CHERNOZEM. FROM CONCEPT TO CLASSIFICATION: A REVIEW

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ABSTRACT

In this paper, we put together the most important facts that lead to the research on chernozem. Thanks to the work of V. V. Dokuchaev (1846–1903), chernozem stands at the forefront of pedology. In 1883, Dokuchaev introduced the first concept of chernozem: he defined chernozem as a steppe soil with pedogenesis dominated by a dry continental climate and steppe vegetation, with calcareous parent material. Chernozem is a soil well known for its high agronomical potential; therefore the perception of chernozem as something extraordinary valuable goes back far into history. Our review presents the key factors of the pedogenesis of chernozem by explaining the causes of the high stability of its organic matter and the role of vegetation and fauna in this process. Moreover, it shows that chernozem can have many aspects due to various (a) textures, (b) chemical compositions, (c) influence of water, (d) fauna, or (e) anthropogenic factors. We examine the position of chernozem in numerous national and international soil classifications over time. We have found out that chernozem had been classified, according to its properties, as a "steppe soil", as a "calcic soil" or as an "isohumic soil".

Keywords: chernozem, history of research, soil classification, Central Europe, literature review

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1. Introduction

Chernozem is an iconic soil. Because chernozem is a symbol of fertility, it has always been a centre of high interest for agronomists and pedologists. However, the perception of chernozem has varied over time and differs depending on pedological schools of thought and geographical location. The main objective of the presented work is to give a complete overview of the meaning of the term "chernozem" in pedology. Since V. V. Dokuchaev defined chernozem as a zonal soil formed under steppe and dry continental climates on loess parent material, the concept has been developed and reviewed.

In this paper, we present the main characteristics and features of chernozem. These are consequences of the soil formation processes, including long maturation of soil organic matter, steppe vegetation and intensive faunal activity. At the same time, we emphasize that behind the model definition of chernozem there is a wide range of soils included in the concept. We have therefore reviewed numerous soil classifications to see their perception on global and regional scales, with a special focus on the Czech national soil classification.

2. Chernozem: a long story of research interest

The term chernozem is derived from the ordinary Russian words chornyi – black and zemlja – soil. It means simply "black soil". The black colour is linked to its richness in organic matter. According to historical sources, the regions covered by black organic soils have always been described as fertile (Krupenikov et al. 2011). In literature, the "chernozem" was probably mentioned for the first time in 1645 by Salmon Gubert (Reintam 2001). At that time, the word "chernozem" was commonly used by farmers to designate black steppe soils (Boulaine 1989; Akonin 1771 in Kubiena 1953). In scientific literature, the term chernozem was used for the first time by the Russian scientist M. Lomonosov in 1765 (Krupenikov et al. 2011). Lomonosov used the term chernozem for both: the soil itself and the form of humus (Krupenikov et al. 2011). He believed that chernozems formed after the decomposition of plant and animal matter. Subsequently, various theories were constructed during the 18th and 19th centuries – theories that today have only a historical value (Prokhorov 1969–1978; Boulaine 1989; Krupenikov et al. 2011).

Great expansions of chernozems have always been a benefit for the concerned regions. In their report on a mission to Russia for the Geological Society of London in 1840, English geologists referred to chernozem by comparing its value to that of the coal mines in England (Boulaine 2005).

This context opened up a new era for research, triggered by the work of V. V. Dokuchaev (1846–1903). Indeed, the extensive research work on chernozems is directly responsible for the creation of a new science: pedology. This research work was the result of a request from the Free Economic Society of Russia. The aim of this research was to find out why some soils are fertile and the others are less so, for taxation purposes (Johnson and Schaetzl 2015). It was necessary to clarify the concept of chernozem. For a long period of time the agricultural land market had been distorted by speculators and swindlers who sold any kind of black soils, such as peat, rendzinas or vertisols, under the name of chernozem. The buyer, who thought he was buying fertile soil, was left with swamp or stony, dry land (Boulaine 1989). Dokuchaev spent several years on fieldwork in southern Russia. He studied and mapped the soils (Boulaine 1989; Hartemink et al. 2013). His thesis "The Russian Chernozem" was presented in 1883 in the University of Geognosy and Mineralogy in Saint Petersburg (Figure 1).

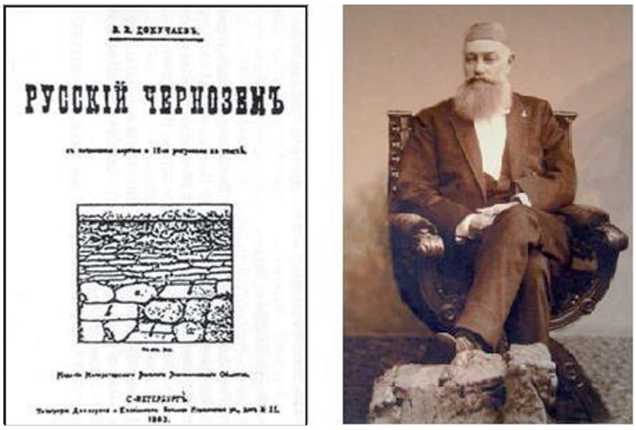

Fig. 1 The flyleaf of the thesis by Dokuchaev (1883) and a portrait of the author (taken from European Commission, 2005).

