 | 5 | 1 | pl / S |
| 11 | Ap1 | 0–15 | 10YR 2/2 | subangular | – | umbric | 81 | 10 | 9 | gp / SL |
| | Ap2 | 15–40 | 10YR 3/2 | subangular | – | umbric | 88 | 5 | 7 | pg / LS |
| | Apg | 40–62 | 10YR 2/1 | subangular | – | umbric | 88 | 4 | 8 | pl / LS |
| | Cg | >62 | 10YR 8/3 | loose | – | gleyic | 93 | 4 | 3 | pl / S |
| Soils on the Pleistocene river terrace (non-flooded) | | | | | | | | | | |
| Calcaric CambicEndogleyic Phaeozem (Anthric, Arenic) | | | | | | | | | | |
| 5 | Ap1 | 0–23 | 10YR 3/2 | subangular | – | mollic | 84 | 10 | 6 | pg / LS |
| | Ap2 | 23–46 | 10YR 3/3 | subangular | – | mollic | 77 | 17 | 6 | pg / LS |
| | ABg | 46–80 | 10YR 5/3 | subangular | – | – | 86 | 7 | 7 | pg / LS |
| | 2Cg | >80 | 10YR 6/6 and 10YR 8/1 | subangular | – | gleyic | 68 | 16 | 16 | gp/SL |
| 6 | Ap1 | 0–23 | 10YR 3/1 | subangular | – | mollic | 87 | 9 | 4 | ps / S |
| | Ap2 | 23–58 | 10YR 4/1 | subangular | – | – | 87 | 9 | 4 | ps / S |
| | Cg | 58–135 | 10YR 8/2 | subangular | + | gleyic | 86 | 11 | 3 | ps / S |
| | C2g | >135 | 10YR 6/3 | subangular | + | gleyic | 91 | 3 | 6 | ps / S |
| Greyzemic Fluvic Endogleyic Phaeozem (Anthric, Arenic) | | | | | | | | | | |
| 7 | Ap1 | 0–16 | 10YR 2/1 | subangular | – | mollic | 85 | 13 | 2 | pg / LS |
| | Ap2 | 16–42 | 10YR 2/2 | subangular | – | mollic | 85 | 11 | 4 | pg / LS |
| | C | 42–63 | 10YR 7/2 | subangular | – | – | 87 | 4 | 9 | pg / LS |
| | Cg | 63–68 | 10YR 6/1 | subangular | + | gleyic | 68 | 10 | 22 | gpi / SCL |
| | C2g | 68–85 | 10YR 7/2 | subangular | + | – | 94 | 1 | 5 | ps / s |
| | C2g | 85–90 | 10YR 7/1 | subangular | + | gleyic | 88 | 1 | 11 | pg / Ls |
| | G | >90 | 5Y 6/1 | subangular | + | gleyic | 92 | 1 | 7 | ps / S |

Explanations: Texture class according to PTG 2008 and USDA: pl, ps/S – sand, gp/SL – sandy loam, pg/LS – loamy sand, gpi/SCL – sandy clay loam.

(up to 0.45%). This ensures a narrow C:N ratio (in the range of 6 to 14.8) and indicated high biological activity and high rate of decomposition process. In addition, this ratio also demonstrated a balance between the mineralisation and humification of organic matter.

Soils on the Holocene flooded terraces were either completely decalcified (profile 2) or had very low calcium carbonate content (1–2%) in the deeper soil horizons only, hence they had significantly more acidic reaction as compared to soils located on the Pleistocene non-flooded terraces. In the Pleistocene terraces, the calcium carbonate occurred in almost all horizons, at levels ranging from 2 to 20% (Table 2). The cation exchange capacity (CEC) depends on the organic matter, the presence of residual carbonates, the soil reaction and soil texture, but only in deeper subsoil horizons. The highest CEC value occurs in the humus horizon and decreases with depth. In turn, base saturation significantly increases along with the profile's depth (except for profile 6). The base saturation in the humus horizon of the soils on the Holocene flooded terraces is much lower (24.6–66.7%) as compared to the soils on the Pleistocene non-flooded terraces (69.3–96.6%).

