UDC 631.44(497.11-11)
doi: 10.46793/AASer2661.021Z

Acta Agriculturae Serbica, 31 (61), 21–30, 2026

Publisher: Faculty of Agronomy Čačak

www.afc.kg.ac.rs

Acta Agriculturae Serbica

Article

The presence of Phaeozems formed on loose parent materials in Serbia

Ljubomir Životić[1*], Jovica Vasin[2], Goran Dugalić[3], Boško Gajić[1], Mirko Knežević[4]

[1] *Faculty of Agriculture, University of Belgrade, Nemanjina 6, 11080 Beograd, Serbia*
[2] *Institute of Field and Vegetable Crops, Laboratory for Soil and Agroecology, Maksima Gorkog 30, 21101 Novi Sad, Serbia*
[3] *Faculty of Agronomy Čačak, University of Kragujevac, Cara Dušana 34, 32102 Čačak, Serbia*
[4] *Biotechnical Faculty, Podgorica, University of Montenengro, Mihajla Lalića 15, 81000 Podgorica, Montenegro*

**Corresponding author: ljubomirzivotic@yahoo.com*

Received 5 November 2025; Accepted 26 January 2026

A B S T R A C T

Phaeozems in the World Reference Base for Soil Resources (WRB) are thick, eutric soils which have a mollic horizon and lack secondary carbonates. The term 'Phaeozems' is not used in the National Soil Classification System (NSCS) in Serbia at any systematic level, but soils with these characteristics exist. The aim of this work was to compare the results of the national and international classifications of 18 soil profiles investigated at the toeslopes of Mountain Vukan, East-Central Serbia. The soils are mainly thick, formed on alluvial deposits, with a moderately high humus content, well-developed humus-accumulative horizons, and high base saturation. The WRB classification identified 16 profiles of Phaeozems; however, according to the NSCS, ten soil profiles correspond to Chernozems and eight to Eutric Cambisols. Five Cambic Chernic Phaeozems of the WRB correspond to Leached Chernozems and four to Eutric Cambisols. Three Cambic Phaeozems correspond to Leached Chernozems and two to Eutric Cambisols. In Serbia, Leached and Brownized varieties of Chernozems might be the closest to Phaeozems if they fulfill mollic and intermediate horizons criteria. In this work, we indicated that many Serbian soils may belong to Phaeozems, such as Calcareous and Gleyic varieties of Chernozems, Non-calcareous and Calcareous Humofluvisols, etc. Soil investigation in the WRB requires detailed soil description and quantitative verification. The attempts to correlate the two systems in Serbia were not very accurate because of the missing data on soils. The importance of Phaeozems is outstanding because they are highly-fertile soils prone to degradation, which probably cover more than 300,000 ha or ~6% of agricultural land in Serbia.

Keywords: phaeozems, mollic horizon, chernozems, secondary carbonates, Humofluvisols

И З В О Д

Феоземи (Phaeozems) у Светској референтној основи за земљишне ресурсе (WRB) представљају дубока еутрична земљишта са моличним хоризонтом и недостатком секундарних карбоната. Термин „феоземи" не постоји у националној класификацији земљишта (НСКЗ) у Србији ни на једном систематском нивоу, али земљишта са оваквим карактеристикама постоје. Циљ овог рада је био да се упореде резултати националне и међународне класификације на 18 профила земљишта испитаних у подножју планине Вукан, у Источној Србији. Земљишта су углавном дубока, образована на алувијалним наносима, са умерено високим садржајем хумуса, развијеним хумусно-акумулативним хоризонтом и богата базама. WRB класификација је идентификовала феоземе у 16 испитаних профила; према НСКЗ, десет профила земљишта одговара черноземима, а осам еутричним камбисолима. Пет Cambic Chernic Phaeozems из WRB-а одговара излуженим черноземима, а четири еутричним камбисолима. Три Cambic Phaeozems одговарају излуженим черноземима, а два еутричним камбисолима. У Србији су излужени и посмеђени варијетети чернозема вероватно најближи феоземима, уколико испуњавају критеријуме потребне за дефинисање моличних и прелазних хоризоната. У овом раду смо истакли да многа земљишта у Србији могу припадати феоземима, као што су и варијетети карбонатног и оглејаног чернозема, бескарбонатни и карбонатни варијетети хумофлувисола и др. Истраживање земљишта према WRB захтева детаљан опис земљишта са квантитативном верификацијом резултата. У старијој литератури често нема довољно података да би се упоредила два система, те се овакве анализе изводе са превише претпоставки. Значај феозема је изузетан јер су то веома плодна земљишта подложна деградацији, која у Србији вероватно покривају више од 300.000 хектара или ~6% пољопривредног земљишта.

Кључне речи: Феоземи, молични хоризонт, черноземи, секундарни карбонати, хумофлувисоли

1. Introduction

Soil classification deals with the systematic categorization of soils based on their characteristics as well as the defined criteria that dictate choices in use (Životić et al., 2021). It serves as a basis for the assessment of a soil's production and ecological value. The classification of soils according to the World

Reference Base for Soil Resources (WRB) is based on soil properties defined in terms of diagnostic horizons, diagnostic properties, and diagnostic materials, which to the greatest extent possible should be measurable and observable in the field (IUSS, 2015). The National Soil Classification System (NSCS) used in Serbia is based on the principles of genetic classification, and it utilizes the concept of genetic soil horizons. The difference between genetic and diagnostic horizons creates an obstacle in the correlation between NSCS soil types and WRB reference soil groups (RSGs).

