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Magnetic properties as indicators of Chernozem soil development

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ABSTRACT

A detailed magnetic study of four types of Chernozem profiles developed on the loess in the Homutovsky Steppe (Ukraine), Middle Poland and Moravia (Slovakia) was carried out. The magnetic methods were used to examine the subtle differences between four Chernozems, their pedogenic horizons and mechanism of soil formation. Loess of Ukrainian Chernozem (H2) revealed the greatest values of magnetic susceptibility ($25\ 10^{-8}\ m^3kg^{-1}$) and frequency-dependence of susceptibility (6.5%), which indicates weathering processes responsible for loess alternation at the beginning of the soil formation. The advanced pedogenic processes in the mollic horizon resulted in the formation of superparamagnetic grains of pedogenic maghemite. The Chernozem from Middle Poland (MDZ) has the lowest values of all magnetic parameters but one of the highest intensities of pedogenesis expressed by the relative changes of frequency-dependence of susceptibility between top-soil and parent material. It could be the consequence of the short duration of pedogenic activity. The correlations between the organic matter content expressed by loss on ignition and magnetic parameters were found. For the mollic A-horizon the organic matter influences the magnetic enhancement ($\Delta\chi$) and the production of SP grains through stimulation of pedogenesis. The correlation between mean annual rainfall – MAR and pedogenic component of susceptibility – magnetic enhancement gives the opportunity to look at the history of studied profiles. The data for studied Chernozems fit well with the relations between MAR and $\Delta\chi$ for loessic soils from Russia, Ukraine and Europe.

1. Introduction

Environmental study has widely used magnetic properties of soil (Thompson and Oldfield, 1986) for evaluation of the magnetic structure of soil (Hanesch and Scholger, 2005; Jeleńska et al., 2008; Jordanova et al., 2010).

The magnetic structure of different soil types and individual horizons were studied for the purpose of soil surveying, discrimination of pedogenic and anthropogenic input and environmental influence (Maher, 1986). Hanesch and Scholger (2005) gave description of the types of soil related to parent material, whereas Hanesch and Petersen (1999) propose mechanisms leading to soil formation. The influence of parent material lithology on value and vertical distribution of magnetic susceptibility of soils was studied by Hanesch et al. (2001), Shenggao (2000) and Vidic et al. (2000). The magnetic characteristic of different soil types was described by Jeleńska et al. (2004, 2008), Jordanova and Jordanova (1999) and Torrent et al. (2006). Pedogenic transformation of magnetic minerals in a vertical soil profile was studied by Deng et al. (2001), Geiss et al. (2004), Jeleńska et al. (2010), Sangode and Bloemendal (2004), Singer and Fine (1989) and Virina et al. (2000).

Eckmeier et al. (2007) reported a review of the most important literature of pedogenesis of Central European Chernozems since the 1920s. The authors showed that the definition of Chernozem deduced from Russian soils by Dokuchaev (1883) cannot be directly transferred to Central European Chernozems. This definition does not include the different factors controlling the formation, conservation and degradation of soils. Eckmeier et al. (2007) stated that no absolute age and time of Chernozem formation could be established. Most authors assume Early Holocene as the period of Chernozem's formation (Blume et al., 2010; Roeschmann et al., 1982) but the radiocarbon data gave Holocene age spread over 3700 years. The Central European Chernozems were formed not only under steppe but also under forest-steppe vegetation. Climate and relief influence Chernozem preservation, but often these factors alone are not sufficient to explain their occurrence and distribution in certain geographical regions.

The diagnostic horizons of Chernozem are argic and calcic (Driessen et al., 2001). Increasing precipitation and leaching lead to development of Haplic, then Cambic and Luvic horizons while in humid conditions Chernozems transform into Phaeozems and then Luvisols. However, Eckmeier et al. (2007) suggest that still unknown factors can influence conservation and transformation of Chernozem towards these soils. They pointed to the prehistorical anthropogenic activities: a fire or agriculture that could be responsible for patchy distribution of Chernozem-like soils in Central Europe.

Eckmeier et al. (2007) show that Chernozem soils formed on loess, although classified as Chernozem, differ significantly because Chernozem from Central Europe and from Eastern Europe developed in different climate conditions and under different vegetation.

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Different methods are needed for more specified classification of soil than current taxonomic and horizon-based models allow. Magnetometry was proposed to be a suitable tool for modeling vertical structure of soil profile fitting to pedogenic factors. Magnetic properties of soil are determined by lithogenic (parent material) and pedogenic factors. During the weathering processes of parent rock the secondary pedogenic iron minerals such as Fe-oxides, Fe-hydro-oxides, Fe-containing clay silicates and Fe-carbonates, sulfides and phosphates are formed (Cornell and Schwertmann, 2003). Then, development of pedogenic processes: autogenesis, diagenesis and dissolution affected magnetic properties of soil creating characteristic depth distribution of magnetic parameters. The type of Fe-minerals, concentration of Fe-rich grains, their morphology and size give information about processes of soil formation and reflect the real soil forming conditions.