TABLE 2. Selected physico-chemical properties in soil profiles on the river Holocene and Pleistocene terraces in the Barycz valley

| Profile No. | Soil horizon | Depth [cm] | pH | | $CaCO_3$ | TOC | TN | C:N | Ha | S | CEC | Bs [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | $H_2O$ | KCl | [%] | | | | cmol(+) $kg^{-1}$ | | | |
| Soils on the Holocene river terraces (potentially flooded) | | | | | | | | | | | | |
| Gleyic Umbrisol (Anthric, Arenic) | | | | | | | | | | | | |
| 1 | Ap1 | 0–10 | 6.3 | 5.1 | 0 | 1.70 | 0.13 | 12.7 | 3.3 | 2.3 | 5.6 | 41.1 |
| | Ap2 | 10–30 | 6.6 | 5.7 | 0 | 0.60 | 0.06 | 10.0 | 3.1 | 3.0 | 6.1 | 49.2 |
| | AB | 30–52 | 6.6 | 5.6 | 0 | 0.62 | 0.62 | 14.8 | 2.1 | 2.1 | 3.2 | 66.7 |
| | C | 52–60 | 7.3 | 6.3 | 1 | 0.05 | 0.05 | n.o. | 1.2 | 1.2 | 1.5 | 80.0 |
| | Cg | 60–77 | 7.3 | 6.4 | 1 | 0.02 | 0.02 | n.o. | 1.3 | 1.3 | 1.5 | 84.8 |
| | C2g | >77 | 7.2 | 6.2 | 2 | 0.01 | 0.01 | n.o. | 1.3 | 1.3 | 1.6 | 80.6 |
| Gleyic Umbrisol (Anthric, Arenic) | | | | | | | | | | | | |
| 2 | Ap1 | 0–8 | 5.2 | 4.0 | 0 | 3.30 | 0.30 | 11.0 | 9.3 | 3.5 | 12.7 | 27.3 |
| | Ap2 | 8–33 | 4.8 | 3.9 | 0 | 3.18 | 0.22 | 14.4 | 8.2 | 2.7 | 10.8 | 24.6 |
| | C1g | 33–50 | 4.4 | 3.7 | 0 | 0.09 | n.o. | n.o. | 1.8 | 1.0 | 2.8 | 35.0 |
| | C2g | >50 | 4.2 | 3.7 | 0 | 0.02 | n.o. | n.o. | 1.6 | 0.9 | 2.5 | 34.9 |
| 11 | Ap1 | 0–15 | 3.9 | 3.2 | 0 | 5.61 | 0.45 | 12.5 | 7.1 | 3.0 | 10.1 | 30.0 |
| | Ap2 | 15–40 | 4.5 | 4.0 | 0 | 0.85 | 0.06 | 14.2 | 5.0 | 4.1 | 9.1 | 44.8 |
| | Apg | 40–62 | 5.2 | 4.6 | 0 | 0.99 | 0.07 | 14.1 | 3.3 | 6.6 | 9.9 | 66.7 |
| | Cg | >62 | 7.1 | 6.4 | 1 | 0.20 | n.o. | n.o. | 0.5 | 5.1 | 5.6 | 91.1 |
| Soils on the Pleistocene river terrace (non-flooded) | | | | | | | | | | | | |
| Endoeutric Umbric Gleysol (Anthric, crenic. Nechic. Pachi) | | | | | | | | | | | | |
| 5 | Ap1 | 0–23 | 6.2 | 5.6 | 0 | 1.67 | 0.18 | 9.3 | 3.2 | 7.9 | 11.1 | 71.2 |
| | Ap2 | 23–46 | 6.7 | 6.4 | 2 | 1.49 | 0.16 | 9.3 | 1.8 | 7.5 | 9.3 | 80.6 |
| | ABg | 46–80 | 7.5 | 7.2 | 3 | 0.24 | 0.04 | 6.0 | 0.7 | 5.3 | 6.0 | 87.7 |
| | 2Cg | >80 | 7.7 | 7.3 | 2 | 0.01 | n.o. | n.o. | 0.7 | 8.4 | 9.1 | 92.5 |
| Greyzemic Endogleyic Phaeozem (Anthric, Arenic) | | | | | | | | | | | | |
| 6 | Ap1 | 0–23 | 7.6 | 7.4 | 20 | 2.95 | 0.26 | 11.3 | 0.9 | 25.3 | 26.2 | 96.6 |
| | Ap2 | 23–58 | 7.7 | 7.3 | 4 | 1.90 | 0.21 | 9.05 | 0.9 | 13.0 | 13.0 | 93.0 |
| | Cg | 58–135 | 7.8 | 7.5 | 1 | 0.03 | n.o. | n.o. | 0.5 | 4.0 | 4.5 | 89.9 |
| | C2g | >135 | 7.9 | 7.6 | 1 | 0.01 | n.o | n.o. | 0.5 | 2.9 | 3.4 | 85.1 |
| Greyzemic Fluvic Endogleyic Phaeozem (Anthric, Arenic) | | | | | | | | | | | | |
| 7 | Ap1 | 0–16 | 6.4 | 5.9 | 2 | 3.78 | 0.36 | 10.5 | 4.0 | 9.0 | 13.0 | 69.3 |
| | Ap2 | 16–42 | 6.3 | 5.7 | 1 | 2.33 | 0.17 | 13.7 | 3.7 | 6.0 | 9.7 | 62.0 |
| | C | 42–63 | 6.8 | 6.4 | 2 | 0.19 | n.o. | n.o. | 1.1 | 2.8 | 3.8 | 72.4 |
| | Cg | 63–68 | 6.6 | 5.5 | 0 | 0.36 | n.o. | n.o. | 2.2 | 6.6 | 8.8 | 75.1 |
| | C2g | 68–85 | 7.1 | 6.8 | 1 | 0.19 | n.o. | n.o. | 0.8 | 2.4 | 3.1 | 75.8 |
| | C2g | 85–90 | 7.0 | 6.3 | 1 | 0.16 | n.o. | n.o. | 1.2 | 4.2 | 5.4 | 77.8 |
| | G | >90 | 7.4 | 6.9 | 0 | 0.01 | n.o. | n.o. | 0.8 | 2.9 | 3.7 | 79.6 |

