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Soil classification of Ukraine and its correlation with WRB (2022)

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Abstract

During an extensive period of research on Ukrainian soils, a substantial amount of factual data regarding their properties has been gathered. However, this knowledge has not yet been sufficiently disseminated within the international scientific community. The aim of this article is to present to the global academic audience the soil resources of Ukraine, as well as the problems and challenges faced by Ukrainian soil scientists in addressing the issue of soil classification. The lack of a new national soil classification system, aligned with modern global trends, that both preserves comprehensive knowledge about soils and simultaneously functions as a normative document, represents the most pressing issue in Ukrainian soil science today. Historically, Ukrainian soil classifications have predominantly been factor-genetic in nature, which makes direct comparison with the substantive classification system of the WRB particularly challenging. Rather than comparing entire classification systems, this study focuses on correlating the national soil nomenclature with the WRB system, particularly through analysing soil types based on their diagnostic and analytical characteristics. The methodological approach involved determining the corresponding WRB equivalents for the soil categories used in the Soil Map of Ukraine, compiled from regional soil maps at a scale of 1:200,000. A distinctive feature of Ukrainian soil nomenclature is the verbosity of soil names and the utilisation of landscape and ecological terms, which significantly complicates the process of correlation with the WRB. In this study, soil names were correlated primarily based on central archetypes and soil-forming factors, given that the Ukrainian classification does not incorporate the concept of diagnostic horizons. In total, the soils of Ukraine were classified into at least 21 reference soil groups under the WRB, including *Anthrosols*, *Arenosols*, *Calcisols*, *Cambisols*, *Chernozems*, *Fluvisols*, *Gleysols*, *Histosols*, *Kastanozems*, *Leptosols*, *Luvisols*, *Phaeozems*, *Planosols*, *Regosols*, *Retisols*, *Stagnosols*, *Technosols*, *Umbrisols*, *Vertisols*, *Solonchaks*, and *Solonetz*. The largest proportions are occupied by the following soils: *Chernozems* (47.0%), *Phaeozems* (18.5%), *Luvisols* (6.4%), *Arenosols* (5.4%), *Retisols* (4%).

1. Introduction

The establishment of a unified global soil information framework has long been a priority in the field of soil science. The WRB classification system, which facilitates communication among soil scientists from different countries through a common "international soil language" and serves as a basis for the global synthesis of soil knowledge, is central to this effort. Addressing the challenge of harmonising the names of soils in national classifications with the WRB system will facilitate the successful integration of research conducted by soil scientists worldwide, including in Ukraine.

No universally accepted methodology exists for comparing soil classification systems on a global scale. Existing correlation methodologies are often subjective, influenced by the scientific school to which a researcher belongs, their methodological approach, and the taxonomic level of classification. Consequently, all attempts to correlate soil classification systems involve a degree of creativity, resulting in approximate and partially subjective outcomes.

Efforts to correlate soil classification systems have been undertaken in several countries, including Finland (Yli-Halla and Mokma, 2002), Estonia (Reintam and Köster, 2006), Hungary (Michéli et al., 2019), China (Shi et al., 2010), the Czech Republic (Zádorová and Penížek, 2011), Poland (Charzyński, P., 2006; Kabała et al., 2016), Lithuania (Volungevičius et al., 2016), Latvia (Karklins, 2016), Ireland (Creamer et al., 2018), and Azerbaijan (Ismayilov et al., 2020), among others. In Ukraine, notable contributions to soil classification correlation have been made by researchers such as Medvedev et al. (1999, 2003), Polupan et al. (2005), Polchyna (2005, 2008), Ivanyuk (2013), Zinchuk et al. (2014), Solovei et al. (2023), and Solovei and Lebed (2024).

As one of the largest countries in Europe, Ukraine spans approximately 60.3 million hectares and exhibits diverse climatic conditions, complex topography, and varied parent rock compositions. These factors have led to the development of a highly heterogeneous soil cover (website 1; Fertilizer use, 2005). Despite decades of extensive research on Ukrainian soils, the dissemination of findings in international scientific literature remains limited. A notable English-language publication by researchers from the National Scientific Centre "Institute for Soil Science and Agrochemistry Research named after O. N. Sokolovskyi" (Medvedev et al., 2003) provides a comprehensive analysis of soil formation factors, soil properties, and the morphological and genetic characteristics of Ukraine's soil cover. This work correlates Ukrainian soil nomenclature with the World Reference Base for Soil Resources (WRB, 1998) and the FAO soil map nomenclature (1997). However, it was primarily intended to introduce international audiences to Ukrainian soils and has received limited international recognition. Further contributions include the *Atlas of Soil Properties of Ukraine* (Medvedev et al., 2019) and the "Soil Properties of Ukraine" database, which contains attribute data for 2,075 soil profiles (Laktionova et al., 2015). Both resources employ nomenclature from the Ukrainian and WRB classification systems to encode soil names.