The name Phaeozems is derived from *Greek* 'phaios', meaning 'dusky', and *Russian* 'zemlja', meaning 'earth' ('soil'), and it is connotative of dark-colored soils rich in organic matter. This term has been used for many years in the FAO legend for soils (FAO, 1971–1981; FAO, 1988), which was a soil classification system prepared for communication among various systems. This system recognized Calcaric, Haplic, Luvic, Stagnic, and Gleyic Phaeozems. In 1998, the FAO legend for soils was replaced with the WRB, and the term Phaeozems was still in use. In the meanwhile, the WRB survived four editions (FAO, 1998; IUSS Working Group, 2006; IUSS Working Group, 2015; IUSS Working Group, 2022) and Phaeozems are nowadays the Reference Soil Group (RSG) found in the key at the 19th place, after Chernozems and Kastanozems and before Umbrisols. Briefly, these soils are characterized by a pronounced accumulation of organic matter in the mineral topsoil and, therefore, dark color, and, furthermore, a base status >50% throughout to a depth of 100 cm from the soil surface or to continuous rock, and no presence of secondary carbonates (unless they are very deep). The difference relative to the adjacent RSGs in the key is that: a) Chernozems, which are also encountered in Serbia, have very dark topsoils and secondary carbonates in the subsoil, b) Kastanozems are characterized by dark topsoil and the presence of secondary carbonates, but they are not found in climatic regions in Serbia, which are more humid; c) Umbrisols have low base saturation (<50%).

Phaeozems are soils that cover around 190 million of ha worldwide. Nevertheless, black-colored humus-rich Chernozems and Phaeozems cover around 420 million ha worldwide (IUSS Working Group, 2022; Chesworth, 2016). As they are among the most fertile soils in the world, they have been used for agriculture for a long period of time (Altermann et al., 2005; Liu et al., 2012; Brigand and Weller, 2013; Lisetskii et al., 2013; Pleasant, 2015; von Suchodoletz et al., 2019). Worldwide, Phaeozems are found in relatively wet grasslands, usually with udic water regime, and in forest regions in temperate climates. The main zones of distribution are humid and subhumid Central Lowlands and easternmost parts of the Great Plains of the United States of America (70 million ha), subtropical pampas of Argentina (Diaz-Zorita et al., 2002) and Uruguay (50 million ha), and northeastern China (18 million ha), followed by discontinuous areas in the center of the Russian Federation and regionally smaller, mostly discontinuous areas of Central Europe, notably the Danube area, where Serbia partly belongs. Also, they are distributed in montane areas in the tropics (IUSS Working Group, 2015). In other countries of the world, Phaeozems are termed Brunizems in Argentina and France, Dark Grey Forest Soils and Leached and Podzolized Chernozems in the former Soviet Union, Chernossolos in Brazil, or Phaeozems and Greyzems according to the FAO soil map of the world (IUSS Working Group, 2015). The United States of America soil taxonomy classifies them into the order of Mollisols (Soil Survey Staff, 2022) and mainly into the Great Group of Udolls and Albolls (IUSS Working Group, 2015). In Germany, Chernozems and Phaeozems can be found as adjacent soils in the landscape, and they have been subject to both natural alterations and human influences for a long period of time (Eckmeier et al., 2007; van Suchodoletz et al., 2025).

In the National Soil Classification System in Serbia (NSCS), the Phaeozems RSG does not correlate directly at the soil type level with the existing soil types, nor do Phaeozems exist at lower systematic levels as an ''existing term'', but soils with these characteristics occur in Serbia. Therefore, their presence must be accommodated in the other existing soil types. Deep Phaeozems formed on unconsolidated parent materials like loess or aluvial and deluvial sediments may be encountered, in the genetic sense, between Chernozems and Eutric Cambisols, whereas soils with the mollic horizon formed on hard parent materials like Calcomelanosols, Rankers, or Rendzinas could also match the criteria required for Phaeozems. As the NSCS follows genetic principles, from the point of view of soil genesis, some of ''possible/existing'' Phaeozems in Serbia are the next step in the genesis of Chernozems, which further evolve into Eutric Cambisols. Phaeozems in the WRB are also more intensively leached (found in more humid areas) compared to Chernozems and Kastanozems, and that is why they are free of secondary carbonates, or $CaCO_3$ concentrations are found at greater depths. Their topsoil is dark and rich in humus, but it might be less dark than the topsoil of Chernozems (only if the chernic horizon is very rich in calcaric material), due to a lower humus content, and they might have lower base saturation than the A horizons of Chernozems and Kastanozems. Nevertheless, they are eutric soils throughout the thickness of the upper meter of the soil profile.

The aim of this work was to classify 18 soil profiles excavated at the toeslopes of Mountain Vukan on unconsolidated alluvial sediments and correlate the soils in the WRB and the NSCS. All profiles have well-developed humus-accumulative horizons with moderately high humus contents, and they are also rich in bases. In the NSCS, they are classified as different subtypes of Chernozems and Eutric Cambisols (Životić, 2016), but the WRB classifies them in a different manner (Životić et al., 2017).

Phaeozems are of large importance because they are naturally fertile soils used for the growth of field crops like wheat, soybeans, corn, sunflower, and sugar beet, and they are also possible media for vegetables and orchards due to their thickness and good water-holding, physical, and chemical properties. Phaeozems in Serbia are used for intensive agricultural production and can be prone to degradation, which affects not only their agricultural productivity but also their morphological characteristics and, accordingly, their evolution and classification. As a quantitative soil classification system, the WRB can be used in some cases to monitor soil evolution since diagnostic criteria for RSGs are far narrower than the diagnostic/genetic criteria used in the NSCS. The importance of this work is to qualitatively and quantitatively indicate the presence of Phaeozems in Serbia and to locate their place in the NSCS, as well as to tackle diagnostic criteria in the NSCS and the WRB in terms of soil evolution.