As part of his work, Dokuchaev (1883) developed in detail the holistic concept of pedology (Boulaine 1984). He described soil as a natural body, just like those of plants and animals (Boulaine 1989). Soil became the key component of biosphere and the best mirror of properties and of the history of surface areas (Pedro 1984). Dokuchaev (1883) formulated the concept of the soil profile and clarified the concept of genetic horizons as he observed them in the field. He identified five factors of pedogenesis: bedrock, climate, biological action, relief and time (Yaalon 1997; Boulaine 1984; Monnier 1966). Although he was a geologist, or because he was a geologist, he was able to show that the horizons are not strata. The presence of vast virgin, uncultivated areas allowed him to look at soil in its full complexity. He studied the topsoil, which is in the focus of agronomists (Monnier 1966).

Dokuchaev (1883) developed a theory that the organic matter of chernozems originated in terrestrial plants (Ruprekht, quoted by Prokhorov 1969–1978). He concluded that the formation of chernozems is related to the interaction between steppe vegetation, continental climate, topography and calcareous parent material. The richness in organic matter of chernozems is a consequence of the interactions between these factors. As these are zonal, the chernozem itself is also zonal. Thanks to his research on chernozems, Dokuchaev is the author of the theory of zonal distribution of soils on a global scale: each major bioclimatic region (currently called biome) is characterized by a dominant soil type. The formation of such dominant soil type is related to the action of climate and vegetation. This soil is called zonal soil (Boulaine 1989).

Therefore, chernozem has a fundamental role in pedology. It was the first soil that was properly studied and that received wide publicity. At the Paris World's Fair of 1900, Dokuchaev brought and displayed a block of several cubic metres of chernozem, which was admired by French farmers (Boulaine 2005). A part of this chernozem monolith is still kept in the French National Institute for Agricultural Research (INRA) in Grignon and Orleans. It was recently presented at the occasion of the 9th Journées nationales de l'Étude des sols in 2007. There are institutes of soil research named after V. V. Dokuchaev in Russia: the Dokuchaev Research and Development Institute of Agriculture of the Central Chernozem Zone in Voronezh and the V. V. Dokuchaev Soil Science Institute in Moscow. A museum dedicated to chernozem and a research station are located 20 km south of Kursk in Russia at the V. V. Alekhin Central Chernozem Biosphere State Reserve.

In 1880, E. W. Hilgard (1833–1916), an American pedologist and a contemporary scientist of Dokuchaev, edited the "Report on Cotton Production of the United States Census Report of 1880", which describes the soil regions of the USA (Boulaine 1989). He also commented on the zonal distribution of soils. In 1892, he published a report on the relationship between climate and soil. Hilgard classified the calcareous and non-calcareous soils. He gave a leading role in the storage of humus – especially in grassland soils – to the carbonate content, which was reassessed later by European authors who then opposed Dokuchaev (Boulaine 1989). Indeed, for Dokuchaev, it was the climate and herbaceous vegetation and not the carbonates that explained the richness of chernozems in the organic matter.

3. What is chernozem: definition and properties

Since Dokuchaev's studies on Russian chernozem, the given definition has been considered to be a reference group of soils with specific characteristics (Eckmeier et al. 2007). Chernozem is defined as a dark brown or black soil because of its richness in well-humified organic matter. The thickness of the organic layer is at least 40 cm. The base saturation, particularly in Ca^{2+} and Mg^{2+}, is high, while the pH is around 7; the aggregate structure is stable and the bioturbation is well expressed (Altermann et al. 2005; Němeček et al. 2001; Duchaufour 1977; Legros 2007). Chernozem develops on calcareous parent material, usually loess. Its formation is conditioned by bioclimatic factors: cold continental climate and dry steppe vegetation (Dokuchaev 1883; Duchaufour 1977; FAO/ISRIC/ISSS 1998). Chernozem is very fertile and valued for its high agricultural potential (Figure 2).

Fig. 2 A typical landscape of Eastern Ukraine of today in the region of Sumy. Chernozems are intensively exploited for agriculture. In the valley, there is a remnant of a steppe. Photo: B. Vysloužilová.

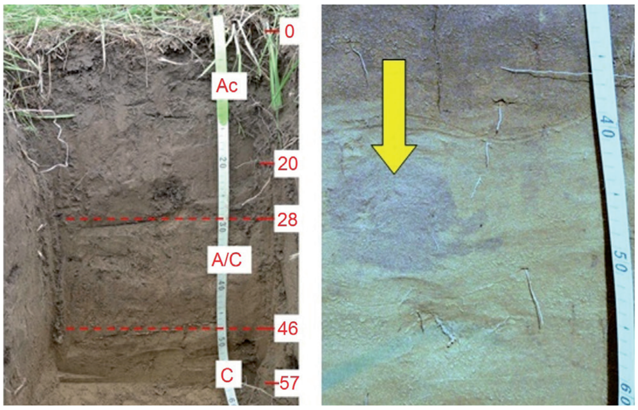

Fig. 3 Left: A modal chernozem profile in Gödölö Hills, Hungary. Right: Krotovina, marked with an arrow, a characteristic item for chernozem, remains of rodent burrows. In Bugac Puszta, Hungary. Photos: D. Schwartz.

