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REVIEW

Invited Contribution

World Reference Base for Soil Resources—Its fourth edition and its history

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Abstract

The fourth edition of the international soil classification system World Reference Base for Soil Resources (WRB) was released in 2022. It maintains the 32 Reference Soil Groups at the first classification level. Most qualifiers (second level) and most diagnostic horizons, properties and materials were maintained but some were abolished and new ones introduced. The main part of the fourth edition is followed by six annexes, most of them are new. For the first time, the WRB has a Field Guide (Annex 1) to facilitate field survey and to assure that all field characteristics required in the classification are reported. The fourth edition also provides designations for horizons and layers (Annex 3), which was not the case in the second and the third edition. The wordings of the definitions were harmonized, and the same features are worded in the same way throughout the text (including the annexes). Ambiguities have been corrected and many definitions written in a more concise and a more didactical way. The WRB has a long history. Four editions have been published: 1998, 2006 (with update 2007), 2014 (with update 2015) and 2022. Editor is the Working Group WRB of the International Union of Soil Sciences. The WRB followed the Legend and the Revised Legend of the Soil Map of the World. This map was edited by FAO (Food and Agriculture Organization of the United Nations) and UNESCO, and the system is known as the FAO Soil Classification System. In addition, WRB incorporated ideas from the former Working Group International Reference Base for Soil Classification that existed from 1982 to 1994.

KEYWORDS
diagnostic horizon, field soil survey, soil classification, soil description, soil horizon designation, soil map legend

1 | INTRODUCTION

The World Reference Base for Soil Resources (WRB) is an international soil classification system for naming soils and creating legends for soil maps. On 1 August 2022, at the World Congress of Soil Science in Glasgow, the fourth edition was published (IUSS Working Group WRB, 2022). In this article, first, this fourth edition is explained, then, the changes from the third to the fourth edition are highlighted, and afterwards, an overview of the history of the WRB is given.

2 | THE FOURTH EDITION OF THE WRB (2022)

2.1 | The WRB Manual

The WRB is published online as open access document under the terms of the Creative Commons Attribution License, which permits use, distribution and reproduction in any medium, provided that the original work is properly cited. The WRB Manual comprises seven chapters and six annexes:

1. Background and basics
2. The rules for naming soils and creating legends for soil maps
3. Diagnostic horizons, properties and materials
4. Key to the Reference Soil Groups (RSGs) with lists of principal and supplementary qualifiers
5. Definitions of qualifiers
6. Codes for the RSGs, qualifiers and specifiers
7. References
8. Annex 1: Field Guide
9. Annex 2: Summary of analytical procedures for soil characterization
10. Annex 3: Horizon and layer designations
11. Annex 4: Soil Description Sheet (provided as a separate excel file)
12. Annex 5: Guidance on database set-up (provided as a separate file)
13. Annex 6: Colour symbols for RSG maps

Chapters 2.2–2.8 of this article describe the fourth edition, but many aspects are also true for previous editions.

2.2 | The system

The WRB has two hierarchical levels, which are just called the first level and the second level. The first level comprises 32 RSGs, which are identified using a key. The second level has constructed names: A set of qualifiers, which are adjectives, is added to the names of the RSGs. All elements of a soil name (i.e., RSG and all qualifiers) start with capital letters.

2.3 | Diagnostics

Many criteria in the key and in the definitions of the qualifiers are based on diagnostic horizons, diagnostic properties and diagnostic materials, altogether called 'diagnostics', which are defined in Chapter 3 of the WRB Manual. The features of all of them can be observed or measured in the field or the laboratory and require a minimum or maximum expression to qualify as diagnostic. Diagnostic horizons are characterized by a combination of attributes that reflect widespread, common results of soil-forming processes. In addition, diagnostic horizons require a certain minimum thickness, thus forming a recognizable layer in the soil. Diagnostic properties may reflect results of soil-forming processes but may also indicate specific conditions of soil formation, for example, reducing conditions. Contrary to the diagnostic horizons, the diagnostic properties have no minimum thickness criterion. Diagnostic materials are materials that significantly influence soil-forming processes. Their characteristics may be inherited from the parent material or may be the result of soil-forming processes. Diagnostic materials do not describe parent materials; they describe soil materials, and the characteristics refer (as for all diagnostics) to the fine earth, unless stated otherwise. They have no minimum thickness criterion.