## DISCUSSION

All of the analysed soils that were formed from the Holocene and Pleistocene alluvial sediments in the Barycz valley have thick humus horizons, which are almost black, structural and rich in organic matter. They all fulfil the criteria for umbric (on the Holocene flooded terraces) or mollic (on the Pleistocene non-flooded terraces) diagnostic horizons, despite the sandy texture. Soil profiles do not have other diagnostic horizons and always have redoximorphic features (gleyic properties). In some cases, these properties are found directly below humus horizons, or rarely, only in the bottom part of the profile. Soil stratification that is typical for the fluvic materials (unchanged alluvium) was observed only on the Pleistocene terraces and generally not in soils derived from younger Holocene sediments. All of the examined soils have evolved in the direction of chernozemic-type soils (having humus-enriched mollic or umbric horizon) under excessively moist conditions. Similar soils were identified in the valleys and glacial valleys in south-central Poland, e.g. in the Kampinoski National Park (Konecka-Betley et al. 1996), the Sandomierz valley (Klimowicz 1980), the Roztocze region (Uziak et al. 2010), the Bug valley (Borowiec et al. 2007), and in the Lower Silesia region (Kabała et al. 2011; Łabaz et al. 2006).

The basic question concerns the origin of the deep humus horizons. On the Polish territory, mineral alluvial sediments with organic matter content high enough to create black-coloured mollic/umbric horizons with a thickness more of 30 cm rarely occur naturally (Strzemski et al. 1973). This type of river sediment is practically unknown from the Pleistocene period. Therefore, it is considered that the contemporary alluvial soils, which currently have deep humus horizons, were originally swamp-alluvial or bog-alluvial soils that were periodically flooded or were located in the former river-beds channels and troughs overgrown by hydrophilic plants, in which the water periodically stagnated (Konecka-Betley et al. 1996; Kowaliński 1952; Prusinkiewicz and Kowalkowski 1964; Tomaszewski 1956, 1957). In the context of current classifications, these soils would be classified as Histic Gleysols (IUSS Working Group WRB 2014), which, in PSC (2011), are reflected in different subtypes of ground-gleyed soils (gleby torfowo-glejowe, torfiasto-glejowe, murszowo-glejowe, and murszowato-glejowe). Relics of these soils still exist locally in the river valleys. Their transformation to mineral soils with thick humus horizons was the result of large-scale river regulation and drainage, which were conducted in the valleys (Klimowicz 1980).