A modal chernozem is presented in Figure 3. The A–C profile is characterized by a very thick topsoil horizon A. The organic matter content decreases slightly with depth (Kuntze et al. 1983, Duchaufour 1977). This phenomenon is defined as isohumism. The essential process of evolution of this organic matter is a long maturation of various humic compounds, called melanization (Mathieu 2009, Němeček et al. 1990). The transitional horizon between the topsoil and the subsoil is marked by abundant traces of macrofaunal activity, called *krotovinas*. Krotovinas are circular or linear forms (depending on the direction of the cut), which are old rodent burrows filled with soil (Parfenova and Yarilova 1967, Pietch 2013). A circular krotovina is clearly visible in Figure 3 (right). There are krotovinas in chernozem because rodents are very numerous in steppe regions. The bottom of the transitional horizon is a calcareous C horizon. In the C horizon carbonate is present in the form of white spots, usually called pseudomycelia (Mathieu 2009). They have a finely fascicular shape that follows the contours of the ancient rootlets where calcium precipitated. Accumulations may also take various forms (Khokhlova et al. 2001, Becze-Deák et al. 1997). The hardened concretions and nodules are called loess dolls (Duchaufour 1977, Barta 2014, Baize and Girard 2008).

The structure of chernozem is characterized by the formation of irregular crumbs. These aggregates are very stable and about the size of a grain of wheat. In cultivated chernozems, this structure is often destroyed at the ploughing horizon, where it becomes compacted (Duchaufour 1977; Głąb and Kulig 2008). The granular structure is conserved in the lower part of the A horizon, where the soil is not affected by ploughing. Moreover, the chernozem is predominantly a loamy soil (Chlpík et al. 2003; Eckmeier et al. 2007; Gorbunov 1974). The clay content in Russian chernozem varies between 15% and 20%. The nitrogen-rich plant debris is source of humus. The C/N ratio of chernozem is about 10 (Duchaufour 1977).

The most recent version of the WRB (IUSS Working group WRB 2014) defines chernozem as a soil with a chernic horizon. According to the WRB (IUSS Working group WRB 2014), the chernic horizon is considered as a diagnostic horizon. The chernic horizon is a relatively thick, well-structured blackish surface horizon, with a base saturation, a high biological activity and with a moderate to high content of organic carbon. Chernozem has a calcic horizon or a layer with protocalcic properties that starts in 50 cm below the lower limit of the mollic horizon. A calcic horizon or a layer with protocalcic properties can be eventually found above a cemented or indurated layer. The mollic horizon is defined as a structured surface horizon, dark in colour, with a high saturation base and moderate organic matter content. Consequently, a chernic horizon meets the criteria of a mollic horizon. The mollic horizon may be extended below the chernic horizon. The base saturation of the soil surface to the calcic horizon or to the layer with protocalcic properties is 50 percent or more, or when there are high concentrations of carbonates throughout the profile.

The definitions of the WRB (1998, 2006, 2014) are derived from the description of zonal chernozems that served as a reference for all chernozems. It can be difficult to assign soils called chernozems in the Central European classifications to the WRB (Nestroy 2007; Altermann et al. 2005; Zádorová and Penížek 2011). The Soil Taxonomic classification system of the Czech Republic (Němeček et al. 2011) describes chernozem as a soil with a chernic horizon (Ac) (30 to 60 cm thick) and an adsorbent complex of saturated and organic material content between 2% and 4.5%. The particle size distribution varies from sandy to clay. The parent material may be sandy loess, loess or marl. The main difference between the definition of chernozem given by the WRB (FAO/ISRIC/ISSS 2006) reference system and the Soil Taxonomic Classification System of the Czech Republic (Němeček et al. 2011) is the absence of criteria on the position of the calcic horizon in the profile and on the concentration of carbonates in the 50 cm below the lower limit of the mollic horizon (Zádorová and Penížek 2011). Zádorová and Penížek (2011) compared a soil population classified as chernozems under the Czech system with the WRB (FAO/ISRIC/IUSS 2006) system: 91% of the Czech chernozems fitted to the classification in the WRB 2006 system.

In general, the chernic Ac horizon is characterized by (a) ≥ 30 cm thick, dark colour (value and chroma ≤ 3.5 wet), (b) saturated or subsaturated adsorbent complex mainly of calcium, (c) base saturation rate ≥ 60%, (d) pH ranging from 6 to 8.3, and (e) intense polymerization of humic acids. Humic acids prevail over fulvic acids (humic acids/ fulvic acids ≥ 1.5). The humic acids are well stabilized (Němeček et al. 2001).

According to Němeček et al. (2001) again, the typical chernozem is characterized by Ac horizons: A/Ck – K – Ck under natural steppe vegetation and Ap – Ac – Ck under cultivated land. The A/Ck horizon is a transition between the chernic Ac horizon and the parent substrate. The K horizon is characterized by the accumulation of pedogenic $CaCO_3$ with a thickness of at least 15 cm. The $CaCO_3$ content is ≥ 15%. The difference between the $CaCO_3$ content of the K horizon and the horizon located just above is at least 5%. Accumulations of $CaCO_3$ are the size of clays or silts in the form of fine calcite (lublinite). Conversely, $CaCO_3$ is present as coarse crystals in the loess (Němeček et al. 2001). The Ck horizon is the horizon of carbonate alteration. There are secondary calcite accumulation traits, in the form of veins, nodules (Figure 4), or pseudo-mycelia. The Ap horizon is equal to the plough horizon.

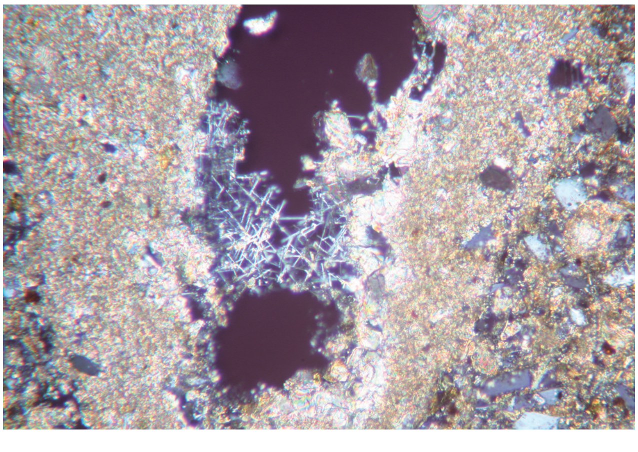

Fig. 4 The needle form of calcite in the calcic horizon in chernozem. The polarised light magnified 20×. The site of Hrušov, Czech Republic. Photo: A. Gebhardt.

