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Human-induced development of mollic and umbric horizons in drained and farmed swampy alluvial soils

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ABSTRACT

River regulation since the 17th century, large-scale drainage, and intensive farming have seriously transformed soils in the river valleys of Poland. Flood suppression and groundwater lowering have created oxidizing conditions in topsoil and allowed biological activity and plant rooting, which has retarded original stratification of the alluvial substratum. However, ploughing has led to the development of thick humus horizons. In particular, soils with organic topsoil horizons have been changed, i.e. they have lost their initial swampy nature and have undergone an anthropogenic transformation to mineral soils. Despite the long-term agricultural land use, it is still possible to recognize the peaty character of organic matter in some soils and this allows reconstruction of their origin. This study investigated a sequence of soils in the valley of the river Barycz: (i) occasionally flooded, very moist Fluvic Histic Gleysols, with a Murshic organic layer, (ii) weakly drained soils with a high groundwater table, deeply ploughed, where the sandy plough layer contains easily recognizable peat-derived organic material, weakly bound to the mineral fraction (Fluvic Anthromollic Gleysols), and (iii) deeply drained soils, deeply ploughed, where organic carbon content in the plough layer is below 10%, but peat-derived particles of organic matter are still recognizable and are weakly bound to the mineral fractions [(Endogleyic Phaeozems (Anthric) or Endogleyic Umbrisols (Anthric)]. None of the thick plough layers, although intentionally created by humans by mixing the organic layer with underlying sandy material, fulfill the requirements of the anthropogenic diagnostic horizons. Therefore, two new qualifiers are proposed to the WRB classification in relation to the recent addition of the “Murshic” qualifier, namely “Anmooric” and “Atric”, to allow accurately naming the postswampy soils at subsequent stages of their transformation.

1. Introduction

River valleys and soils in river valleys underwent various natural and anthropogenic transformations during the Holocene period (Dotterweich, 2008). Erosion and accumulation processes, closely related with fluctuations in climate conditions appeared to be the most intense during extreme flooding, mainly at the turn of the Atlantic and Subboreal (Starkel, 2002). Starkel (2002) itemizes a few periods of time, during which there occurred regular disastrous floods in the center of Europe (8.5–7.8, 6.6–6.0, 5.5–4.9, 4.5–4.0, 3.5–3.0, 2.8–2.7, 2.2–1.8 ka BP). These intense floods overbuilt materials of the floodplain in many places and “restarted” the soil processes. Also, in modern times catastrophic floods have been widespread phenomena and longer periods of time without catastrophic floods only occurred at the beginning of the 16th century, in the period between 1675 and 1784 and from after the 1890s until today (Brazdil et al., 1999, 2005). Huge and regular spring floods were recorded in the Dniepr valley at the beginning of the 19th century and these were not only the result of natural climatic fluctuations but also the effect of wide-scale deforestation and intensive tillage (Bronnikova et al., 2003). At high water level, the lowland rivers changed their course, created new river channels and abandoned old meanders, which became overgrown over time and transformed to the swampy areas (Plit, 2004). Maps from the 17th century depict many river valleys in west Poland as extensive mud areas with elongated oxbow lakes (Hildebrandt-Radke and Przybycin, 2011). In other regions of Poland, vast areas of lowland river valleys were covered with swampy wetlands up to the 19th century (Klimowicz, 1980). Thus, in flat-bottomed valleys, next to mineral alluvial soils, organic and transitional organic–mineral soils fairly often occur. Usually, there is a patchwork of mineral alluvial and organic soils, in which the share and distribution of individual soil types depend on the micro-relief variability in the valley bottom, the water regime or drainage, and the frequency of contemporary floods (Niewiarowski and Kot, 2011; Rytelewski and Piascik, 1964). In the smaller lowland valleys, with relatively high levels of groundwater, alluvial soils have clearly marked stratification of the parent material and strong reductimorphic features, at least in the bottom part of soil profiles. In the lower positions redoximorphic features prevail throughout the profile and soils may have an organic layer at the surface or near the soil surface. Sometimes,