The current research is addressed to find the subtle differences between four Chernozems from Central Europe and the Ukrainian Steppe which are caused by pedogenic processes. For this purpose, we studied the set of magnetic parameters characterizing a vertical structure of Chernozem and observed differences in soil development in relation to the various climatic conditions and the mechanism of their formation. Our special approach involved the magnetic description of a genetic horizons structure, the changes in mineralogy, and a distribution of grain size. Additionally, we investigated a link between magnetic signatures and the soil parameters like reactivity (pH), approximate amount of organic matter (LOI) and content of carbonates ($CaCO_3$).

2. Material and methods

2.1. Study area and soil sampling

The Eurasian Chernozem occurs in an area stretching from the Southern Ural to Ukraine. A typical feature of Chernozem is its formation from mostly aeolian and carbonaceous sediments like loess. Calcification indicates weak eluviation and the formation of secondary calcium carbonate in subsoil horizons. A stable, black type of humified organic matter forms a typical A horizon and often also the top part of any directly underlying B or C horizon. The transitional AB, and/or AC or BA horizons are commonly present and typical E horizons are absent in Chernozem (Fanning and Fanning, 1989). Chernozems were formed in continental climatic zones with seasonal rainfall of 450–600 mm per year, coming in the spring or early summer with cold winters; and in relatively short, hot summers (Driessen et al., 2001; Eckmeier et al., 2007).

Parent rock is an especially important factor for the formation of soil. The European Chernozems have been developed on one of the thickest loess complexes deposited during the last 800 ka (Evlogiev, 2007; Haase et al., 2007).

Four profiles of Chernozems developed on loess were selected for the study. One profile (H2) occurs in the area of the Ukrainian Steppe and three (MDZ, VOD and KOL) in Central Europe. Profile H2 was sampled from the Homutovsky Steppe (Ukraine) and was formed in the steppe belt of the transition zone, in moderately warm and dry continental climate, where the maximum rainfall occurs in the hottest period of summer. Two Chernozems: MDZ (non-degraded) and KOL (degraded) were formed in the same area in Central Poland, Little Poland. Profile VOD (calcaro-haplic) was formed in the area of Moravia (Slovakia). Profiles from Central Europe were formed in different climatic conditions. They are characterized by variability in vegetation (steppe-forest) and higher rainfall in relation to Chernozem from the Ukrainian steppe. Chernozems H2 and MDZ have similar arrangement of pedogenic horizons: mollic A horizon, transitional AC_k (enriched by calcium carbonates) and parent rock C_k. Profile KOL has a browning horizon $B_{br}B_t$ enriched by clay fraction and located directly below the humic horizon A, which is characteristic for degraded Chernozem. The

Table 1
Description of the Chernozem profiles.

Sampled profiles		Geographical coordinates of sampling location Geological settlement
Horizon	Depth [cm]	Description
Homutovsky Steppe H2 typical Chernozem		47°17′N, 38°11′E Black Sea Depression
A_p	0–10	Humus soddy horizon, clumpy, roots, dark-gray vein black
A	10–48	Humic horizon, dark-gray-straw colored, compressed, monolithic, heavy loess, mole's burrows, gradual transition
AC_k	48–73	Transitional horizon, light-brown with gray spots, clumpy, carbonates, sharp transition
C_k	>73–86	Parent rock horizon, pale-yellow heavy loess, dark-yellow loess, carbonates
Młodzawy MDZ non-degraded Chernozem		50°40′N, 20°11′E Szczecin–Lodz–Miechow syncline
A_p	0–10	Humus soddy horizon, roots, clay dust with aggregate and lumpy structure, dark-gray–brown
A	10–50	Humic horizon, clay dust with lumpy-sharp-edges structure, dark gray–brown, dense with roots
AC_k	50–80	Transitional horizon, carbonate concretions
C_k	>80	Parent rock horizon, typical loess with blocky structure, light yellow, dry with carbonates
Village Kolosy KOL degraded Chernozem		50°19′N, 20°37′E Szczecin–Lodz–Miechow syncline
A_p	0–10	Humus horizon, dust with lumpy structure, dark gray
A	10–60	Humic horizon, thick dust with lumpy structure, dark gray–brown
$AB_{br}(B_t)$	60–80	Cambic/humus horizon, clay dust with lumpy structure, dark gray–brown
$B_{br}C$	80–120	Cambic horizon, clay dust with lumpy structure, dark brown
C_k	>120	Parent rock horizon, loess with lumpy structure, light brown, carbonates
Voderady VOD calcaro-haplic Chernozem		48°16′N, 17°32′E Neogene and Quaternary deposits
A_p	0–30	Humus soddy horizon, silty clay loam, medium granular to subangular blocky, roots, clear smooth boundary
A	30–60	Humic horizon, silty clay loam, slightly calcareous, roots, diffuse irregular boundary
AC	60–85	Transitional horizon, silty clay, contrast colors, strongly calcareous, medium angular blocky, abundant calcareous pseudomycelia and roots, diffuse irregular boundary
C_k	85–130	Parent rock horizon, loess, strongly calcareous, blocky in upper part of the horizon, massive in lower part, abundant pseudomycelia