A significant challenge in Ukrainian soil science is the absence of a modern national soil classification system aligned with contemporary trends in classification development. Current Ukrainian soil classifications are rooted in a genetic-factor approach, which complicates correlation with international systems and reduces accuracy. In factor-genetic classifications, soils are characterised based on their genesis, evaluating the central archetype or a set of soil-forming factors. Diagnostic horizons, a cornerstone of many international systems, are not prioritised, and the concept of diagnostic horizons remains underdeveloped (Pozniak and Ivanyuk, 2024).

The challenge of correlating soil names in the Ukrainian soil classification system with the World Reference Base for Soil Resources (WRB) is evident in the *Soil Atlas of Europe* (Soil Atlas, 2005). The atlas highlights discontinuities in the classification of certain soils at the administrative border between Ukraine and the European Union, specifically along the Ukrainian–Polish border. Notably, page 14 of the atlas provides translations of the word "soil" into 31 European languages but omits Ukrainian. This omission may reflect the limited engagement of Ukrainian soil scientists in promoting domestic soil science within the global scientific community.

The aim of this study is to identify the correlations between soil names in the Ukrainian soil classification system and the World Reference Base for Soil Resources (WRB), to present Ukraine's soil resources to the international community, and to highlight the challenges faced by Ukrainian soil scientists in addressing classification issues.

2. History of soil classification development in Ukraine

The development of soil classification in Ukraine has a long and complex history. The issue of classification was first addressed in the early 20th century by prominent Ukrainian scientists, including O. Nabokykh, M. Frolov, K. Bozhko, O. Sokolovskyi, H. Makhiv, and others (Papish, 2004; Ivanyuk, 2023).

The methodological basis for the large-scale mapping of Ukraine's soil cover from 1957 to 1961 was provided by the most well-known work on soil classification (Hrinchenko et al., 1958). Soils were differentiated according to zonal principles, soil formation type, parent materials, texture, degree of erosion and cultivation, with detailed quantitative diagnostics based on morphological and genetic characteristics. This classification included approximately 800 genetic soil types.

The *Classification and Diagnostics of Soils of the USSR* (Classification, 1977) was the officially approved classification in the Soviet Union, which included Ukraine at that time. In Ukraine, no alternative classification has ever been formally adopted as a regulatory document. In 1981, another significant classification work was published under the editorship of M. Polupan (Polupan et al., 1981), presenting a detailed systematic list of Ukrainian soils along with diagnostic descriptions. This classification improved upon the 1958 system by incorporating new research in soil genesis and agronomic properties, as well as changes resulting from anthropogenic impacts on the soil-forming process. Subsequent developments included the updated nomenclature of Ukrainian soils in 1986 (Vernander et al., 1986), the 1988 classification scheme for Ukrainian soils (Polupan, 1988), and modifications to the taxonomic units. All of these classifications were factor-genetic hierarchical systems (Papish et al., 2008; Ivanyuk, 2023; Pozniak and Ivanyuk, 2024). The main taxonomic units in Ukrainian soil classification are: type, subtype, genus, species, variety, and order, as initially introduced in the 1977 system (Pozniak, 2010).

Following Ukraine's independence, various classification frameworks were proposed for specific soil types, as well as alternative national models. However, these remained authorial initiatives and were not officially adopted (Tychonenko, 2005; Polchyna, 2008; Papish et al., 2008).

In 2005, scientists of the National Scientific Centre "Institute of Soil Science and Agrochemistry named after O.N. Sokolovskyi" published a genetic ecological-substantive soil classification of Ukraine, based on a parametric approach (Polupan et al., 2005). This classification introduced humus content as an indicator of typological and ecological memory, with type and subtype levels defined by quantitative parameters of humus and clay distribution within the soil profile. However, this classification remains an authorial initiative, lacks wide application, and does not hold national status. It has been subject to extensive criticism from Ukrainian soil scientists (Kanivets, 2007; Kovalyshyn, 2008; Ivanyuk, 2023).

3. Materials and methods

A combination of historical (examining the development of various soil classification systems in Ukraine), comparative-geographical (comparing soils and soil-forming factors across different regions to identify similarities and differences in soil profile structure), and profile-analytical methods (analysing soil properties based on individual soil profiles) was employed in this study.

Ukrainian scientists (Solovey et al., 2023; Solovey and Lebed, 2024) have formulated methodological principles for comparing the national soil nomenclature with the WRB system. Rather than comparing classification structures, they propose comparing individual soil nomenclature units along with their inherent sets of diagnostic properties. It is essential to consider the relationship between these properties and the factors and processes of soil formation when determining diagnostic characteristics. In this context, soil-forming processes should not serve as diagnostic criteria themselves but rather aid in comprehensively characterising soils. A "data cloud" of specific diagnostic properties from the national classification is compiled for each nomenclature unit taken from the legend of a given soil map, using reference sources on Ukrainian soil characteristics.