2. Materials and methods

2.1. Study area description

This study was conducted in east-central Serbia, in the area called Great Field (Veliko Polje) (44°18′N, 21°29′E), which is located between 175 and 210 m a.s.l. The area is characterized by a temperate climate (T_{avg} = 11.4 °C) and a mean annual precipitation of around 645 mm, which indicates higher vertical water fluxes than in the Central-European Chernozem zone. The foot and toe slopes of 2–5% are uniform throughout the Great Field, and the terrain is geomorphologically simple. The western part of the Great Field is formed on an old alluvial terrace of the River Mlava, whereas the eastern parts are under geogenic processes originating from soils formed on limestones. The common agricultural practices used in the study area include primary tillage to a depth of 20–25 cm and disking as a means of secondary tillage. The most commonly grown crops are winter wheat (*Triticum aestivum* L.), maize (*Zea mays* L.), and alfalfa (*Medicago sativa* L.). The western parts of the Great Field are mapped as non-calcareous Brownized Fluvisols (Tanasijević et al., 1959), but a recent study has found the presence of Eutric Cambisols and Leached Chernozems (Životić et al., 2016).

2.2. Methods

This work examines a total of 18 soil profiles excavated in the western part of Great Field. Soils were described and investigated according to the FAO Guidelines for Soil Description (FAO, 2006). The profiles were excavated to 100–120 cm depth. Soil sampling comprised a collection of disturbed soil samples and soil cores from all soil horizons. A detailed explanation of soil preparation and a laboratory analysis are given in a broader study conducted by Životić et al. (2017). The following soil analyses were conducted: particle-size distribution (Rowell, 1997), soil pH in a 1:2.5 soil–water suspension (Rowell, 1997), cation exchange capacity (van Reeuwijk, 2002), soil organic carbon (Rowell, 1997), total carbonate (Nelson, 1982), and soil color (Munsell, 1975).

2.3. Soil classification criteria – rationale for classification

Soil profiles were classified according to the WRB (IUSS, 2022) and the NSCS (Škorić et al., 1985). The main WRB criteria used for soil classification were those required to define mollic, chernic, and cambic horizons, and diagnostic materials, such as: soil horizon thickness, base saturation, grade of soil structure development and type of soil structure, content of soil organic matter, soil color criteria in terms of Munsell value and chroma, calcium carbonate equivalent, presence of secondary carbonates, soil texture class, portion of fine earth in total soil volume, relationship with underlying and overlying layers, such as difference in color, clay content, calcium carbonate equivalent, and presence of protocalcic properties. For the purpose of the NSCS, the most important criteria were calcium carbonate equivalent, soil reaction in water, base saturation, soil structure development and type of soil structure, and soil texture classes.

In the WRB, the chernic horizon is described as a very dark topsoil horizon with a strong grade of granular or subangular blocky structure development, thicker than 30 cm, eutric, having a moderate to high content of organic matter and high animal activity. Compared with the mollic horizon, the chernic horizon can have a higher content of soil organic carbon, a lower chroma, generally better developed soil structure, and a greater minimum thickness. The mollic horizon is a special case of the chernic horizon with a thickness higher than 20 cm, and a higher chroma. Both horizons can be easily identified but the analysis should approve the existence of one of them. The cambic horizon is a subsurface horizon showing evidence of pedogenic alterations that range from weak to relatively strong (IUSS, 2022). This definition is much broader compared to the NSCS. It also has soil aggregate structure requirements and specific criteria related to its difference with respect to underlying or overlying layers, such as clay content, carbonate removal, oxide and soil organic matter content, and/or soil color.

3. Results and discussion

3.1. Pedogenic consideration

The survey (Životić, 2016; Životić et al., 2017) classified soils in the area of Great Field according to the WRB (IUSS Working Group, 2015). The results were presented by means of diagnostic horizons and diagnostic properties and materials. For this analysis, 18 soil profiles from the study were divided into three groups of soils: 1) soils with chernic and mollic horizons formed on unconsolidated parent materials, 2) soils with mollic and cambic horizons formed on unconsolidated parent materials, and 3) soils with cambic horizons, without a defined overlying horizon, formed on unconsolidated parent material. Soil characteristics and photographs of all soil profiles are given in Životić et al. (2017).

3.1.1. Soils with chernic and cambic horizons

These soils are mainly located at the elevation range from 175 to 195 m a.s.l. Table 1 presents morphological and some physical and chemical characteristics of soils having chernic and cambic horizons formed on unconsolidated silicate or calcareous parent materials. The characteristics of these horizons are briefly presented in Table 1. Topsoil horizons formed on silicate deposits have an average soil organic carbon content of 1.42 ± 0.45%, average thickness 38.1 ± 5.8 cm, moderate to strong grade of soil structure development, and mainly granular soil aggregates. Soil color is typically 10YR 3/2 when moist, and Munsell color value is ≤ 5 dry. The chernic horizon on calcareous deposits has an average of 2.07 ± 0.24% of soil organic carbon, average thickness 42.1 ± 8.0 cm, moderate to moderate to strong grade of soil structure development, mainly granular soil aggregates sized 2–10 mm, and the abundance of fine roots as few. Soil color is darker than the color of chernic horizons on silicate deposits. The base saturation of all chernic horizons examined is higher than 85% on a weighted average, throughout the thickness of the horizon.

3.1.2. Soils with mollic and cambic horizons

These soils are mainly located at the elevation range from 178 to 195 m a.s.l. Mollic horizons formed on unconsolidated rocks have an average thickness of 38.3 ± 8.3 cm, whereas an average soil organic carbon content is 1.47 ± 0.36% (Table 1). Mollic horizon boundary has abrupt to clear distinctness and occasionally gradual because of the agricultural activity. It has a moderate or a moderate to strong grade of soil structure development, which is mainly granular or granular to subangular. The dominant size of aggregates is 3–10 mm. Root abundance is mainly few or very few to few, as well as the abundance of biological activity. Root size is usually <2 mm. The base saturation of all mollic horizons examined is higher than 85% throughout the thickness of the horizon. The Munsell's hue is 10YR in dry and wet conditions, whereas chroma moist is higher than 2, which excluded this horizon from being chernic. Mollic and chernic horizons examined in this study differ mainly in terms of soil color, namely, chroma moist. According to all other criteria, these horizons are very similar.

