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Landscape-related transformation and differentiation of Chernozems – Catenary approach in the Silesian Lowland, SW Poland

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ABSTRACT

The unfavourable environmental conditions to Chernozem development in Central Europe has led to questions regarding their origin and age, and conditions necessary for Chernozem persistence in Central Europe under a humid climate. This paper deals with Chernozem transformation during the Holocene period in SW Poland in relation to land morphology. The study was based on a catenary approach, with additional remarks on parent material homogeneity and soil classification. Based on textural and geochemical indices, the homogeneity of aeolian material (loess) was proven in the main part of the catena, which confirmed that the differentiation of "dry" and "wet" chernozemic soil across the catena did not result from the variability of parent material. No differences in morphological or physicochemical characteristics of mollic horizons were identified between the well-drained and wet sections of the catena. The strong redoximorphic features (manifested as stagnic or gleyic properties) in the lowermost part of catena are, therefore, secondary features, i.e. developed after the mollic horizon development, presumably in late Holocene period. Chernozems with chernic horizon, weakly developed subsurface argic horizon and free of redoximorphic features prevail in the central, well-drained and not eroded section of the catena. It has been hypothesized that the loess soils in the uppermost, more inclined part of the catena have been truncated by erosion during the first agricultural period, then afforested and transformed into Luvisols, probably due to temporary abandonment of those sites less favourable for farming. The soils in the transitional zone received the colluvial addition of humus material from the eroded hill summit; however, the colour of the humus layer has a chroma too high for a chernic horizon that surprisingly shifted these soils to the Kastanozems group. This study showed that the direction of transformation of native Chernozems in the Holocene period was strongly related to their position in the landscape, which affected the erosion/accumulation intensity and water drainage conditions (soil moisture regime). As a final result of these transformations, a relief-related zonality of soils has developed with Stagnic/Gleyic Chernozems – Luvic Chernozems – colluvial "Kastanozems" – Haplic Luvisols, in the lower (moist), middle (well-drained), and upper colluvial/eroded sections of the undulating loess plain, respectively.

1. Introduction

Loess soils with a deep black humus layer and secondary carbonates accumulated in the subsoil are some of the most productive agricultural soils and have been highly valued by farmers since the Neolithic period. Even today, when genetic and technological developments allow for the intensification of agricultural production on much weaker soils, particular attention is paid to Chernozems in many countries, including special conservation rules or legal protection (Altermann et al., 2005). Chernozems are also the focal point of various disciplines, as their occurrence and properties are sources of information about environmental conditions in the past and their transformation in the Holocene period, as well as about human activity over millennia (Alexandrovskiy and Chichagova, 1998; Chendev et al., 2017a; Eckmeier et al., 2007; Targulian and Goryachkin, 2004).

Although discussion on the genesis of Chernozems has a longer history than pedology, it is still difficult to state that the origin of Chernozems is fully explained and that one model is universally accepted. Interdisciplinary investigations governed by Dokuchaev (1883) led to an understanding of Chernozems as autogenic zonal soils of the continental climate, which have developed from carbonate-rich, silty- and silty-loamy-textured materials (mostly of loess), by stabilization of humified organic matter provided by steppe vegetation and under great impact from soil fauna responsible for both soil deepening and structure