This study follows the above approach by identifying equivalent WRB classifications for soil categories presented in regional soil maps of Ukraine at a scale of 1:200,000 (Soil maps, 1966–1967). A vector-based soil map of Ukraine (Soil Cover Map, 2022) has also been used; it features a highly detailed nomenclature comprising 198 soil names, all of which have been correlated with WRB (2022) categories.

A notable feature of Ukrainian soil nomenclature is its verbosity and the incorporation of landscape and ecological descriptors (e.g., *meadow*, *meadow-bog*, *bog*, *meadow-chernozem*, *chernozem-meadow*, *grey forest*, *brown mountain-forest* soils) (Kanivec', 2008). These names are intuitive and reflect soil genesis, but it is often difficult to identify direct equivalents in substantive classification systems.

To establish correlations between national and international classification systems, a variety of sources on soil properties were consulted, most notably detailed descriptions of soil morphology, properties, and landscape context (Hrinchenko et al., 1958; Polupan et al., 1981).

Some analytical procedures commonly used in Ukraine differ from those recommended by the WRB. For instance, in most Ukrainian classification studies, soil colour was not assessed using the Munsell system (*Munsell Soil Colour Charts*, 2000). This presents a significant difficulty in aligning the Ukrainian system with the WRB.

To generalise the nomenclature, soil units were grouped according to their genesis and key properties. Soil names were assigned at various taxonomic levels in the new nomenclature list in order to preserve information about a wide range of soils. For WRB classification, we selected the most spatially dominant soil unit within each group. The area of each soil contour was determined using GIS tools. In cases of complex soil cover, where primary maps marked contours as combinations of soils, the area was assigned based on the dominant soil (i.e., the first listed). Therefore, a certain degree of relativity in the calculated areas must be considered.

The number of principal and supplementary qualifiers varies across soils. We aimed to accurately reflect the main features of the soil type when selecting WRB qualifiers (Table 1).

4. Results and discussion

This study proposes a revised correlation table aligning Ukrainian soil names with their WRB (2022) equivalents (Table 1). According to the *Soil Atlas of Europe* (2005, p. 76), Ukrainian soils belong to 15 RSGs, of which 50% are *Chernozems*, 14% *Phaeozems*, 14% *Albeluvisols* (now classified as *Retisols)*, and 22% to other groups. Our research reveals that Ukrainian soils can be assigned to 21 RSGs – 66% of the total number defined by WRB – including *Anthrosols*, *Arenosols*, *Calcisols*, *Cambisols*, *Chernozems*, *Fluvisols*, *Gleysols*, *Histosols*, *Kastanozems*, *Leptosols*, *Luvisols*, *Phaeozems*, *Planosols*, *Regosols*, *Retisols*, *Stagnosols*, *Technosols*, *Umbrisols*, *Vertisols*, *Solonchaks*, and *Solonetz* (Table 1, Fig. 1 and 2).

Soils characterised by a pronounced accumulation of organic matter in the mineral topsoil occupy the largest area in Ukraine – approximately 70% of the total soil cover (Fig. 1). *Chernozems* are the most widespread among them. However, not all soils classified as *chernozems* in the national system correspond to the *Chernozems* in the WRB system. *Podzolic chernozems* have carbonates leached into the parent material; they lack a *calcic* horizon and do not exhibit *protocalcic* properties. *Secondary carbonates* are also absent in *chernozems* developed on hard (calcareous and non-calcareous) rocks. These soils are correlated with the *Phaeozems*. *Meadow-chernozemic* soils are correlated with *Gleyic Chernozems*, as they feature a *chernic* horizon, carbonate accumulation within the profile, and a layer starting ≤75 cm from the mineral soil surface that exhibits *gleyic* properties throughout and *reducing conditions*.

Vertisols are not represented in the legends of Ukrainian soil maps and are likewise absent from our map. Nevertheless, some soils – particularly certain *Chernozems* developed on clay substrates – may fulfil the criteria for *Vertisols*, exhibiting a *vertic* horizon within the upper 100 cm of the profile and *shrink–swell cracks*. Comparable soils have been documented in Poland, Romania, Hungary (Dudek et al., 2019; Orzechowski et al., 2020; Mocanu et al., 2008; Fuchs et al., 2015) and several other neighbouring countries of Ukraine.