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the organic layers are thick enough that they satisfy the criteria for organic soils (Dengiz et al., 2009; Roj-Rojewski and Walasek, 2013). Some soils in regulated and intensively cultivated valleys have deep and dark colored plough horizons, rich in organic matter (Klimowicz, 1980; Konecka-Betley et al., 1996; Labaz and Kabala, 2014b; Uziak et al., 2010). The stratification of the fluvial substratum is variably preserved in these soils; sometimes it is only weakly recognizable in the bottom part of the soil profile, frequently below the groundwater level (Kabala et al., 2011a; Labaz and Kabala, 2014a; Kabala, 2015).

In Central Europe, the anthropogenic transformation of alluvial soils started at least at the beginning of Neolithic period (about 5500–5000 BP), when the first human tribes settled in some valleys (Wasylikowa et al., 1985). The river valleys were the natural channels for migration, delivering people water and fish, and later, considering the high fertility of the soils, enabling cereal cultivation (wheat, barley, leguminous plants, poppy, and flax). Early animal breeding led to the transformation of natural, non-swampy riparian forests into "open" forests of park/pasture type (Jensen et al., 2006; Tockner and Stanford, 2002). Repeated waves of settlement from the Middle Ages caused a higher expansion of humans in river valleys, valley deforestation and the development of animal breeding. Local, but very intensive transformations of the lower floodplains were also a result of bog-iron exploration and fishpond construction, which were a typical practice, especially in monastic possessions (Brazdil et al., 1999). Large-scale and intensive river regulation projects were undertaken across Europe at the turn of the 18th and 19th centuries to minimize losses from flooding (Prokof'eva et al., 2010). Regulation of the Rhine was conducted almost throughout the entire 19th century. The originally meandering river with a lot of oxbow lakes and islands was channeled, and the hydrotechnical infrastructure accelerated the water runoff from river valleys. Drained floodplains were entirely cleared of forests and used for agriculture (Van den Brink et al., 1996). Another aim of river regulation was to make them navigable and enable the transport of goods and people (Decamps et al., 1988; Jensen et al., 2006).

In Poland, the most intense and large-scale regulation of rivers and drainage projects in valleys also took place in the 19th century. These are documented throughout Poland, in the watersheds of all larger rivers (Hildebrandt-Radke and Przybycin, 2011; Kabala et al., 2011b; Kalisz et al., 2010; Marcinek and Spychalski, 1998; Rzasa, 1963). Those regulation projects which started in the 19th century were in most cases continued into the 20th century, and in some regions reached the highest intensity in the 1960s–1970s (Niewiarowski and Kot, 2011). These regulations included not only rivers but also lakes. A fall in the water level led to the shrinkage or complete disappearance of lakes, as well as to rapid pedogenic transformation of limnic sediments (Gonet et al., 2010; Jäger et al., 2015; Meller et al., 2009; Mendyk et al., 2015; Sammel, 2004).

Concomitant with increases in the human population, the structure and function of natural ecological floodplain systems were increasingly changed (Jensen et al., 2006). Despite the fact that river regulation and the construction of embankments, dams, and ditches brought rational economic benefits and made possible the agricultural use of valley bottoms directly at the watercourse, this also created the threat of the degradation of natural wetland habitats (Sztyber and Pawlat, 2008). Unreasonable management of the spatial resources in the river valleys, especially the abandoning of the mosaic form of fields, grasslands and forests due to intensification of agriculture, led to a decrease in landscape differentiation and biodiversity, and a reduction of the ecological capacity of ecosystems (Tokarczyk-Dorociak et al., 2011). Currently, it is assumed that floodplains are the most anthropogenically changed and threatened ecosystems in Europe (Tockner and Stanford, 2002).