The general idea of using diagnostics is as follows: We do not use every characteristic for classification at higher level but pick out some. The alternative would be to classify soils by full horizon and layer sequences. This would end up in a large number of narrowly defined soil units, always with the risk that some horizon sequences found in nature have not been considered in the defined sequences. Having in addition to diagnostic horizons, the diagnostic properties and materials allows defining characteristics not restricted to a certain horizon, which makes the system more flexible.

The diagnostics in the WRB are presented with the following:

- General description
- Diagnostic criteria
- Field identification
- Additional information
- Relationships with some other diagnostics

For the decision whether a soil has a certain diagnostic, only the diagnostic criteria are relevant. Therefore, the diagnostic criteria are always provided. The other information may or may not be provided.

2.4 | Key to the Reference Soil Groups (RSGs)

The key is presented in Chapter 4 of the WRB Manual. For the first level of the WRB classification, the combination of diagnostic horizons, properties and materials and/or additional characteristics of the described soil is compared to the WRB key in order to allocate the soil to the appropriate RSG. The user must go through the key systematically, starting at the beginning and excluding, one by one, all RSGs for which the specified requirements are not met. The soil belongs to the first RSG for which it fulfils the criteria. Table 1 gives a brief description of the RSGs of the fourth edition of the WRB (in the order of the key), together with their codes.

2.5 | Qualifiers

Chapter 5 of the WRB Manual gives the definitions of the Qualifiers in alphabetical order. Many of the definitions are based on diagnostics. The fourth edition of the WRB has 202 qualifiers. Some of them are available for many RSGs, others only for a few ones, and some for just one. For every RSG, the key in Chapter 4 provides a list of the qualifiers available for this particular RSG. The Gleysols have the longest list with 79 available qualifiers (they are defined by groundwater but may in addition have many characteristics of the soils not affected by groundwater), and the Nitisols have the shortest one with 40 (Nitisols have a very specific and narrow definition).

For every RSG, the qualifiers are divided into principal and supplementary qualifiers. (A qualifier may be principal for one RSG and supplementary for another one.) The principal qualifiers are ranked

TABLE 1 Simplified guide to the World Reference Base for Soil Resources (WRB) Reference Soil Groups (RSGs) with codes (IUSS Working Group WRB, 2022)

Description	RSG	Code
1. Soils with thick organic layers	Histosols	HS
2. Soils with strong human influence		
With long and intensive agricultural use	Anthrosols	AT
Containing significant amounts of artefacts	Technosols	TC
3. Soils with limitations to root growth		
Permafrost-affected	Cryosols	CR
Thin or with many coarse fragments	Leptosols	LP
With a high content of exchangeable Na	Solonetz	SN
Alternating wet-dry conditions, shrink-swell clay minerals	Vertisols	VR
High concentration of soluble salts	Solonchaks	SC
4. Soils distinguished by Fe/Al chemistry		
Groundwater-affected, underwater or in tidal areas	Gleysols	GL
Allophanes and/or Al-humus complexes	Andosols	AN
Subsoil accumulation of humus and/or oxides	Podzols	PZ
Accumulation and redistribution of Fe	Plinthosols	PT
Stagnant water, abrupt textural difference	Planosols	PL
Stagnant water, structural difference and/or moderate textural difference	Stagnosols	ST
Low-activity clays, P fixation, many Fe oxides, strongly structured	Nitisols	NT
Dominance of kaolinite and oxides	Ferralsols	FR
5. Pronounced accumulation of organic matter in the mineral topsoil		
Very dark topsoil, secondary carbonates	Chernozems	CH
Dark topsoil, secondary carbonates	Kastanozems	KS
Dark topsoil, no secondary carbonates (unless very deep), high base status	Phaeozems	PH
Dark topsoil, low base status	Umbrisols	UM
6. Accumulation of moderately soluble salts or non-saline substances		
Accumulation of, and cementation by, secondary silica	Durisols	DU
Accumulation of secondary gypsum	Gypsisols	GY
Accumulation of secondary carbonates	Calcisols	CL
7. Soils with clay-enriched subsoil		
Interfingering of coarser-textured, lighter-coloured material into a finer-textured, stronger coloured layer	Retisols	RT
Low-activity clays, low base status	Acrisols	AC
Low-activity clays, high base status	Lixisols	LX
High-activity clays, low base status	Alisols	AL
High-activity clays, high base status	Luvisols	LV
8. Soils with little or no profile differentiation		
Moderately developed	Cambisols	CM
Stratified fluviatile, marine or lacustrine sediments	Fluvisols	FL
Sandy	Arenosols	AR
No significant profile development	Regosols	RG