Table 1
Correlation between Ukrainian soil nomenclature and WRB (2022)

Soil group name (literal translation into English)	Code	Soil name in the nomenclature of regional soil maps (scale 1:200,000) (literal translation into English)	Square thousand ha	Soil name in WRB (2022)
1	2	3	4	5
Soddy-podzolic soils on ancient alluvial, glaciofluvial deposits and moraine	1	Sandy and clayey-sandy soddy-hidden-podzolic soils (pine forest sands)	2211	Dystric/Eutric Brunic Arenosols (Claric, Ochric)
	2	Soddy-podzolic soils	1658	Albic Retisols / Albic Luvisols
		Podzol-soddic soils	94	
Gley and surface gleyed soddy-podzolic soils on ancient alluvial, glaciofluvial deposits and moraine	3	Gley soddy-podzolic soils	1051	Dystric Gleysols
	4	Surface-gleyed soddy-podzolic soils	491	Albic Stagnic Retisols; Glossic/Retic Albic Stagnosols
Grey forest soils and ashen (podzolic) chernozems, inc. gleyed soils, mainly on loess deposits	5	Light grey forest soils	705	Albic Luvisols
	6	Grey forest soils	2897	Haplic Luvisols
	7	Dark grey forest soils	2601	Luvic Phaeozems
	8	Podzolic chernozems	2570	Luvic Chernic Phaeozems
Regraded soils mainly on loess and loess-like deposits	9	Dark grey and grey regraded soils	110	Endocalcic Luvic Phaeozems
		Regraded chernozems	1438	Endocalcic Chernic Phaeozems
Typical chernozems on loess and loess-like deposits	10	Shallow chernozems	555	Haplic Chernozems; Luvic Chernozems
	11	Deep chernozems	7817	Haplic Chernozems (Pachic); Luvic Chernozems (Pachic)
		Deep residual solonetzic chernozems	378	Luvic Chernozems (Pachic, Endosodic)
Ordinary chernozems on loess and loess-like deposits	12	Deep ordinary chernozems, incl. the micellar carbonate	2857	Calcic Chernozems (Pachic)
	13	Ordinary chernozems, incl. the micellar carbonate	7802	Calcic Chernozems
		Residual solonetzic ordinary chernozems	61	Luvic Chernozems
	14	Shallow ordinary chernozems, incl. the micellar carbonate	1738	Calcic Chernozems
Southern chernozems on loess and loess-like deposits	15	Southern chernozems, incl. the micellar carbonate	3445	Calcic Chernozems / Calcic Kastanozems
		Residual solonetzic southern chernozems	315	Luvic Chernozems (Endosodic) / Luvic Kastanozems (Endosodic)
Chernozems on clays	16	Chernozems on clays	532	Vertic Phaeozems (Clayic); Haplic Vertisols; Sodic Vertisols
Gravelly chernozems and soddy soils on the eluvium of hard rocks	17	Gravelly chernozems and soddy soils on the eluvium of hard non-calcareous rocks	395 311	Skeletic Phaeozems; Umbric Skeletic Leptosols
	18	Calcareous gravelly chernozems and rendzinas on the eluvium of hard calcareous rocks	654 546	Skeletic Rendzic Phaeozems; Rendzic Leptosols
Solonetzic chernozems on various deposits	19	Deep solonetzic chernozems	309	Luvic Chernozems (Pachic, Sodic)
		Ordinary solonetzic chernozems	203	Luvic Chernozems (Sodic)
		Southern solonetzic and solodic chernozems	163	Luvic Chernozems (Sodic); Stagnic Phaeozems (Albic)
		Solonetzic chernozems on the eluvium of non-calcareous Pre-Quaternary rocks and calcareous rocks	45	Luvic Chernozems (Sodic)