The channeling of rivers has limited or eliminated natural alluvial sedimentation in valley bottoms (Klimowicz, 1980; Sztyber and Pawlat, 2008). Additionally, the decrease in groundwater level supports an increase in vertical biological activity and an intensification of soil processes (Kabala et al., 2011b; Laskowski, 1986; Matyka-Sarzynska and Sokolowska, 2005). Gradually, the stratification of alluvial sediments disappears, and subsurface horizons develop that often fulfil the criteria for diagnostic horizons, for example *cambic* (Labaz and Kabala, 2014b).

The greatest environmental consequences are seen in the transformation of swampy soils with organic horizons, for example Histic Gleysols (Dengiz et al., 2009; Mendyk and Markiewicz, 2013; Okruszko, 1994; Piascik and Gotkiewicz, 2004). The drainage of these soils leads to a halt in peat formation and its rapid transformation towards mursh, in which, due to oxidation and an increase in biological activity, an aggregate structure is formed. An even more drastic transformation affects organic and mineral–organic soils, which are ploughed and sometimes artificially mixed with sandy subsoil (Kowaliński, 1964).

These "post-bog" soils have diversified morphology, physicochemical properties and agricultural productivity. In the Classification of Soils in Poland (2011), these soils have separate designations that describe subsequent degrees of organic (or mineral–organic) soil transformation towards mineral soil. These terms are known in the international literature only to a limited degree and are variously translated into English and German (Ilnicki, 2002; Ingram, 1978; Kuntze, 1995; Vepraskas et al., 2000).

The aim of this research was: (i) to recognize the transformations of the swampy–alluvial soils as a result of regulation of the river Barycz, long-term drainage of the valley bottom and farming practices, (ii) to determine the diagnostic features of surface horizons in the subsequent stages of their transformation, and also (iii) to analyze to what extent the FAO-WRB classification reflects the specific features of "post-bog" alluvial soils.

2. Area of investigation and methods

The Barycz River, the right tributary of the Odra River, is one of the most strongly transformed river valleys in SW Poland (Tokarczyk-Dorociak et al., 2011). It is a lowland valley, with very poorly morphologically marked transitions between lower flooded terraces (lower floodplains), upper flooded terraces (higher floodplains), Pleistocene non-flooded terraces, and moraine highlands. The most intensive development of the valley was during the initial recession of the Warta ice-sheet (Riss2/Illinoian), while in later periods the valley was filled out with sandy sediments delivered by numerous tributaries (Kondracki, 2000).

The first registered manifestations of human interference in the Barycz Valley were fish ponds established in the 12th/13th century by Cistercian monks (Ranoszek and Ranoszek, 2004). These extremely beneficial conditions for the breeding of common carp led to the creation of a unique landscape consisting of channels, fishponds, arable fields and meadows, forests, and human settlements (Fig. 1). Construction of fishponds was certainly accompanied by regulation and melioration works in the valley. Currently, the riverbeds are embanked for considerable distances, and have many ducts, floodgates, dikes and weirs, which are used to gather the water and fill up ponds. This has fundamentally changed the original layout of the river network that in many places are impossible to reconstruct. The greatest intensification of land amelioration projects, which aimed to increase the acreage of agricultural fields, occurred in the late 19th century (Drabiński and Sasik, 1995; Labaz and Bogacz, 2014).

The fluvial terraces in the Barycz River valley and the valleys of its tributaries mainly consist of Holocene alluvial sands and gravels. In some areas, the lower floodplains are covered with a thin layer of fine-textured sediments formed in the late Holocene, in relation to human-induced erosion of the loamy arable soils in the surrounding moraine highlands (Kondracki, 2000). Coarse-textured (sandy, gravelly-sandy) Fluvisols and Fluvic Gleysols prevail in the valley bottom, accompanied by Fluvic Cambisols, Phaeozems, and Gleysols with fine-textured upper layers. In depressions where the groundwater level is high or seasonally stagnates on the surface, various swampy soils occur, including Histic (Murshic) Gleysols. In the surroundings of