Intensive regulation of the Barycz river and its tributaries was mainly associated with the construction of fishponds in the 17$^{th}$ century. The riverbed was canalised and embanked at large lengths. Numerous channels and floodgates were built to pile up water used to fill the fishponds. An amelioration conducted in the area fundamentally changed the original hydrographic network and led to the elimination of flooding and lowering the groundwater table in large areas. The former wetlands were drained and almost disappeared, transformed into meadows, pastures and even arable land (Bac 1949; Tomaszewski 1949). Organic soils currently occupy only small areas in the valleys of Żmigród and Milicz region (Ranoszek and Ranoszek 2004). The majority of the former swamps were turned into mineral soils after drying and ploughing. Organic horizons, which formerly were lying on the soil surface, were mixed with mineral subsoil. Nowadays, due to soil homogenisation by repeated ploughing and increasing activity of soil fauna, the organic materials do not form separate horizons or inserted "lenses", but are totally dispersed in the mineral topsoil, sometimes resulting in the peaty or murshic-like characteristic of arable horizon (Łabaz et al. 2006, 2011).

Key facts, which indicate human impact on the formation of thick humus horizons include: (1) the sharp lower boundary of humus horizons, (2) abrupt change of the soil structure, as well as (3) abrupt disappearance soil fauna activity directly below the ploughing horizon. These findings contradict the natural formation of the humus horizons that involves gradual development based on zooturbation (Alexandrovskiy 2007). This confirms the opinion of Strzemski (1954) that the majority of Polish black earths, in particular on alluvial sediments, were formed primarily as a result of human intervention in the river valley environment – river regulation, drainage and deep ploughing of drained swamp soils.

PSC (2011) classifies soils that are ”developed from fluvic material", undergo flooding (and thus, are located on the Holocene flooded terraces), and have mollic horizon as black-earth alluvial soils (mady czarnoziemne). Unfortunately, none of the studied soils in the Barycz valley can be classified as this soil type. First of all, the term "developed from fluvic material" is unclear. Fluvic materials are identified by their stratification, however, it disappears under pedogenic transformation and cannot be recognized in any diagnostic horizon, particularly in the humus horizon. It may be easily recognised only below genetic or diagnostic horizons, sometimes in the bottom part of soil profile. Unfortunately, PSC (2011) does not define whether and at what depth fluvic material should occur in the soil profile. In the soils under investigation, which are developed from young alluvial sediments on the Holocene flooded terraces, the stratification is not visible, at least to a depth of 100 cm or to groundwater table. It means that the alluvial nature (and classification) of these soils cannot be judged based on sediment stratification.

Moreover, the definition of black-earth alluvial soils (mady czarnoziemne) requires the mollic horizon, while in the Barycz valley soils derived on flooded terrace have umbric horizons only. Mollic horizons and the stratification of parent materials in soil profiles occur in soils located on the Pleistocene non-flooded terraces. Morphologically, these soils meet the requirements of black-earth alluvial soils (mady czarnoziemne), however, they are not included in this soil type due to the location on the non-flooded terraces (out of range of floodwater) and due to the Pleistocene age of their parent material.

All of the tested soils are morphologically similar to each other and could be classified as one type – black earths (czarne ziemie) – because all of them have thick mollic/umbric humus horizon and gleyic properties in the soil profile. Soils on the Pleistocene non-flooded terraces can be classified as black earths (czarne ziemie). Unfortunately, the classification of the soils on the Holocene flooded terraces is much more problematic in the PSC (2011). According to the concept of chernozemic soil order (PSC 2011), these soils should be primarily classified as black-earth alluvial soils (mady czarnoziemne). However, as mentioned above, only their occurrence on the Holocene flooded terraces supports such classification, because they do not have fluvic materials in the profiles and they have umbric, rather than mollic, diagnostic horizons.

On the other hand, the soils studied can be also classified as leached or gleyed black earths (czarne ziemie wyługowane/glejowe) because the definition of these types involves "late Pleistocene and Holocene parent materials, such as varied sands, loams, clays and silts on various origins, mostly rich in calcium carbonates" (PSC 2011). Finally, the lack of clear criteria, and especially the lack of classification key hinders the separation between black earths and black-earth alluvial soils (Kabała 2014; Łabaz and Kabała 2014).