Table 1.
Characteristics of chernic and mollic horizons of the studied profiles

Soil horizon	Average thickness (cm)	Average Soil organic content (%)	Grade of soil structure development	Size of aggregates (mm)	Root abundance	Root size
Chernic on silicate parent material (n=11)	38.1 ± 5.8	1.42 ± 0.45	moderate to strong	3–15	few	fine*
Chernic on calcareous parent material (n=2)	42.1 ± 8.0	2.07 ± 0.24	moderate to moderate to strong	2–10	few	fine
Mollic on silicate parent material (n=5)	38.3 ± 8.3	1.47 ± 0.36	moderate or moderate to strong	3–10	Very few to few	fine

* < 2 mm

3.1.3. Soils with cambic horizons without a distinct overlaying horizon

The investigated cambic horizons have a well-developed soil structure, fine textural classes, an absence of rock structure in the fine earth fraction, and less dark color than the overlying horizons. They satisfy the Munsell color and thickness criteria (> 15 cm) and do not form part of the plough layer. Soil aggregates have a weak to moderate grade of structure development, although they are quite rich in clay content, and are of granular to subangular blocky type, with their size ranging from 2 to 10 mm (Životić et al., 2017). They are dark yellowish brown to yellowish brown when dry, and dark brown and dark yellowish brown when moist.

3.1.4. Calcaric material

Calcaric material in the investigated profiles occurs in the form of primary carbonates in two soil profiles formed on loose calcareous parent materials. The content of calcium carbonate equivalent in these profiles is around 10% throughout the thickness of Profile 19, and between 10 and 2% in Profile 24, where the higher amount of calcium carbonate in the topsoil indicates that this soil is formed under the impact of geogenic processes (colluviation).

3.2. Soil classification – WRB vs. NSCS

The soil classification analysis according to the WRB indicates that there are 11 profiles with chernic and cambic horizons, five profiles with mollic and cambic horizons, and two profiles having a cambic horizon without a distinct overlying horizon. Namely, there are nine Cambic Chernic Phaeozems, two Calcaric Cambic Chernic Phaeozems, five Cambic Phaeozems, and two Eutric Cambisols (Table 2). Among the mentioned 18 soil profiles, the NSCS distinguished two Calcaric Chernozems, eight Leached (Degraded) Chernozems, and eight Eutric Cambisols. These Chernozems are classified as subtypes of Chernozems on alluvial sediments, and as Calcaric and Leached/Brownized soil varieties. The criterion used to classify them as Calcaric Chernozems in the NSCS is the presence of calcium carbonate equivalent throughout the thickness of the soil profile. In the NSCS, secondary carbonates are not a required criterion to classify soils as Chernozems. In all mentioned Chernozems, the thickness of A horizons is lower than 40 cm, and they belong to a shallow Form of Chernozems. The criterion used to classify these soils as Leached and Brownized Chernozems but not as Eutric Cambisols is soil reaction in water, which must be lower than 7 (or even lower than 6.8–6.9) in Eutric Cambisols. Therefore, soils with subsurface horizons formed on alluvial sediments which have well-developed A horizons and well-developed subsurface horizons are classified as Eutric Cambisols, if their soil reaction in water is lower than 7. As these soils in the study area have base saturation higher than 50%, the presence of Dystric Cambisols was not identified in the study area. Table 2 presents the results of soil classification.

4. Discussion

4.1. Phaeozems on loose parent materials – a possible position in the national classification system

Although not reported as a unique soil type in the NSCS, Phaeozems can be identified in Serbia as part of other soil types, at the soil type level or at the lower hierarchical levels. In the Serbian scientific literature, the term Phaeozems is linked to the term Chernozems (Antonović et al., 1975, 2008; Dugalić and Gajić, 2012) but no detailed explanation of differences between the two soils is provided. Also, it is related to Meadow Black Soils – Humofluvisols (Knežević et al., 2011). The authors mostly correlate Phaeozems with one of these two soil types. When presenting Phaeozems in Serbia, Životić et al. (2017) indicated the difference between Leptic Phaeozems and deeper Phaeozems formed on unconsolidated parent materials, which are the scope of this study. Moreover, Radmanović et al. (2017) correlated some of the investigated Rendzina soil profiles of the NSCS with Phaeozems, but these Phaeozems are also Leptic and are not the scope of this study.

Table 2.
Classification of soils according to the WRB and the NSCS

Profile No.	WRB 2022	NSCS
6	Cambic Chernic Phaeozem	Eutric Cambisols
7	Cambic Chernic Phaeozem	Eutric Cambisols
8	Cambic Chernic Phaeozem	Eutric Cambisols
19	Calcaric Cambic Chernic Phaeozem (Colluvic)	Calcareous Chernozems
24	Calcaric Cambic Chernic Phaeozem (Colluvic)	Calcareous Chernozems
25	Cambic Chernic Phaeozem	Leached Chernozems
26	Cambic Chernic Phaeozem	Eutric Cambisols
27	Cambic Phaeozem	Leached Chernozems
29	Cambic Phaeozem	Eutric Cambisols
30	Eutric Cambisols	Eutric Cambisols
31	Cambic Phaeozem	Leached Chernozems
32	Cambic Chernic Phaeozem	Leached Chernozems
33	Cambic Chernic Phaeozem	Leached Chernozems
34	Cambic Chernic Phaeozem	Leached Chernozems
36	Cambic Phaeozem	Leached Chernozems
39	Cambic Chernic Phaeozem	Leached Chernozems
40	Eutric Cambisol	Eutric Cambisols
41	Cambic Phaeozem	Eutric Cambisols

In the NSCS (Škorić et al., 1985) Chernozems are differentiated at the subtype level according to the parent materials from or over which they are formed: loess, calcareous aeolian sand, and alluvial sediments. At the variety level, the classification recognizes Chernozems formed on loess as Calcareous, Leached, and Brownized, another three Gleyic varieties of the three mentioned varieties, and Salinized and Alkalized Chernozems. In the NSCS, Chernozems on aeolian sands and alluvial sediments can be Calcareous, Leached, Calcareous Gleyic, and Leached Gleyic.