1	2	3	4	5
Meadow-chernozemic soils mainly on loess and loess-like deposits	20	Meadow-chernozemic soils	403	Gleyic Chernozems (Pachic) / Gleyic Chernic Phaeozems (Pachic)
		Solonetzic meadow-chernozemic soils	381	Gleyic Chernozems (Pachic, Sodic)
Kastanozems on loess-like deposits	21	Residual solonetzic dark chestnut soils	1067	Haplic Kastanozems (Sodic); Luvic Kastanozems (Sodic)
		Solonetzic dark chestnut soils	480	
	22	Residual solonetzic and solonetzic chestnut soils	179	
Meadow-kastanozems on loess-like deposits	23	Solonetzic meadow-kastanozem soils	294	Gleyic Kastanozems (Salic, Sodic)
Meadow soils on deluvial and alluvial deposits	24	Chernozemic-meadow and meadow soils, incl. alluvial soils	222 490	Gleyic Chernic Phaeozems (Pachic); Gleyic Phaeozems (Pachic); Gleyic Fluvisols (Humic)
		Chernozemic-meadow and meadow solonetzic soils, incl. alluvial soils	380 671	Gleyic Chernic Phaeozems (Pachic, Sodic); Gleyic Phaeozems (Sodic); Gleyic Fluvisols (Humic, Sodic)
	25	Meadow and gley soddy soils, incl. alluvial soils	350	Gleyic Fluvisols; Mollic Gleysols
Boggy soils on alluvial, deluvial, and glaciofluvial deposit	26	Meadow-boggy and boggy soils, incl. alluvial soils	350 213	Histic Gleysols; Gleyic Histic Fluvisols
		Peat-boggy soils	279	Histic Gleysols
Peatlands	27	Peatlands	1103	Sapric/Fibric Histosols
Solonetz	28	Steppe, meadow-steppe and meadow solonetz	243	Gleyic Solonetz; Haplic Solonetz; Endogleyic Solonetz
Solonchaks	29	Solonchaks	54	Haplic Solonchaks
Solods and other gley soils in relief depressions	30	Solods and gley-solods soils	128	Albic Planosols
	31	Meadow-chernozem, meadow-chestnut, gley solonetzic and solodic soddy soils	133	Mollic Stagnosols
Soddy soils	32	Sandy and clay-sandy soddy soils, incl. gleyed; weakly sodded sands	851 152	Arenosols (Ochric); Gleyic Arenosols (Ochric); Protic Arenosols; Fluvisols (Arenic)
	33	Loamy sand and loamy soddy soils, incl. gleyed; clay-sandy and sandy-loams chernozems	1063	Haplic Phaeozems (Arenic/Loamic); Gleyic Phaeozems (Arenic/Loamic); Fluvic Phaeozems (Arenic)
	34	Soddy podzolized loamy soils, mostly gleyed	403	Gleyic Phaeozems (Albic)
Brown-podzolic soils mainly on deluvial deposits	35	Brown-podzolic soils, incl. gleyed	210	Dystric Stagnic Cambisols; Dystric Cambisols
Mountain-forest brown soils on the eluvium and deluvium of solid rocks	36	Mountain-forest mainly gravelly brown soils, incl. gleyed	1683	Dystric Skeletic Cambisols (*Carpathians*); Eutric Skeletic Cambisols (*Crimea*)
Soddy-brown and mountain-meadow soils	37	Soddy-brown and mountain-meadow soils	391	Cambic Umbrisols / Dystric Cambisols (Humic); Cambic Gleyic Umbrisols
Meadow-brown soils on alluvial and deluvial deposits underlain by gravel		Meadow-brown soils	28	Fluvic Gleyic Cambisols (Humic)
Mountain cinnamonic soils on the eluvium and deluvium of hard rocks	38	Mountain rubbly cinnamonic soils	103	Calcaric Cambisols; Eutric Cambisols
	39	Rock outcrops and initial soils	54	Lithic Leptosols
	40	Eroded soils, landslides	74	Eutric/Dystric Regosols

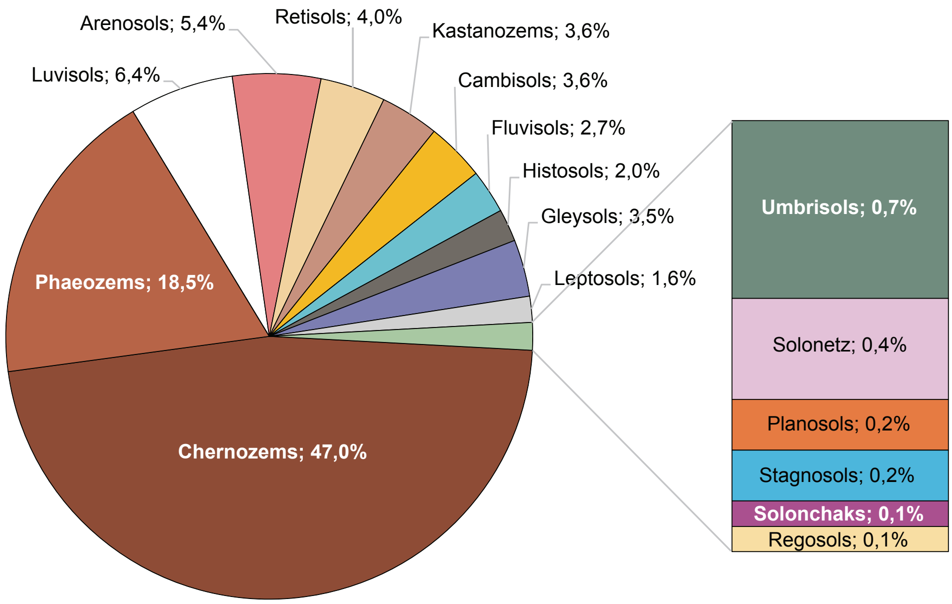

Fig. 1. Distribution of soil types in Ukraine

The *Kastanozems* reference group includes *typical chestnut* soils of the dry steppe zone, as well as some *southern chernozems* that lack a *chernic* horizon. Most of these soils have a *calcic* horizon starting at a depth of ≤100 cm from the mineral soil surface and often contain salt accumulation, elevated levels of sodium and magnesium, and, in some cases, an *argic* horizon.