Moreover, PSC (2011) does not take into account the anthropogenic nature of some humus horizons, both in black earths and black-earth alluvial soils. Meanwhile, mollic/umbric horizons meet the criteria of anthric horizon in almost all of the studied profiles, and it would be the most advisable to classify them as separate subtypes with an anthric horizon. However, it is not possible, because there is no mention in the PSC (2011) that black-earth alluvial soils (mady czarnoziemne) can have a humus horizon of anthropogenic origin. In the four soil profiles (1 and 11 on the Holocene flooded terraces, and 5 and 6 on the Pleistocene non-flooded terraces) the humus (anthric) horizons have a thickness exceeding 50 cm, which meet the basic criteria for rigosols (culturozemic anthropogenic soils). Thus, according to the PSC (2011), the analysed soils belong to leached black earth – czarne ziemie wyługowane (profiles 2 and 7) and rigosols (profiles 1, 5, 6 and 11), regardless of location (flooded or non-flooded terraces) and age of alluvial sediment (Holocene or Pleistocene).

Due to the lack of stratification of the primarily alluvial materials in the upper part of the soil profile, none of the analysed soils belong to Fluvisols (IUSS Working Group WRB 2014), which are considered to be poorly developed alluvial soils. According to the international FAO-WRB classification, the soils on the Holocene flooded terraces belong to Gleyic Umbrisols (Anthric, Arenic) or Umbric Gleysols (Anthric, Arenic). In turn, the soils on the Pleistocene non-flooded terraces were classified as Phaeozems (Table 1). These assignments reflect the priority for mollic and umbric horizons in FAO-WRB classification, as well as for strong redoximorphic features. Anthropogenic influences (e.g. deep ploughing) are reflected in soil classification at second level (by addition of the "Aric" qualifier), as these features are too week to fulfil criteria of diagnostic horizons in the Antrosols reference group (e.g. for hortic horizon).

## CONCLUSIONS

1. Large-scale river regulation, drainage and intense farming in the Barycz valley conducted since the $17^{th}$ century caused the transformation of the primary swamp-alluvial soils to mineral soils with thick, black-coloured and structural humus horizons (mollic and umbric).
2. Due to imprecise criteria in the Polish soil classification (2011), alluvial soils with umbric horizon, can be classified both as black-earth alluvial soils and black earths.
3. Mollic and umbric horizons in all of the studied soils were formed by deep ploughing and meet the criteria of anthric horizons, which should be reflected in soil classification at the lower level.
4. Current definition of the rigosols causes controversial classification of many alluvial soils as culturozemic (anthropogenic) soils based on very deep ploughing only.
5. Polish soil classification (2011) should provide clear criteria for precise distinguishing of soil types in chernozemic order that reflect overlapping combinations of diagnostic horizons and properties.

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# Antropogeniczne przekształcenia gleb w Dolinie Baryczy – wnioski dotyczące klasyfikacji gleb

*Streszczenie:* Wielkoskalowa regulacja, odwodnienia oraz intensywne rolnicze zagospodarowanie doliny Baryczy zainicjowane w XVII wieku uruchomiły transformację pierwotnych gleb aluwialnych i błotno-aluwialnych. Gleby na holoceńskich terasach zalewowych mają głęboki, kwaśny poziom próchniczny (umbric) i są płytko oglejone, a do głębokości 100 cm nie zaznacza się stratyfikacja materiału macierzystego. Mimo położenia na terenach zalewowych, gleb tych nie można zaliczyć do mad czarnoziemnych posługując się kryteriami Systematyki gleb Polski (2011). Gleby na plejstoceńskich terasach nadzalewowych mają głęboki, wysycony zasadami poziom próchniczny (mollic) i oglejenie w dolnej części profilu, co przybliża je do czarnych ziem. Dobrze widoczna stratyfikacja materiału macierzystego nie ma w tych glebach znaczenia klasyfikacyjnego ze względu na wiek osadów. Niemal wszystkie poziomy próchniczne spełniają kryteria poziomu anthric, a ponad połowa badanych gleb może być zaliczona do gleb kulturoziemnych – rigosoli, co podkreśla istotną rolę człowieka w transformacji i kształtowaniu cech morfologicznych tych gleb. Brak precyzyjnych kryteriów identyfikacji typów w rzędzie gleb czarnoziemnych w Systematyce gleb Polski (2011) powoduje trudności w klasyfikacji gleb na terasach rzecznych, a w szczególności rozgraniczanie między madami czarnoziemnymi oraz czarnymi ziemiami.

*Słowa kluczowe:* mady czarnoziemne, czarne ziemie, gleby kulturoziemne – rigosole