Our attention in this paper is mainly given to Leached and Brownized Chernozems, which are potentially mostly related to Phaeozems, but each single profile investigated in the field has to be described accurately for soil classification purposes. In the NSCS, Leached (Degraded) Chernozems are characterized by the absence of $CaCO_3$ in the humus-accumulative horizon, whereas carbonates might be present in the intermediate layer or in the loose parent material. It is not defined whether the classification requires primary or secondary carbonates. Dugalić and Gajić (2012) reported around 70,000 ha of Leached Chernozems in Serbia. Brownized Chernozems have a (B)v cambic horizon thinner than the overlying A horizon, and both are non calcareous. Without the presence of a calcic horizon, these two soil varieties might not be identified as Chernozems in the WRB, although they fulfill the other criteria required, and their place in the key might be added to Phaeozems. Chronologically, Brownized Chernozems were termed Degraded Chernozems, at the soil type level, until 1952, and then, until 1963, they were identified as a subtype of Chernozems, whereas Škorić et al. (1963) considered them a soil variety. According to Dugalić and Gajić (2012), there are around 92,000 ha of Brownized Chernozems in Serbia.

As regards Humofluvisols, they are classified into subtypes according to the depth at which gleization occurs. Humofluvisols varieties are divided into Calcareous and Non-Calcareous, and further into Calcareous/Non-Calcareous Salinized and Alkalized. Of all the Humofluvisols identified, Non-Calcareous Humofluvisols might fulfill all required criteria for the RSG of Phaeozems, whereas Calcareous Humofluvisols might also take part of this RSG if they lack secondary carbonates. Dugalić and Gajić (2012) reported around 120,000 ha of Leached Humofluvisols in Serbia.

4.2. Reported soil profiles in literature – missing data for WRB classification

The majority of the soil profile information in existing literature is lacking the required WRB soil classification criteria. This especially stands for soil color and other morphological features. In their older study, in the area of Stig, Tanasijević et al. (1965) reported Calcareous Chernozems, Leached Chernozems, Degraded Chernozems, and Gleyed Chernozems. According to their data, Calcareous Chernozems potentially could have calcic horizons and can be classified into the RSG of Chernozems. Leached

Chernozems are characterized by $CaCO_3$ leaching, but, due to insufficient data on whether their intermediate horizon is a calcic horizon, we cannot say whether these Chernozems belong to Chernozems or Phaeozems in the WRB. Topsoil horizons are mainly leached, but AC horizons have different amounts of $CaCO_3$, but it is not mentioned whether these are primary or secondary carbonates. Degraded Chernozems in the NSCS is an old term for a stage of soil evolution between Chernozems and Eutric Cambisols. In fact, from the point of view of the latest version of soil classification (Škorić et al., 1985), the profiles of Degraded Chernozems with a pH lower than 7 in A and (B) horizons should actually be classified as Eutric Cambisols. In the WRB system, some of the profiles reported by Tanasijević et al. (1965) can potentially be classified as Phaeozems, if they satisfy all criteria required for a mollic horizon. Nevertheless, the vast area of alluvial sediments adjacent to the river bed of the River Morava is covered with various soil types, with Meadow Soils – Humofluvisols predominating. The majority of them are Non-Calcareous, groundwater level is below 150–200 cm, soil texture is mainly medium, and they have moderately thick A horizons (40–80 cm). If these Humofluvisols satisfy the mollic horizon criteria, they might be classified as Phaeozems. These soils can also be found adjacent to the tributaries of the Morava River and near the River Mlava. The Eutric Cambisols reported in their study can be classified as Phaeozems if they fulfill the mollic horizon criteria, mainly soil color and, in some cases, soil thickness.

The soil survey conducted in Vojvodina (Živković et al., 1972) mentioned five subtypes of Chernozems and nine varieties. Of these five subtypes, Chernozems formed on sandy loess may be Phaeozems if they do not fulfill the criteria required for a calcic horizon. Also, this means that all reported subtypes of Calcareous Chernozems, according to the NSCS, can be classified as Calcaric Phaeozems if they do not have secondary carbonates. However, most of the investigated Calcaric Chernozems in the Vojvodina region, according to the NSCS, have pseudomycelia in the intermediate layer, and therefore they are classified as Chernozems in the WRB. The subtype of Chernozems formed on alluvial sediments might also be classified as Phaeozems, but this is less often the case. Furthermore, some Chernozem varieties, such as Non-Calcareous Chernozems, Weakly Brownized Chernozems, and Brownized Chernozems might be classified as Phaeozems. In order to be classified, it is important: a) to have an absence of secondary carbonates in the AC horizon (an intermediate horizon, once designated as B or Bv, but not as Bca), and b) not to have soil reaction in water below 7, in the AC horizon, if they are not calcareous. There are also Chernozems formed on sandy loess fulfilling these criteria, and Chernozems with a sandy loam texture formed on sand are also described. As already noted, data from the past analysis regarding the correlation between the NSCS and the WRB are, in the majority of cases, missing, mostly with respect to the information about soil color, a criterion required for soils to be classified in the WRB.

The Non-Calcareous Chernozems described in Vojvodina by Živković et al. (1972) might be classified as Phaeozems if their AC horizon (an intermediate or subsurface horizon) does not form a calcic horizon, and also if it fulfills the other criteria for chernic or mollic horizons, including soil texture, soil structure, color, thickness, base saturation, and soil organic carbon content. Therefore, the AC horizons with secondary carbonates thicker than 15 cm can be identified as calcic horizons, and, accordingly, the soils might be classified as Chernozems, not as Phaeozems. Weakly Brownized Chernozems should not have the presence of a calcic horizon (secondary carbonates), should fulfill the criteria for chernic or mollic horizons, and should have soil reaction in water greater than 7, at least in the AC horizon, in order to be classified as Phaeozems. Otherwise, if their pH in water is <7 in A and AC horizons, they should be classified as Eutric Cambisols in the NSCS. The same explanation can also be used for Brownized Chernozems.