4. Key pedogenesis factors

4.1 High stability of soil organic matter (SOM)

The main pedogenesis features of chernozems are the long maturation of soil organic matter (SOM) and the formation of weathering complex (Duchaufour 1977). The SOM is an essential functional component of the soil (Kögel-Knabner 2002). It comes almost entirely from the decomposition of plants and from the production of organic substances exuded by roots, but it is also partly composed of microbial mass (Guggenberger 2005). The SOM enters the soil through the root network or litter.

The humification and mineralization processes are controlled by the continental-type climate (Duchaufour 1977; Němeček et al. 1990; Kuntze et al. 1983; Phokhrov et al. 1969 to 1978; Fischer-Zujkov 2000). Seasonal climate fluctuations lead to the development of a specific soil climate. The best conditions for humification occur in spring and early summer, when soil moisture increases significantly due to the snow melting. The impregnation of water into the partially frozen ground causes temporary aerobic conditions, which are favourable to the accumulation and preservation of the water-soluble compounds produced in large quantities by the roots of steppe grasses. During the summer – the dry season – the humification process weakens. Indeed, in the dry season, as during the cold season, the activity of microorganisms is slowed (Bridges 1970).

The seasonal alternations result in the formation of molecules of high molecular weight, characterized by polymerization (condensed aromatic rings) and by high stability of the SOM revealed through a high mean residence time (MRT). The stability of humic acids in chernozems is recorded through the radiocarbon dating that gives the apparent "age" of the SOM. In general, the SOM is heterochronous – it is composed of fractions of different ages, ranging from days to millennia (Scharpenseel and Pietig 1970; Gregorich et al. 1994). In fact, the measurements of "age" through 14C show the life expectancy of the SOM: its average lifespan between an input through the decomposition of the fresh SOM and an output of the soil through mineralization. This result is called mean residence time (MRT) and it corresponds to the non-arithmetic mean of the ages of the SOM fractions (von Lützow et al. 2007). There is a strong MRT gradient with depth in chernozems. The average SOM decrease is 486.2 years for 10 cm of depth (Vysloužilová 2014). Němeček (1981) estimated this value for chernozems as 473 years for 10 cm of depth. When we compare this value with the data about other soil types in literature (Guillet 1979; Schwartz 1991; Scharpenseel and Pietig 1971; Ertlen 2009), we see that the MRT gradient for chernozems is among the highest values.

4.2 The role of vegetation and fauna

The characteristic steppe vegetation on chernozems offers special conditions for biochemical degradation (Phokhrov et al. 1969 to 1978; FAO/ISRIC/ISSS 1998 Fuller 2010; USDA 1999). The 70% to 80% of the plant biomass exists in the form of roots. The above-ground part of a plant does not provide much SOM as it decays, or is grazed, mowed or burned. Most of the SOM comes either from the decomposition of roots or root exudates.

Tab. 1 The soil classifications of the world and their principles. The main criterion used for the classification of "chernozem".

Soil classification		**Chernozem**	
Name and Author	**Principle**	**Name of Chernozem**	**Main classification criterion**
Soil Classification (Dokuchaev 1900; Russia)	Geographic and genetic	Chernozem	Steppe soil
Soil Classification (Vilenskiy 1927 in Segalen 1978; USSR)	Geographic, climate zonality	Chernozem (black soil)	Steppe soil
Soil Classification (6th International Congress of Soil Science (Ivanova 1956; USSR)	Bioclimatic	Chernozemic soils of steppes	Steppe soil
General Scheme of Soil Classification (Gerasimov and Ivanova 1958 in Segalen 1978; USSR)	Bioclimatic	Chernozem	Steppe soil
Soil Classification of the USSR (Tiurin 1965 in Segalen 1978; USSR)	Bioclimatic	Chernozem	Steppe soil
Systematic List of the Soils of the USSR (Rozov et Ivanova 1967)	Ecologic, genetic (bioclimatic)	Chernozem	Steppe soil
Historic and Genetic Classification of Soil of the Soil Map at a Scale of 1:5,000,000 (Kovda et al. 1967; USSR)	Tertiary and quaternary history of soils	Typical Chernozem	Steppe soil
Soil Classification (Volobuyev 1964; USSR)	Organic and mineral	Chernozem	Calcic soil
Categories of soils (Marbut 1927; USA)	Organic and mineral	Chernozem	Calcic soil
Soil Classification in the USA Based on their Characteristics (Baldwin et al. 1938; USA)	Morphologic and analytic characters of soils	Chernozem	Calcic soil
Higher Categories of Soil Classification (Thorp et al. 1949; USA)	Climatic (zonal soils) Mineral, hydric (interzonal soils)	Chernozem	Steppe soil
Soil Classification Project (Aubert and Duchaufour 1956; France)	Pedogenetic and morphologic	Chernozem	Calcic soil
Classification (Aubert 1965; France)	Pedogenetic and morphologic	Chernozem	Isohumic soil
Classification CPCS (1967; France)	Pedogenetic and morphologic	Chernozem	Isohumic soil
Référentiel Pédologique (Baize and Girard 2008; France)	Pedogenetic and morphologic	Chernosol	Reference group
Soil Taxonomy 1999, USA (USDA)	Objective	Order: Mollisols Suborders: Ustolls, Udolls, Xerolls	Isohumic soil
World Reference Base for Soil Resources IUSS Working group WRB 2014., 2014	Soil properties and morphogenetic processes	Chernozem	Reference group

The development of the root system to a great depth explains the thick organic impregnation of chernozems. The development of the root system is largely related to climatic conditions, with seasonal droughts requiring exploration of a large volume of soil by the plant.