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formation. However, new surveys have identified a variety of Chernozems and Chernozem-like soils existing under different environmental conditions and separate pathways of development and classification schemes have been postulated for these variants (Brevik et al., 2016; Labaz and Kabala, 2014; Vysloužilová et al., 2016). In Germany, the steppe origin and late-Pleistocene/early Holocene age are commonly accepted for soils developed in more southern, loess-covered areas (Ehwald et al., 1999; Gehrt et al., 1999; Markgraf, 1964), whereas the other scenarios, including polygenetic ones, and the medium/late Holocene age are suggested for "black earths" in the northern, post-glacial landscapes (Acksel et al., 2016; Albrecht and Kühn, 2011; Fischer-Zujkov et al., 1999). Based on the investigations of charcoals, arboreal sporomorphs, and the near-infrared spectra of soil organic matter, some Chernozems of Central and Western Europe are considered to develop and persist under open-forest or woodland-type vegetation (Kreuz, 2008; Vysloužilová et al., 2014, 2015). An analysis of charred organic carbon in soils has led to a questioning of the late Pleistocene/early Pleistocene origination of Central European Chernozems and to an emphasizing of the active human impact on their development during the Neolithic period (Eckmeier et al., 2007; Gerlach and Eckmeier, 2012; Schmidt et al., 1999). Also, the contemporary perception of Chernozems may be heavily impacted by their transformation under changing climate and changing land use, that may affect soil properties directly, or indirectly through the vegetation changes and acceleration of erosion. Catenary studies are known as particularly beneficial for explaining the spatial soil variability and soil transformation pathways. Fischer-Zujkov et al. (1999), Zádorová et al. (2013), Kołodyńska-Gawrysiak et al. (2017), and Smetanová et al. (2017) have shown the importance of human-accelerated erosion (in particular after 1950s) for the degradation of initial Chernozems, including the thinning or total truncation of the mollic horizon, versus their aggradation in a thick humous colluvium. Those processes may transform initially homogeneous Calcic Chernozems into Calcisols, Cambisols and Regosols in the eroded sites, or into deep Phaeozems in the colluvial "sinks". Local depressions are also considered better protecting the Chernozems against degradation due to moisture accumulation that may prevent both the carbonate leaching and humus decomposition (Thater and Stahr, 1991).

Therefore, it is still under discussion, if the occurrence and variability of Chernozems in Central Europe is associated with: (1) primary differentiation of the conditions of Chernozem formation, and features inherited and still preserved since their formation period; or (2) variable and/or multiple secondary transformations of Chernozems during the Holocene period (Chendev et al., 2017a; Lorz and Saile, 2011; Miedema et al., 1999; Vysloužilová et al., 2015). This may lead to the general conclusion that the Chernozems in Central Europe do not have one single and simple formation pathway, as they are both relic and, not rarely, polygenetic soils (Albrecht and Kühn, 2011; Ehwald et al., 1999; Pawelec et al., 2015).

Discussion of some aspects of Chernozem formation or their Holocene and contemporary transformation is currently ongoing in most Central European countries (Acksel et al., 2016; Drewnik et al., 2014; Gal et al., 2017; Jonczak and Šimanský, 2016; Labaz and Kabala, 2014; Kabala et al., 2015b; Novák et al., 2014; Skalský et al., 2009; Thiele-Bruhn et al., 2014; Zádorová et al., 2013). The steppe origin of Chernozems generally has not been questioned in more southern Central European regions, although Vysloužilová et al. (2014, 2015) have argued for the possibility of Chernozem development and long-term existence under open-forest/woodland vegetation. Also in Poland, the steppe origin of Chernozems has not been questioned, but Chernozems which occur in isolated spots on the loess plateaus of southern Poland (from east to west identified as (Fig. 1B): Tomaszów-Hrubieszów, Sandomierz, Kraków-Miechów, and Głubczyce areas) are considered relic and "degraded" Chernozems compared to the Ukrainian and Russian Chernozems (Borowiec, 1968; Licznar, 1976; Miklaszewski, 1930; Turski, 1985). In addition to the above locations, numerous large