In the NSCS, Chernozems might also be Gleyic, and they are also described in the Vojvodina region (Živković et al., 1972), but the meaning of gleyic is not the same in the WRB and in the NSCS. According to the WRB, gleyic means a layer ≥ 25 cm thick, which starts ≤ 75 cm from the mineral soil surface and has gleyic properties throughout and reducing conditions (IUSS Working Geopup, 2022). Gleyic (Gleyed) Chernozems in the NSCS have groundwater at higher depths; if these soils do not have a calcic horizon and if they fulfill the criteria of chernic and/or mollic horizons and other required criteria mentioned above, they can be classified as Phaeozems or Calcaric Phaeozems. In the NSCS, soils whose formation is influenced by groundwater are classified in the order of Hydromorphic Soils. In the WRB, Gleysoils comprise soils with gleyic properties starting <40 cm from the soil surface. In the Serbian SCS, Gleysoils could correlate with Eugleys, whereas Humogleys refer to groundwater fluctuations between 50 cm and 100 cm from the mineral soil surface. In Humofluvisols, groundwater fluctuates from 100 cm to 200 cm from the mineral soil surface. This means that Humogleys and Humofluvisols are two soils that might fulfill the criteria regarding soil thickness, soil color, texture and structure, soil organic matter content, and base saturation, which could classify them into the RSGs having chernic and/or mollic, and/or calcic horizons – Chernozems and Phaeozems. However, Humogleys are mainly known as clayey and heavy clay soils, which are more related to Vertisols of the WRB, whereas Humofluvisols might fulfill the criteria required for Phaeozems.

In Živković et al. (1972), two subtypes of Calcareous Humofluvisols and five varieties of Humofluvisols are identified in Vojvodina. In the NSCS, Humofluvisols are differentiated to soil subtypes based on the depth of the presence of the gleyic color pattern; furthermore, there are varieties of Calcareous and Non-Calcareous Humofluvisols, i.e., Calcareous Salinized and Alkalized Humofluvisols, and Non-Calcareous Salinized and Alkalized Humofluvisols. Calcareous Humofluvisols might be related to Calcaric Phaeozems if they do not fulfill the criteria for the calcic horizon, meaning that they have only primary carbonates and no accumulation of $CaCO_3$ concentrations – they often appear, but not in all soil profiles (data are missing). Therefore, Non-Calcareous Humofluvisols might be related to Phaeozems if they do not have secondary carbonates in the AC horizon (they should have a Bv horizon, but not a Bca horizon), or if they are non-calcareous in A and AC horizons, and if soil reaction in water is higher than 7. A similar conclusion can be related to Brownized Humofluvisols reported in

Živković et al. (1972). The required criteria include the presence of a chernic or mollic horizon, no secondary carbonates in the intermediate horizon, and pH in water greater than 7, at least in the intermediate AC horizon; otherwise, they are classified as Chernozems or Eutric Cambisols in the NSCS.

As regards Humogleys of the NSCS, those with gleyic properties at the 50–75 cm depth from the mineral surface can be classified as soils with Gleyic principal qualifiers. As these soils are known for their high clay content, they might often be classified as Vertisols (Gleyic), but this is out of the scope of this work. Humogleys with a lower amount of clay do not fulfill the criteria for Vertisols, and those having gleyic properties between 75 and 100 cm can be correlated with some other RSGs, mainly Phaeozems, if they fulfill the criteria required. Therefore, as for the previous elaboration, this analysis requires a very precise soil description, i.e., the description of the abundance of mineral concentrations, primary and secondary carbonates, and identification of shrink-swell cracks. Non-Calcareous Humogleys of Vojvodina, which do not fulfill the criteria for Vertisols (a vertic horizon, a clay content, shrink-swell cracks), might be classified in the RSG of Phaeozems, as Gleyic Phaeozems, if they fulfill the criteria for the chernic or mollic horizon and the other mentioned criteria.

In the study of soils in the Timok River basin, Antonović et al. (1974) reported the presence of Leached Chernozems, but they also found that in many of the soil profiles investigated $CaCO_3$ had leached from A horizons and accumulated in AC horizons in the forms of pseudomycelia and concretions. This practically means that Leached Chernozems do not absolutely correlate with Phaeozems, as it appeared in this case, since the leaching of $CaCO_3$ caused its accumulation in the lower parts of the profile and, hence, the potential presence of a calcic horizon, suggesting that these soils might be classified as Chernozems.

The Chernozems south of the Sava and Danube Rivers, although formed on loess, are morphologically different from the Chernozems of Vojvodina, due to a different constellation of pedogenic factors, mainly topographic characteristics and hydrological conditions. There are differences in soil color, soil structure and composition, and water holding characteristics, but these soils still have the properties typical of Chernozems. Four Chernozem varieties are reported by Antonović et al. (1978): Loamy Calcareous Chernozems, Eroded Chernozems, Leached Chernozems, and Chernozems in Brownization. Loamy Calcareous Chernozems have a calcic horizon and a rare presence of only primary carbonates in the profile, which excludes them from being classified in the RSG of Chernozems. Leached Loamy Chernozems of this territory usually have $CaCO_3$ concentrations in the parent material, indicating that they do not have a calcic horizon; therefore, they cannot be classified as Chernozems, but rather as Phaeozems, if they satisfy the other required criteria. Some of the reported soil profiles, due to topographic characteristics and land use, have A horizons thinner than required for a chernic horizon, and therefore they correspond to Phaeozems. The Meadow Loamy Chernozems described, owing to their characteristics, can be classified as Chernozems, whereas Loamy Chernozems in Brownization lack carbonates and can be classified as Phaeozems, if the criteria for the presence of a mollic horizon are fulfilled. The latter have a soil reaction in water greater than 7 throughout the A and intermediate horizons in a vast majority of the investigated soil profiles and cannot be classified as Eutric Cambisols in the NSCS. Also, importantly, some of the reported profiles have a soil thickness of exactly 20 cm, which is the minimum required for the mollic horizon. Furthermore, as in the case of Vojvodina, some of the profiles of Non-Calcareous Loamy Humofluvisols (Meadow Black Soils) described in Antonović et al. (1978) in the area around Belgrade might also be classified as Phaeozems.