The first study about the role of animals for the pedogenesis was already lead by Darwin in 1881 (Johnson and Schaetzl 2015). He described the way how soil animals like moles, susliks, marmots or worms work and aerate the soil (Figure 5). Their activities contribute to uniform the distribution of humus and to intensify the weathering of bedrock (Johnson and Schaetzl 2015). The activity of wildlife also enables a deepening of the chernic horizon (Altermann et al. 2005). The migration of clays is very low (Duchaufour 1977) because of the faunal activities and because of the high calcium content. The earthworms are important regulators of the SOM dynamics in the soil (Hong et al. 2011). Some species dig their burrows deep to protect themselves against drought and cold winters (Baize and Girard 2008). They contribute in this way to the redistribution of calcium in the soil profile (Lambkin et al. 2011). The witnesses of this biological activity are vertical earthworm galleries and krotovinas.

There is a decarbonisation of the material in environments with a high biological activity due to the very high CO_2 production. Calcium is dissolved in bicarbonate form because of the high pressure of CO_2. Consequently, calcium precipitates at the base of the profile, where the CO_2 pressure decreases. Then, a Cca horizon is formed (C carbonated) (Duchaufour 1977).

5. Classification

Chernozem is a major type of soil. Its name has remained stable since the first scientific descriptions, but its position in global and national classifications varies depending on the selected classification criteria.

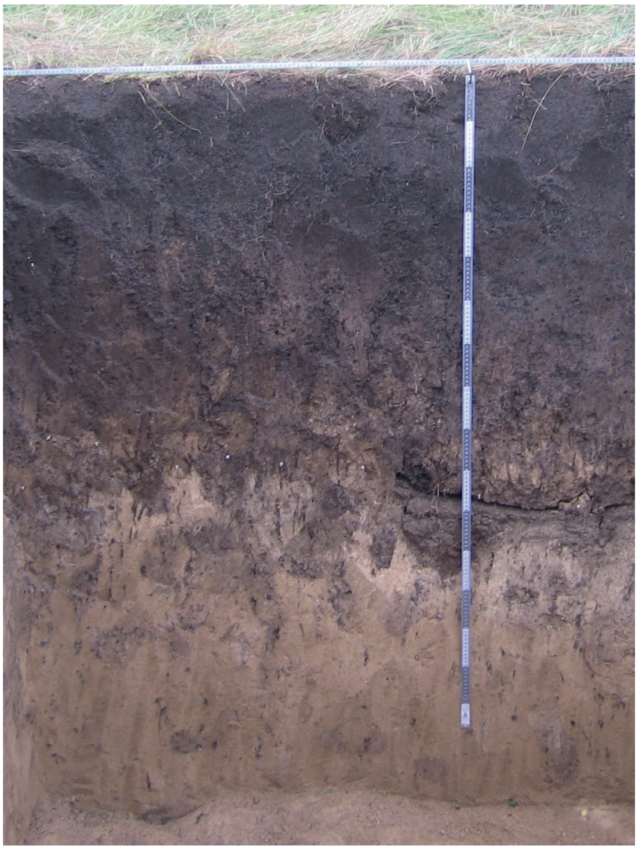

Fig. 5 Chernozem with a high biological activity marked by the vermic qualifier. Southern Russia, the region of Kursk. Photo: B. Vysloužilová.

Němeček et al. (1990) estimate that three national classifications have had a major influence on global soil classification: the Russian classification based on genetic-geographic principles, the French classification encompassing all soils in the world and based on morphogenetic principles, and the American classification based on a complex diagnosis. The World Reference Soil classification of the FAO/ UNESCO, which served as the basis for the global soil map (FAO and UNESCO 1972) is the only globally recognized classification. In each of these classifications, chernozem finds place depending on various criteria (explained below), but these criteria are not entirely disconnected from each other. The positions attributed to chernozem in various classifications are listed in the following table.

5.1 Chernozem: a "steppe soil"

The classification of soils created by Dokuchaev and presented in 1900 at the World's Fair in Paris (Pedro 1984) is based on geographic and genetic principles. There are three soil classes: Class A of normal soils (vegetal, zonal), Class B of transitional soils (intrazonal) and Class C of abnormal soils (azonal). Chernozems are part of Class A, where external phenomena (climatic and biological) are involved in soil formation. Chernozems are classed in Category IV: steppe soils. The classification of chernozems as steppe soils has persisted in subsequent Russian classifications. The climate is taken into account as a zonation factor through the thermal and moisture regimes (Vilenskiy 1927; Ivanova 1956; Gerasimov and Ivanova 1958; Tiurin 1965; Rozov and Ivanova 1967; Kovda et al. 1967; all quoted in Segalen 1978). The principle of zonation also appears in the American classification proposed by Thorp et al. (1949), which adopts the division into zonal, intrazonal and azonal soils from Dokuchaev (1900). The group of steppe soils is often shared with kastanozems (Ivanova 1956; Gerasimov and Ivanova 1958 quoted in Segalen 1978; Tiurin 1965; Rozov and Ivanova 1967). The classification by Kovda et al. (1967) groups chernozems with other arid to humid sub-boreal soils: humified alluvial soils, brunizems, light grey forest soils, grey forest soils and dark grey forest soils. Thorp et al. (1949) categorise chernozems with other semi-arid dark soils, sub-humid and wet meadows: chestnut soils and chestnut reddish soils, grassland soils and grassland reddish soils.