Phaeozems encompass the greatest diversity of soils within the Ukrainian classification (Fig. 2). Their primary diagnostic features are the presence of a *mollic* horizon and a base saturation of ≥50%. This group includes certain subtypes and varieties of *chernozems*, *dark grey forest* soils (including *regraded* ones), *meadow-chernozemic* soils, *meadow* soils, and *soddy* soils that lack *secondary carbonates* in the profile. A wide range of WRB qualifiers has been applied: *Albic*, *Chernic*, *Endocalcic*, *Fluvic*, *Gleyic*, *Haplic*, *Luvic*, *Pachic*, *Rendzic*, *Skeletic*, *Sodic*, *Stagnic*, and *Vertic*.

Soils with an acid top horizon (*umbric*) are correlated with *Umbrisols*. This group includes *soddy-brown* and *mountain-meadow* soils. Some of these mountain soils may belong to other reference groups, where the topsoil does not meet the requirements of an *umbric* horizon in terms of thickness or base saturation. *Meadow* and *soddy* soils, characterized by a thick humus horizon and low base saturation, may also belong to this group.

The greatest difficulties were encountered in correlating *soddy* and *meadow* soils, which may develop in both river floodplains and watershed areas across a range of parent materials. *Meadow* soils are characterised by a thicker humus layer (*Ah+AhC*) (≥50 cm), a granular structure, and signs of gleying due to shallow groundwater table. In contrast, *soddy* soils typically feature a humus horizon <50 cm thick and a less distinct structure. The lack of clearly defined diagnostic horizons, properties, and quantitative thresholds significantly complicates the process of name correlation. Ukrainian scientists have classified *meadow* soils within various WRB Reference Soil Groups, including *Fluvisols*, *Gleysols*, *Leptosols*, *Phaeozems*, and *Umbrisols*. In this study, these soils were most frequently correlated with *Gleysols*, *Fluvisols*, and *Phaeozems*. *Soddy* soils may be assigned to *Arenosols*, *Fluvisols*, *Gleysols*, *Leptosols*, *Phaeozems*, *or Umbrisols*, depending on local characteristics.

Alluvial soils are not recognised as a distinct category in the nomenclature of the fine-scale soil map of Ukraine. Instead, they are generally classified as *boggy*, *meadow*, or *soddy* soils, without differentiation from those developed on interfluves. In our correlation, we assigned all soils formed on alluvial deposits to the reference group *Fluvisols* in order to provide at least an approximate representation of their distribution on the map (Fig. 2). Consequently, the total area of *Fluvisols* is likely overestimated, as we lack detailed data on the actual extent of soils exhibiting stratified profiles or other diagnostic features characteristic of this group.

It is challenging to identify soils within the Ukrainian classification system that clearly correlate with *Retisols*, due to the absence of explicitly described *retic* properties. The area occupied by *Retisols* in the *Soil Atlas of Europe* (2005, p. 76) is more than three times greater than our estimate. Previously, *sod-podzolic* soils of Ukraine were correlated with *Albeluvisols (*Medvedev et al., 1999, 2003; Polupan et al., 2005; Polchyna, 2005*)*. However, according to the WRB 2022 system, not all of these soils exhibit the *retic properties* required for classification as *Retisols*. Therefore, in Table 1, we indicate both *Retisols* and *Luvisols* as potential reference soil groups. For the purposes of the map (Fig. 2), these soils are represented as Retisols, since spatial differentiation is not feasible with the available data.

The substantial proportion of *Retisols* in the soil resources structure of Ukraine, as depicted in the *Soil Atlas of Europe* (2005, p. 76), may also be attributed to the inclusion of certain *grey forest* soils and *soddy podzolised* soils within this group. In contrast, we correlate *grey forest* soils with *Luvisols* due to their high-activity clay content and high base saturation. Although *soddy podzolized* soils are named for their thick humus horizon