In their work referring to the correlation of the national soil map with the WRB classification system (Knežević et al., 2011), Non-Calcareous Chernozems, Degraded and Leached Chernozems, Brownized Chernozems, Degraded Chernozems in Brownization, and Weakly Brownized Chernozems, as soil mapping units of different versions of the NSCS, are classified as Luvic Chernozems of the WRB. The absence of a calcic horizon in any of these soils indicates that they are not Chernozems. Furthermore, the formative element Luvic used for the second level unit refers to the presence of an argic horizon, which is, inter alia, indicative of a distinctly higher clay content than the overlying horizon, caused by various criteria. This clay content criterion is fulfilled in only few of the examined soil profiles of Leached and Degraded (Brownized) Chernozems (Tanasijević et al., 1965; Živković et al., 1972), whereas in Antonović et al. (1978) it is found in more soil profiles only in Brownized Chernozems, and we should rather say that these soils, if they are classified as Chernozems (with a calcic horizon), they are not Luvic. If they do not have a calcic horizon, they can be classified in the WRB 2006 as Greyic or Haplic Phaeozems, if they satisfy the color and other criteria. Furthermore, Knežević et al. (2011) refer some of the soil mapping units of Humofluvisols (Meadow Black Soils) to Gleyic Phaeozems of the WRB, namely, Non-Calcareous, Brownized, Salinized, Alkalized, Loamy, Clay, Loamy Alluvial, with signs of salinization. Also, most of them have the prefix qualifier Gleyic, which is not correct as gleyic properties must appear within 1 m of the soil mineral surface according to the WRB 2006 criteria, whereas in Humofluvisols of the NSCS groundwater appears 100–200 cm below the soil mineral surface. The authors also use the Pachic suffix qualifier, which refers to the thickness of the mollic horizon of more than 50 cm. These Phaeozems might be Greyic if they satisfy the color criteria or Haplic Phaeozems in the WRB 2006 document. Also, if the intermediate horizon of any of these Humofluvisols is rich in secondary carbonates, they should be classified as Chernozems, if they fulfill the other required criteria.

4.3. Soil degradation, evolution and mapping

Phaeozems in Serbia are used for intensive agricultural production and are/can be prone to degradation, which affects both their agricultural productivity and soil morphological characteristics. The process of degradation can lead to loss of organic matter and nutrient depletion, soil compaction, loss of soil due to wind erosion, and loss of bases through leaching, which all together triggers the deterioration of soil structure, which is of utmost importance for these soils. Further evolution of these soils can go in the direction of ''loosing'' the criteria specified for the mollic horizon and the reclassification of these soils to Eutric Cambisols and, further, to Luvisols, after additional processes of acidification and leaching within the soil profile. It is already documented that, in Central Germany, these soils were degraded to varying degrees by decalcification, followed by silicate weathering, clay translocation, and clay formation (Baumann et al., 1983; Eckmeier et al., 2007; von Suchodoletz et al., 2019). The evolution to Luvisols is rather seen in more humid Central European regions with less calcareous soil parent materials, where former Chernozems/Phaeozems have been completely transformed to Luvisols and Retisols (Hejcman et al., 2013; Kabała et al., 2019; van Suchodoletz et al., 2025). Typical soil horizon sequences of Chernozems and Phaeozems of the WRB and soil horizon sequences of Chernozems, Eutric Cambisols, and Luvisols of the NSCS are presented in Figure 1, with their genetic/evolutionary pathways. Unfortunately, the changes in Chernozems/Phaeozems characteristics over time are not well documented in Serbia. Contrary to our conditions, in Northeast China these alterations in soil characteristics are documented (Teng et al., 2024), and it is even stated that the condition of Phaeozems has deteriorated significantly. Phaeozems are for good reason treated in China as a valuable and scarce soil resource that is rich in humus, has high natural fertility, and is the most suitable for cultivation. Teng et al. (2024) stated that Phaeozems experienced high-intensity economic development and human activities in Northeast China during the 120 years from 1900 to 2020, and that these processes have led to soil erosion, thinning, degradation, soil pollution, soil fertility decline, and other issues resulting in a serious destruction of the Phaeozem ecosystem. Approximately 10% of China's Phaeozems has lost its productive capacity, and the soil quality crisis has hampered the development and improvement of land productivity as well as restricted the sustainable development of China's agriculture (Teng et al., 2024). These degradation processes have resulted in the Chinese central government bringing and implementing several ”No. 1 Central Documents'' focused on protecting Phaeozems in Northeast China.

There is an important question about Chernozems in Serbia, their distribution and the area they cover, which is around 1,05 mil ha. Chernozems are the most fertile soils and the corner stone of development in our country. From the point of view of the WRB, with an introduction of Phaeozems, the area covered by Chernozems is diminished. Small-scale maps of our country created abroad show that Chernozems mapping units are replaced by Phaeozems, which creates confusion among agricultural experts who are not soil scientists and rumors that Serbian soils are not Chernozems and that these ''new soils'' are less fertile and with lower productivity, because the term 'Phaeozem' is not familiar to a broad audience. Of course, the rumor is not true from the point of view of soil productivity, because Phaeozems formed on loose parent material could also have very favorable characteristics. It is important to emphasize that the processes of soil degradation affect the agricultural productivity of these soils, whether they are called Chernozems or Phaeozems. Therefore, it is important to apply sustainable soil management practices in plant production. Similarly to Serbia, in the updated soil map of the Russian Federation, the following initial legend units are partially or completely converted to dark-humus soils, which correlate with Phaeozems in a lot of cases: several units of chernozems, dark gray forest and gray forest non-podzolized soils, soddy-taiga base-saturated and slightly unsaturated soils, several mountain soils, a significant part of soddy-calcareous soils, as well as some mountainous forest-meadow soils (Ananko and Gerasimova, 2021). Therefore, similar soil type/soil group correlation problems are found elsewhere.