and given in an order of importance. They indicate major subdivisions of the respective RSG or describe properties strongly influencing the soil's functionality. The principal qualifiers are added before the name of the RSG without brackets and without commas. The sequence is from right to left, i.e., the uppermost qualifier in the list is placed closest to the name of the RSG. The supplementary qualifiers are added in brackets after the name of the RSG and are separated from each other by commas. The sequence is from left to right, i.e., the first qualifier is placed closest to the name of the RSG. The sequence starts with the qualifiers related to the texture, if applicable. If several ones apply, they are placed in the sequence from the top to the bottom of the soil profile. All other supplementary qualifiers follow them and are used in alphabetical order. Placing the texture qualifiers first, underlines their importance. For the other supplementary qualifiers, no general order of importance could be established, and therefore the alphabetical order was chosen.

Qualifiers conveying redundant information are not added, for example, Eutric (dominance of exchangeable base cations over exchangeable aluminium) is not used if the Calcaric qualifier (containing carbonates) applies. In the qualifier lists in Chapter 4, some qualifiers are separated by a slash (/). This indicates that they are either mutually exclusive or one of them is redundant with the redundant qualifier(s) after the slash(es). In the soil name, supplementary qualifiers are placed according to the above-mentioned rules, even if their position in the list is different due to the use of the slash. In some RSGs, the list of principal qualifiers ends with the qualifier Haplic. Haplic is only used if no other principal qualifier applies to avoid that soil names at the second level may have no principal qualifier.

Constructing the second level by adding qualifiers to the RSG has several advantages compared with a dichotomic key, which may be used by more hierarchical systems (see the WRB Manual):

1. Every soil receives the appropriate number of qualifiers. Soils with few characteristics have short names; soils with many characteristics (e.g., polygenetic soils) have longer names.
2. The WRB is capable of indicating most of the soil's properties, which are incorporated into an informative soil name.
3. The system is robust. Missing data do not necessarily lead to a dramatic error in the classification of a soil. If one qualifier is erroneously added or erroneously omitted based on incomplete data, the rest of the soil name remains correct.

4. The unique definition of a qualifier, identical for almost every combination with an RSG, helps the users overlook the system.

2.6 | Subqualifiers

Qualifiers can be combined with specifiers to form subqualifiers. In the subqualifier Protocalcic, for example, Calcic is the qualifier, and Proto- is the specifier. Depending on the specifier, the subqualifier fulfils all the criteria of the respective qualifier, or it deviates in a defined way from its set of criteria. The WRB Manual states the following rules:

1. If a subqualifier applies that fulfils all the criteria of the qualifier, the subqualifier can – but does not have to – be used instead of its qualifier (optional subqualifiers).
2. If a subqualifier applies that fulfils all the criteria of the qualifier except thickness and/or depth criteria, the subqualifier can – but does not have to – be used, but not the qualifier (additional subqualifiers).
3. If a subqualifier applies that deviates in a defined way from the set of criteria of the qualifier, the subqualifier must be used instead of the qualifier that is listed as available for the respective RSG in Chapter 4 of the WRB Manual (mandatory subqualifiers). This is the case for some subqualifiers with a given definition (see next).

Optional and additional subqualifiers are recommended especially for naming soils. Their use is not recommended for principal qualifiers in map units or wherever generalization is important.

The use of specifiers does not change the position of the qualifier in the soil name, except for the specifiers Bathy- (deep), Thapto- (buried) and Proto- (weakly expressed). If one of these three is used with a principal qualifier, it must shift to the supplementary qualifiers. Those supplementary qualifiers that are added according to the alphabet (i.e., all but the qualifiers related to texture) follow the alphabetical order of the qualifier, not the subqualifier.

There are subqualifiers with a given definition provided in Chapter 5 of the WRB Manual, and there are subqualifiers constructed by the user. The first group includes optional, additional and mandatory subqualifiers. Examples: the Protocalcic mandatory subqualifier (only protocalcic properties, no calcic or petrocalcic horizon), the Akrofluvic additional subqualifier (fluvic material starting at the mineral soil surface, but less thick) and the Skeletohistic optional qualifier (histic horizon with many coarse fragments). The second group comprises only optional and additional subqualifiers, among them the subqualifiers showing the depth of occurrence. If the qualifier refers to a particular layer (e.g., Calcic, Arenic, Fluvic), the depth-related specifiers are Epi-, Endo-, Amphi-, Ano-, Kato-, Panto-, Poly- and Bathy-. The first six are explained in Figure 1. Qualifiers that are mutually exclusive may apply to the same soil profile at different depths. This is indicated using the specifiers. These examples also explain the general idea of the subqualifiers: We are able to add many additional specific features of a soil without enlarging the lists of the qualifiers.