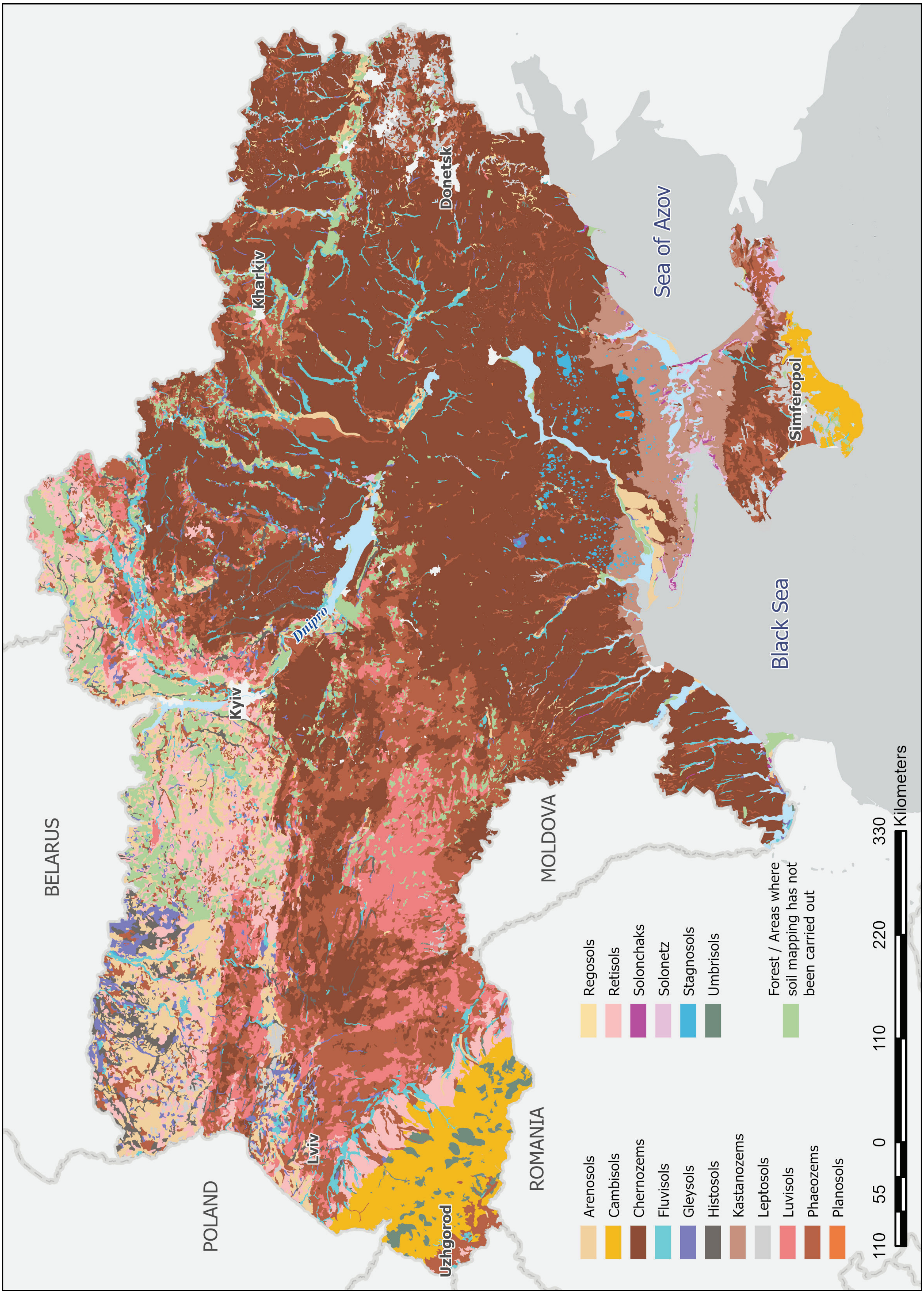

Fig. 2. Soil map of Ukraine (in WRB 2022)

(up to 50 cm) and the presence of *claric* material, this material is more indicative of clay illuviation (lessivage) than of podzolization. Therefore, we classify these soils as *Phaeozems* (Table 1).

The *soddy podzolic surface gleyed* soils are correlated with *Albic Stagnic Retisols* and *Glossic/Retic Albic Stagnosols*. The term "*surface gleying*" in Ukrainian soil nomenclature is somewhat misleading. In this context, gleying affects the entire soil profile but is primarily caused by surface water saturation rather than by groundwater influence. Consequently, these soils may correspond to *Stagnosols* in the WRB 2022 system. Therefore, both names are presented as classification options in Table 1.

Soddy-hidden-podzolic and *soddy-weakly podzolic* soils have a loamy sand or sand texture. These soils developed on glaciofluvial deposits, predominantly under pine forests. Their profiles are weakly differentiated, characterized by an ochric horizon, *claric* material in the upper part, and a poorly developed B horizon that exhibits some features of a *cambic* horizon. These soils are not strongly acidic: the pH_{water} ranges from 6.0 to 6.5, base saturation is 70–85% in arable soils and 40–60% in virgin soils (Polupan, 1988). In correlating these soils with the WRB system, Ukrainian soil scientists (Medvedev et al., 2003) have often focused solely on the term "podzolic" and, disregarding the texture, have assigned them to *Umbric Albeluvisols*. We correlate these soils with *Dystric/Eutric Brunic Arenosols (Claric, Ochric)* (Table 1).