5.2 Chernozem: a "calcic soil"

Another point of view is a classification based on the organo-mineral characteristics. Thus, in some classifications, chernozem is classified according to its high calcium content. The calcium content as a classification criterion was used for the first time by the American soil scientist Marbut in 1927. In his classification, chernozem is a part of the group called pedocals (soils rich in calcium) that are present in mid-latitudes. This group also includes brown soils and grey soils. Baldwin (1938), in his classification of the soils of the USA, retains the concept of pedocals and categorises chernozems with chestnut soils, reddish brown soils, prairie soils and reddish grassland soils in the class of dark zonal soils of semi-arid, sub-humid and humid grasslands. The calcium content is used in the classification by Volobuyev (1964) where chernozem forms with sierozems and chestnut soils a group of steppe soils saturated with calcium. Aubert and Duchaufour (1956) introduced the concept of the evolution´s degree of the soil profile and the physicochemical nature of its evolution in their classification. The chernozem is placed in the calci-morphed AC profile class; it belongs to the subclass of steppe soils with chestnut soils and red brown soil, brown soil and red soil and soil crust.

5.3 Chernozem: an "isohumic soil"

Chernozems are remarkable for their high organic matter content. Aubert (1965) introduced the term isohumic soil in the soil classification in order to describe soils with relatively constant organic matter content over a large thickness (Segalen 1978). Chernozems share the class of isohumic soils with brunizems, brown soils, brown isohumic soils, brown soils and chestnut subtropical soils, sierozems and isohumic soils of pseudo-steppes. The concept of isohumic soils persists in the French classification established by the Commission of Pedology and Soil Mapping (CPCS 1967), which takes into account the physical, chemical and morphogenetic properties of soils. The CPCS sorts chernozems in the class of isohumic soils with a very cold soil climate together with chestnut soils and brown isohumic soils. Duchaufour (1970 in Segalen 1978) adapted this classification; three soil types form an isohumic soil group with a saturated complex. The USA soil classification from 1975 (the Soil Taxonomy) is based on the principle of detailed diagnostics of horizons in terms of their properties, and not of the environmental processes. A new terminology was created. The Soil Taxonomy introduced a term that encompasses active layer soils with thick topsoil, richness in organic matter and fertility. Mollisols are one of the major groups of the Soil Taxonomy, in which chernozems are integrated. In this way, they lost their traditional name. The second edition of the Soil Taxonomy (1999) keeps this system of classification. Soils with characteristics of chermozem can be found in different groups, especially udolls (IUSS Working group WRB 2014).

The WRB 2014 (IUSS Working group WRB 2014) world soil classification – created on the basis of soil properties and morphogenetic processes – made chernozems one of the 32 reference groups. Unlike in other classifications, they are clearly separated from kastanozems and phaeozems, which are separated reference groups on the same hierarchical level.

5.4 Chernozem in the European national classifications

Chernozem also appears in the national soil classifications of Central European countries (Table 2). The German classification from Kubiena and Mückenhausen from 1980 (Kuntze et al. 1983) Die Systematik der Böden Mitteleuropas places chernozem (Tschernosem) in the class of terrestrial soils (= well-drained soils), within the subclass of steppe soils. The Czech classification Taxonomický klasifikační systém půd ČR (Němeček et al. 2011) contains a reference class of černosol that includes two soils: černozem (chernozem) and černice (= gleyic chernozem according to the WRB 2006; Zádorová and Penížek 2011). The Slovak classification (Sobocká et al. 2000) Morfogenetický klasifikačný pôd systém Slovenska defines 10 groups of soils. The chernozem (černozem) forms, together with smonica (vertisols) and čiernice (chernozem gleyic), a group of Mollic soils. The Austrian classification Systematik der Böden Österreichs defines a class of terrestrial soils: raw humus soils with developed A–C, where there are chernozems (Tschernozem), trunk chernozems (Rumpf-Tschernosem) and brown chernozems (Brauner Tschernozem) (Nestroy et al. 2011). The Hungarian Soil Classification System (Szabolcs et al. 1966) defines a group of chernozems that includes five subtypes. The correlation between the chernozem defined by Szabolcs et al. (1966) and the WRB is not obvious: leached chernozems do not meet the criterion of colour and rather correspond to kastanozems, meadow chernozems correspond to chernozem gleyic, terrace chernozems meet mollic fluvisols (FAO/ISRIC/ISSS 2006; Micheli et al. 2006).

Tab. 2 Chernozem in Central European soil classifications.

Country	Name and Author	Name of chernozem
Czech Republic	Taxonomický klasifikační systém půd ČR (Němeček et al. 2011)	Černozem
Slovakia	Morfogenetický klasifikačný systém Slovenska (Sobocká et al. 2000)	Černozem
Germany	Die Systematik der Böden Mitteleuropas (Kubiena and Mückenhausen 1980 in Kuntze et al. 1983)	Tschernosem
Austria	Systematik der Böden Österreichs (Nestroy et al. 2011)	Tschernosem
Hungary	Genetikus Talajtérképek (Szabolcs et al. 1966)	Csernozjom

6. Variety of Chernozems

There are many subtypes of chernozems which are described with various qualifiers. The fundamental isohumic character of chermozems is preserved. There are also secondary features, which reflect the interference of basic and of physicochemical processes that are typical for another type of soil (Duchaufour 1977). We have compared the subtypes represented in the Soil Taxonomic Classification System of the Czech Republic (Němeček et al. 2001; Němeček et al. 2011) and the subtypes defined by the WRB (IUSS Working group WRB 2014). In some cases, we have picked out an equivalent or related subtype from another classification system.