2.7 | Naming a soil

The naming of a soil consists of four steps:

1. Detect diagnostic horizons, properties and materials.
2. Allocate the soil to a Reference Soil Group.
3. Allocate the qualifiers.
4. Decide on subqualifiers.

The WRB Manual gives an example, which is presented here in a modified version. A soil is described in the field as follows: A soil developed from loess with high-activity clays has a marked clay increase at 60 cm depth, clay coatings in the clay-rich horizon, no stratification and a field pH value of around 6 in the depth from 50 to 100 cm. The clay-poor upper soil is subdivided into a darker upper part (0–20 cm, showing an intermediate amount of organic carbon) and a light-coloured lower horizon (20–60 cm). Hand-texturing reveals silty clay loam for the first 60 cm and silty clay from 60 cm to at least 100 cm. The clay-rich horizon has a limited amount of oximorphic features with intensive colours inside the soil aggregates and shows reducing conditions in some parts during springtime. Table 2 informs about the classification possible with these field data.

The field classification is Amphialbic Endostagnic Luvisol (Anoloamic, Endoclayic, Cutanic, Differentic, Endic, Ochric). It is recommended to check texture, content of organic carbon, cation exchange capacity (CEC) and exchangeable cations in the laboratory.

2.8 | Map legends

The WRB Manual provides the following guidelines for creating map legends:

1. A map unit consists of
   a) a dominant soil only
   b) a dominant soil plus a codominant soil and/or one or more associated soils
   c) two or three codominant soils
   d) two or three codominant soils plus one or more associated soils.

   Dominant soils represent ≥50% of the soil cover, codominant soils ≥25% and <50% of the soil cover. Associated soils represent ≥5% and <25% of the soil cover or are of high relevance in the landscape. Further soils should be ignored in the denomination of the map unit.
2. The number of qualifiers specified below refers to the dominant soil. For codominant or associated soils, fewer numbers of qualifiers (or even no qualifier) may be appropriate.
3. Depending on scale, different numbers of principal qualifiers are used:
   a) For very small map scales, only the RSG is used.
   b) For next larger map scales, the RSG plus the first applicable principal qualifier are used.

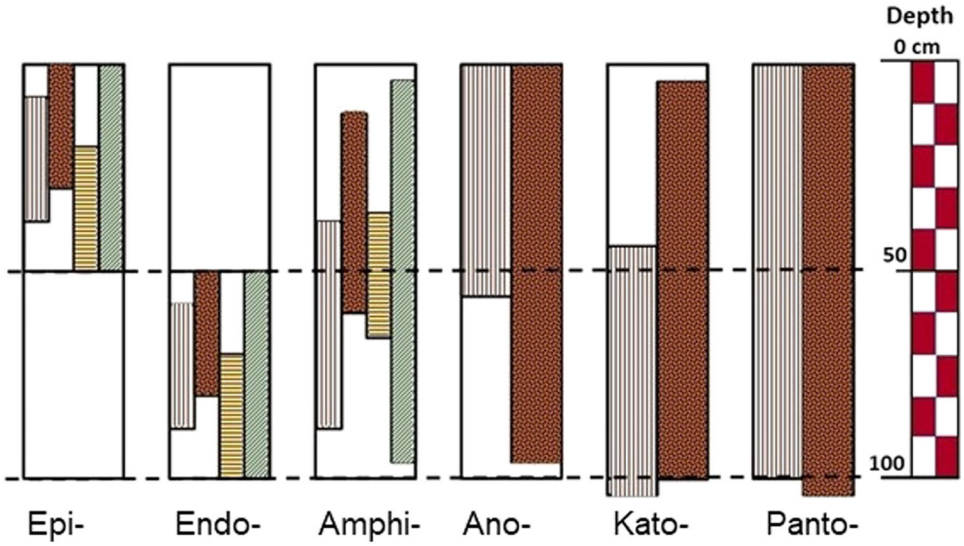

FIGURE 1 Specifiers to construct optional subqualifiers related to depth requirements and referring to a particular layer; Bathy- and Poly- not illustrated; hatching and colours just for better readability. *Source*: IUSS Working Group WRB (2022); courtesy of S. Dondeyne.

c) For next larger map scales, the RSG plus the first two applicable principal qualifiers are used.

It is not possible to give general figures for these scales, because this depends very much on the homogeneity or heterogeneity of the landscape.