In microdepressions of the landscape, known as *pody* or *steppe saucers* – small, flat, often circular depressions – specific conditions develop for soil formation. These *pody* act as natural catchments where surface water stagnation predominates. Under such conditions, *solods* are formed. These soils exhibit a sharply differentiated profile, characterized by a diagnostic *albic* horizon approximately 10–15 cm thick and a dense, silt-enriched middle B horizon that is about 70 cm thick. Key diagnostic features include an *abrupt textural change* ≤ 75 cm from the mineral soil surface, *stagnic* properties, and *reducing conditions*. *Solods* in the Ukrainian classification correlate with *Albic Planosols* in the WRB system. If a distinct textural differentiation is absent within the soil profile, such soils are instead correlated with *Mollic Stagnosols*. This group also includes *meadow-chernozem*, *meadow-chestnut*, *gleyic solonetzic*, and *solodic soddy* soils in the Ukrainian classification (Table 1; Fig. 2).

Soils under strong human influence – *Anthrosols* and *Technosols* – are rarely represented on Ukrainian soil maps. The national classification system is primarily designed for natural (virgin) soils, and little attention is given to anthropogenically modified soils. Artificial soils are not included in any official classification scheme (Ivanyuk, 2008). Researchers studying *technogenic* soils in Ukraine typically adopt WRB nomenclature, referring to *urban* soils in generalised terms.

The concept of a *variant* taxonomic unit was introduced in the classification by Polupan (1988) to reflect changes in soils resulting from agricultural use, without structural disruption of the soil profile. Variants include *virgin*, *developed*, *cultivated*, *irrigated* and *drained* soils. Later works (Polupan et al., 2005) expanded this to include *modal*, *cultivated*, *eroded*, *irrigated*, *secondary-saline*, *secondary-hydromorphic*, *drained*, *drained-irrigated*, *secondary-hydromorphic-saline*, *secondary-surface-gleyed*, *planted*, *radionuclide-contaminated*, *washed*, *technogenically altered*. The growing extent of anthropogenically altered soils necessitates their explicit inclusion in soil classification systems.

As a consequence of the extremely high level of land ploughing in Ukraine (53.8% of the country's area), including sloping lands, the total area of eroded lands has reached 13.4 million hectares (Baliuk et al., 2021). In the Ukrainian nomenclature, eroded soils retain the name of the reference soil with qualifiers such as *weakly eroded* (upper horizon reduced by <50%), *moderately eroded* (>50% reduction), and *strongly eroded* (complete loss of upper horizon with subsoil exposed). Severe erosion in certain soils, particularly in *southern chernozems* and *cinnamonic* soils, may result in the complete removal of the *chernic* or *mollic* horizon. As a consequence, the *calcic* horizon is expressed much closer to the surface than in the original profile. Under such conditions, these soils may satisfy the diagnostic requirements of *Calcisols*. These soils are not delineated separately on medium- or small-scale maps but are included within broader mapping units. Therefore, these soils were not represented on the map and diagram (Fig. 1 and 2).

Currently, approximately 20% of Ukraine's territory has experienced military-technogenic impacts on soils as a result of Russia's aggression against Ukraine. Extensive areas of soil in these regions have undergone mechanical destruction as well as physical and chemical alteration (Spoditel et al., 2023). In the presented materials (Table 1, Fig. 1 and 2), soils affected by war-induced degradation were not classified separately. Addressing this issue will be a significant challenge for Ukrainian soil scientists in the future.

5. Conclusions

Ukraine currently lacks a formally adopted, modern soil classification system. Ukrainian soil scientists continue to rely on legacy classification frameworks, which are primarily factor-genetic in nature. This makes direct correlation with the WRB – a substantive, horizon-based system – particularly challenging. Notably, the concept of diagnostic horizons is either underdeveloped or entirely absent in Ukrainian classifications.

Ukrainian soils are classified into at least 21 reference soil groups. The largest areas are occupied by *Chernozems* (47.0%), *Phaeozems* (18.5%), *Luvisols* (6.4%), *Arenosols* (5.4%), and *Retisols* (4.0%).

The verbose nomenclature of Ukrainian soil names – frequently incorporating landscape and ecological descriptors – poses significant challenges for correlation with the WRB system. *Soddy* and *meadow* soils were particularly problematic.

Furthermore, the Ukrainian classification system gives minimal consideration to anthropogenically modified soils and does not account for technogenic soils or those altered by military activities.

Conflict of interest

The authors declare that they have no conflict of interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper. This research did not involve human or animal subjects.

Author Contributions

Halyna Ivanyuk – Conceptualization, Methodology, Supervision, Investigation, Visualization, Writing – original draft; **Taras Yamelynets** – Investigation, Validation, Visualization, Writing – original draft; **Ihor Papish** – Investigation, Validation, Writing – original draft; **Petro Hnativ** – Data curation, Supervision, Validation; **Zenoviy Pankiv, Oksana Bonishko** – Investigation, Writing – review & editing; **Viktor Ivaniuk, Oksana Haskevych, Dmytro Baranskyi, Mariya Avhustynovych** – Investigation, Writing – review & editing. All authors read and approved the final manuscript.

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