The diversity of chernozems is underlined in the most recent classifications. The number of defined subtypes varies depending on the year of publication, the author and the geographical extension of the use of a classification system. The Soil Taxonomic Classification System of the Czech Republic (Němeček et al. 2001) identified six subtypes: modal, luvic, hydromorphic, arenic, pelic, and vertic. In the latest version of the Czech soil classification (Němeček et al. 2011), two additional subtypes appeared: carbonated and anthropic. The WRB of 1998 (FAO/ISRIC/ISSS 1998) defines only three subtypes of chernozem: calcic, cambic and argic. The WRB of 2006 (FAO/ISRIC/ISSS 2006) set several qualifiers. Some of them are expressed by following prefixes: voronic, vermic, technic, leptic, vertic, endofluvic, endosalic, gleyic, vitric, andic, stagnic, petrogypsic, gypsic, petroduric, duric, petrocalcic, calcic, luvic, haplic, anthric, glossic, tephric, sodic, pachic, oxyaquic, greyic, skeletic, arenic, siltic, clayic, and novic. These are used in a higher hierarchical level. The other qualifiers are expressed by suffixes that are used in a lower level: anthric, glossic, tephric, sodic, pachic, oxyaquic, greyic, skeletic, arenic, siltic, clayic, and novic.

The most recent WRB (IUSS Working group WRB 2014) defines 15 principal qualifiers for chernozems: petroduric/duric, petrogypsic/gypsic, petrocalcic/calcic, leptic, hortic, gleyic, fluvic, vertic, greyzemic, luvic, skeletic, haplic; and 25 supplementary qualifiers: andic, arenic, clayic, loamic, siltic, aric, cambic, colluvic, densic, fractic, hyperhumic, novic, oxyaquic, pachic, ruptic, endosalic, sodic, stagnic, technic, tephric, tonguic, transportic, turbic, vermic, vitric.

The correlation between the term chernozem (IUSS Working group WRB 2014) and the Soil Taxonomy (USDA 1999), used principally in the United States of America, is not obvious because these classification systems are constructed differently. A clear accordance is rather rare between these two classes. The USDA classification takes into account also the water regime and the soil temperature. There are varieties of chernozems included in some suborders of mollisols, like udolls, ustolls, rendolls or xerolls, depending on the soil temperature and on the moisture regime. At the same time, not all the soils classified in these suborders must correspond to a type of chernozem (IUSS Working group WRB 2014). Mollisol is a name for a very dark colored, base-rich, mineral soil of the steppe with a mollic epipedon. Below the mollic surface horizon, there can be a cambic, calcic, natric or argillic horizon. The presence of another horizon or a special feature is indicated by the prefix to the suborder name: natri-, calci-, argi-, pale-, duri-, verm-, hapl- (USDA 1999).

6.1 Description of principal subtypes

A typical chernozem of Central Europe (Němeček et al. 1990; Mathieu 2009) matches by its characteristics with calcic chernozems (FAO/ISRIC/ISSS 1998). The thickness of this chernozem is between 50 cm and 100 cm. There is a horizon with a concentration of secondary carbonates (calcic horizon). The $CaCO_3$ accumulations are in the size of clays or silts (Němeček et al. 2011). The Soil Taxonomy (USDA 1999) also admits the presence of a calcic horizon in mollisol with a mineral horizon, that is marked by a prefix calci- in the name of the soil.

When there are not carbonates concentrated in one layer but there are residues of carbonates in the whole profile, Němeček et al. (2011) defines it as carbonated chernozem. The origin of the carbonates is not specified. The WRB 2014 (IUSS Working group WRB 2014) does not apply a qualifier to refer to this feature. However, a subtype of chernozem with carbonates of a secondary origin along the whole profile is defined for example in German soil classification – *Kalktschernosem* (Altermann et al. 2005) – or in the French soil classification – *chernozem anacarbonaté* (Baize and Girard 2008).

There are two subtypes of chernozems which differ from the modal one by the textural composition. Vertic chernozem (IUSS Working group WRB 2014; Němeček et al. 2011; Duchaufour 1977) is characterized by its high content of swelling clays, which causes the formation of shrinkage cracks in droughts. It is located in lowlands, where fine clays were deposited by water in the periods of flooding (Duchaufour 1977). Němeček et al. (2001) say that vertic chernozem is very difficult to distinguish from pelic chernozem (Němeček et al. 2011). Arenic chernozem is characterized by a high content of fine sands (Němeček et al. 2011; IUSS Working group WRB 2014).

Luvic chernozem (IUSS Working group WRB 2014) is defined as chernozem with a Bt (argic) horizon with clay-humus coatings on the surfaces of aggregates and on the walls of macro-porosity (Baize and Girard 2008). The leaching process is clearly expressed, but the chernic horizon is always present (Figure 6). This is a transitional soil unit between chernozem and luvisol (or albeluvisol). Luvic chernozem in the WRB 2014 corresponds to luvic chernozem in Němeček et al. (2011). The suborders of mollisols with a horizon rich in clay below the mollic horizon are marked by the prefix argic-. The suborders of mollisols, in which the argic horizon is thick or deep, are marked by the prefix pale-. Glossic chernozem is characterized by the tonguic transition between the Ac chernic horizon and the Bt horizon (IUSS Working group 2014).