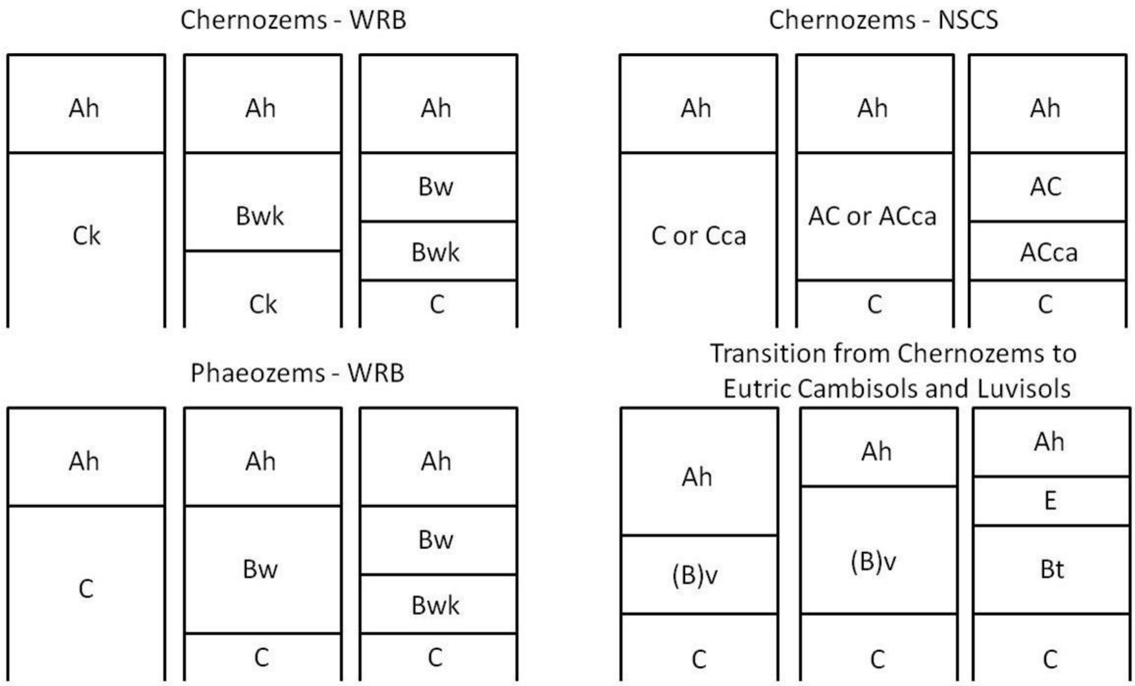

Figure 1. Typical soil horizon sequences of Chernozems and Phaeozems in the WRB and soil horizon sequences of Chernozems, Eutric Cambisols, and Luvisols in the NSCS; the NSCS does not require secondary carbonates to classify a soil as Chernozems

Conclusion

The correlation of the WRB RSGs and the NSCS soil types is not very difficult, but it requires detailed soil investigations. It is easy when there are no missing data required for classification purposes. Otherwise, a lot of assumptions must be made, and mistakes arise. Our analysis shows that two Calcaric Cambic Chernic Phaeozems of the WRB correspond with two Calcaric Chernozems of the NSCS. Furthermore, among nine Cambic Chernic Phaeozems of the WRB, there are five Leached Chernozems and four Eutric Cambisols of the NSCS. Among five Cambic Phaeozems, there are three Leached Chernozems and two Eutric Cambisols. Two Eutric Cambisols of the WRB system correspond with Eutric Cambisols of the NSCS. Conversely, the results show that eight Leached Chernozems, six Eutric Cambisols, and two Calcaric Chernozems of the NSCS are classified as Phaeozems in the WRB. The Phaeozems of Serbia formed on loose parent materials are important arable soils. They are deep soils with good water-holding, physical, and chemical properties. There are no accurate data on their share of the total land area in Serbia, but we assume that there are more than 300,000 ha of these soils, which is almost 4% of the country's territory and probably around 6% of the agricultural area. This practically means that, from the point of view of the WRB, the area covered by Chernozems is diminished, because Phaeozems are introduced. Regardless of the classification differences, both of these soils are intensively used in agriculture, and they are prone to degradation. Therefore, it is important to apply sustainable soil management practices in plant production to conserve these soils. Unfortunately, investigations comparing past and today's soil characteristics are very rare from the point of view of pedology and detailed soil description. The well-known fact is that the content of soil organic matter is diminished in Vojvodina's Chernozems, but there are no accurate and detailed investigations on soil genesis and morphology, which are important for classification purposes. On the one hand, further evolution of Phaeozems can go in the direction of ''loosing" the criteria specified for a mollic horizon, and these soils may further evolve to Eutric Cambisols and further to Luvisols, after additional acidification. On the other hand, the degradation of Chernozems progresses towards the formation of Phaeozems. The job of soil users is not to let degradation processes go on, and the job of soil experts is to warn the farmers and government about the possible threats. The Phaeozems protection policy applied in Northern China could be a good example to follow in the future.

Acknowledgments

This study was financially supported by the Ministry of Science, Technological Development and Innovation of the Republic of Serbia under grants 451-03-137/2025-03/200116 and 451-03-136/2025-03/200088.

Declaration of competing interests

The authors declare that they have no personal or financial relationships with other individuals or organizations that could inappropriately influence or bias their work, ensuring full compliance with the academic code of conduct.

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