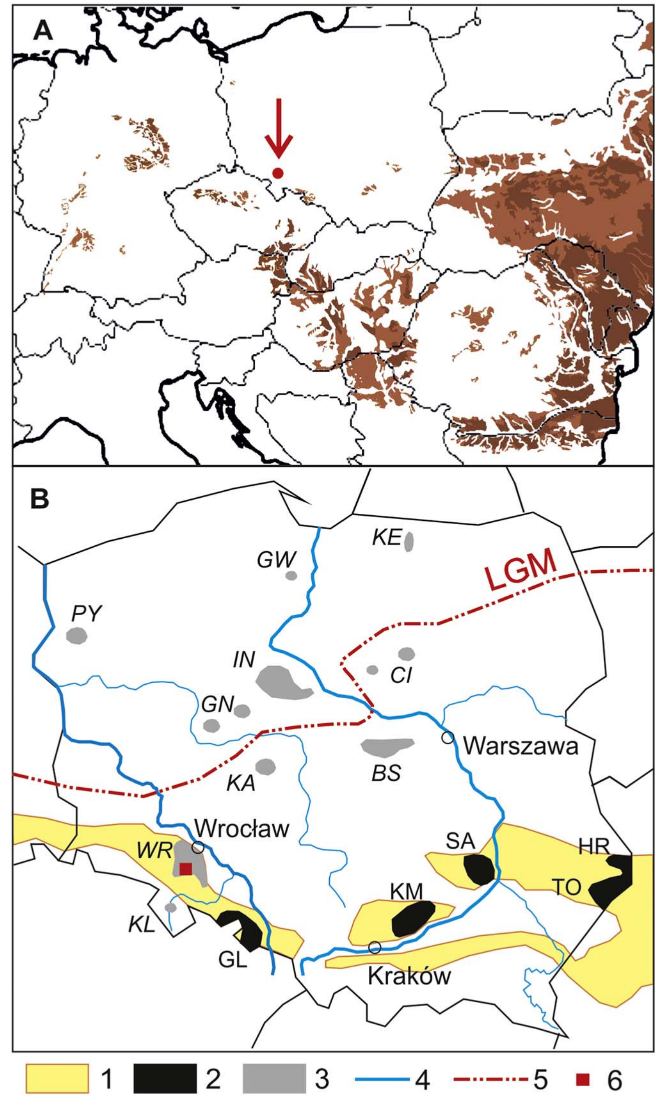

Fig. 1. (A) Distribution of Chernozems (dark brown) and Phaeozems (light brown) in Central Europe as presented in Soil Atlas of Europe (Jones et al., 2005). Red point indicates area under investigation. (B) Distribution of "chernozems" and "black earths" in Poland in relation to loess covers. Soil contours based on Mocek (2015), loess contours based on Jary (2007). Explanation: 1 – loess, 2 – czernozems (dry), 3 – black earths (moist), 4 – main rivers, 5 – Last Glacial Maximum (LGM) extend, 6 – study site; soil contours (names related to the closest town): BS, Błonie + Sochaczew, CI – Ciechanów, GL – Głubczyce, GN – Gniezno, GW – Gniew, HR – Hrubieszów, IN – Inowrocław (Kujawy), KA - Kalisz, KE – Kętrzyn, KL – Kłodzko, KM – Kraków + Miechów, PY – Pyrzyce, SA – Sandomierz, TO – Tomaszów, WR – Wrocaw. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

contours of soils with morphology and physicochemical properties similar to Chernozems have been distinguished, but are located in lowland plains with shallow groundwater tables or prolonged stagnation of rain/melting waters (near the cities of Kłodzko, Wroclaw, Kalisz, Gniezno, Błonie-Sochaczew, Ciechanów, Inowroclaw, Gniew, Kętrzyn, and Pyrzyce, Fig. 1B). Those soils, called "black earths/black soils", are moist throughout the profile (unless drained) and characterised by the presence of strong gleyic or stagnic properties in addition to mollic horizon (Borowiec, 1960; Chojnicki, 1994; Gerasimova and Khitrov, 2012; Kabala et al., 2015b; Kaczmarek et al., 2015). According to Polish classification (Kabala et al., 2016), "czarnoziem" is a soil developed of loess with a thick mollic horizon and secondary carbonate accumulation in the profile (the depth is not specified), but lacking redoximorphic features (excluding very weak stagnic properties). This definition assumes the soil development under relatively dry moisture