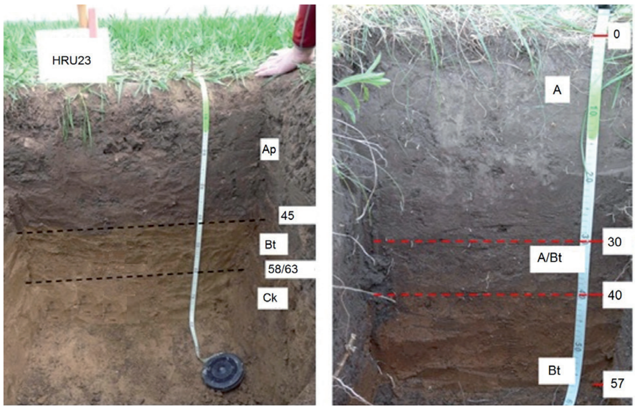

Fig. 6 Left: Luvic chernozem in Hrušov, Czech Republic. The A horizon is completely transformed by ploughing. Right: Luvic chernozem under the secondary steppe in Tard, Hungary. Photos: D. Schwartz.

Chernozem černická (hydromorphic) shows redoximorphic features in the first 60 cm of the profile (Němeček et al. 2001). The gleyic chernozem (IUSS Working group WRB 2014) shows signs of gleyic processes in the first meter of the profile depth. These two types of chernozem are formed in the areas influenced by the presence of a water table.

Cambic chernozem defined in the WRB 1998, 2006, 2014 is characterized by a structural horizon (Bw) between the A horizon and the C horizon (FAO, IUSS, ISRIC 1998, 2006; IUSS Working group 2014). The Bw horizon is characterized by a brownish colour and an absence of carbonates. In the Czech system, this horizon is called transitional A/Ck (Němeček et al. 2011). According to Altermann (2005), chernozem with a Bw horizon is also called decarbonated. There are clay coatings in a Bw horizon, but these are less important than in a Bt horizon.

This corresponds to chernozem with a structural horizon as defined by Baize and Girard (2008).

Němeček et al. (2011) introduce the subtype anthropic in the Czech soil classification. This subtype is defined as chernozem with an anthropic influence where the diagnostic horizons must be persevered, so it can be classified as chernozem. The anthropogenic factor was first introduced in the soil classification in the WRB 2006 (FAO, ISRIC, IUSS 2006). The most recent WRB 2014 differs the subtypes of aric, hortic and technic, which refer to the anthropic influence on the soil (FAO Working group WRB 2014).

7. Conclusion

This paper goes back to the beginnings of pedology as a modern science. The need of a scientific definition of chernozem lead V. V. Dokuchaev to his systematic research on this type of soil in the second half of the 19th century. However, the meaning of chernozem as something very precious and important goes much further into history. The common name for chernozem, that was originally used by people who worked on fields, penetrated amazingly into the scientific terminology around the world. The central concept of chernozem defined by Dokuchaev has been used and developed until now. Chernozem is a result of the process that has been going on for thousands of years. Chernozem is a thick soil of black colour, rich on organic matter, formed on calcareous parent material under specific conditions of the dry continental climate. Chernozem may have a large number of varieties, but the key factors of its pedogenesis are slow maturation and humification of the organic matter.

We have proved that the name of chernozem has a stable place in the soil classifications of different national and international systems. All of them refer to the main characteristics of chernozem: steppe environment, high organic matter content and carbonate content.

When we compare the definition of the central concept of chernozem and all the varieties of chernozem that there can be, we see how difficult it is to enclose the complexity of chernozem. Moreover, every soil classification sets artificial limits to the natural variety of any type of soil. We have to point out that the concept of chernozem is still being developed. Some recent studies show that chernozems could have even more nuances. The main character of chernozem can be resulting from some other pedogenesis cofactors like man and fire (Eckmeier et al. 2007), or chernozem is not necessarily only a product of a steppe environment (Vysloužilová et al. 2014).

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RESUMÉ

Černozem. Od pojmu ke klasifikaci: shrnutí

Černozem představovala vždy v historii díky vysokým zemědělským výnosům výjimečné bohatství. Proto se těšila odjakživa zájmu zemědělců, obchodníků a jako první půda se stala cílem podrobného vědeckého výzkumu. Díky práci V. V. Dokučajeva (1846–1903) se tak černozem octla u zrodu pedologie jako samostatné vědecké disciplíny. Článek pojednává o nejdůležitějších skutečnostech, které vedly k výzkumu černozemě, a také o jejích vlastnostech a způsobu klasifikace. V roce 1883 definoval V. V. Dokučajev ve své doktorské práci černozem jako půdu, kde hlavním půdotvorným faktorem je suché kontinentální klima, stepní vegetace a karbonátová mateční hornina. Definice černozemě se však postupně vyvíjela a byla upravována. Mezi hlavní půdotvorné procesy patří dlouhé vyzrávání organického materiálu, které způsobuje vysokou stabilitu půdní organické hmoty, a činnost vegetace a fauny. Černozem může mít mnoho podob v závislosti na rozdílné zrnitosti, chemickém složení, vlivu vody, fauny nebo činnosti člověka. Černozem má své stálé místo v národních i mezinárodních půdních klasifikacích. Nejčastěji bývá klasifikována mezi stepní půdy, karbonátové půdy nebo humózní půdy.

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