4. If there are fewer qualifiers applicable for the respective RSG than described before, the lesser number is used.
5. Depending on the purpose of the map or according to national traditions, at any scale level, further qualifiers may be added as elective qualifiers. These may be principal qualifiers from further down the list and not already used in the soil name, or they may be supplementary qualifiers. They are placed using the rules for supplementary qualifiers for naming soils.

A landscape usually shows a variety of soils. For a map unit, they generally have to be combined. The WRB Manual shows the principles with the example in Figure 2 and in Tables 3 and 4.

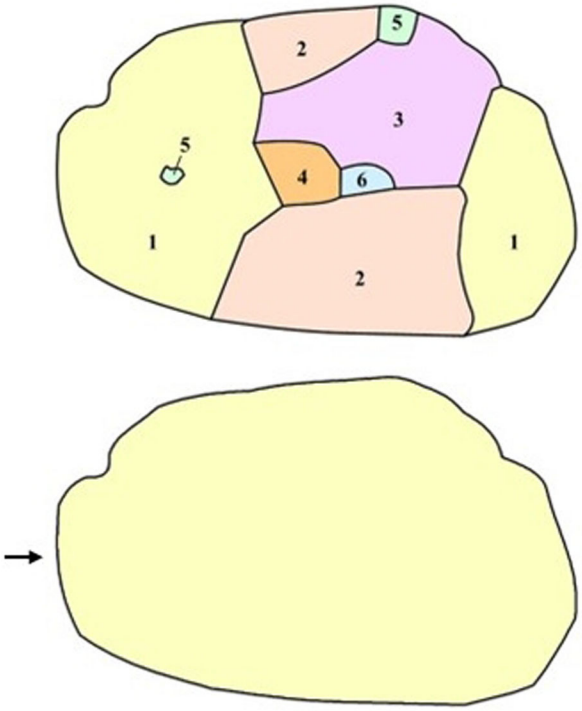

FIGURE 2 Soils in a landscape that need to be combined to form a map unit. *Source*: IUSS Working Group WRB (2022); courtesy of V. Buness.

2.9 | General rules and definitions

Chapter 2 of the WRB Manual starts with general rules and definitions that have to be applied in the whole WRB. They are cited here (shortened):

- All data refer to the fine earth, unless stated otherwise. The fine earth comprises the soil constituents ≤2 mm. The whole soil comprises fine earth, coarse fragments, remnants of broken-up cemented layers, artefacts and dead plant residues of any size.
- All data are given by mass (dried at 105°C), unless stated otherwise.
- A litter layer is a loose layer that contains >90% (by volume, related to the fine earth plus all dead plant residues) recognizable dead plant tissues (e.g., undecomposed leaves). Dead plant materials still connected to living plants (e.g., dead parts of Sphagnum mosses) are not regarded to form part of a litter layer. The soil surface (0 cm) is, by convention, the surface of the soil after removing, if present, the litter layer and, if present, below a layer of living plants. The mineral soil surface is the upper limit of the uppermost layer consisting of mineral material. ('Mineral material' and 'organic material' are diagnostic materials in WRB, differentiated by an organic carbon content of 200 g kg^{-1} [20%], see the WRB Manual.)

TABLE 2 Example for naming a soil

Characteristic	Conclusion
1. Detect diagnostic horizons, properties and materials	
Clay increase without lithic discontinuity and/or with clay coatings	argic horizon
Light colour in the eluvial horizon	claric material
Claric material above the argic horizon	albic horizon
Some oximorphic features inside soil aggregates	stagnic properties
2. Allocate the soil to a RSG	
We go through the key systematically, starting with Histosols, excluding one by one all RSGs for which the criteria are not met; we stop, when the following criteria are requested: argic horizon with high CEC, more exchangeable base cations than Al in the subsoil	Luvisol
3. Allocate the qualifiers	
Stagnic properties and reducing conditions	Stagnic qualifier
Albic horizon	Albic qualifier
Silty clay loam from 0 to 60 cm	Loamic qualifier
Silty clay from 60 cm to at least 100 cm	Clayic qualifier
Clay coatings	Cutanic qualifier
Marked clay increase without lithic discontinuity	Differentic qualifier
Argic horizon starting below 50 cm	Endic qualifier
Intermediate amount of organic carbon	Ochric qualifier
4. Decide on subqualifiers	
Stagnic properties and reducing conditions starting at 60 cm	Endostagnic subqualifier
Albic horizon from 20 to 60 cm	Amphialbic subqualifier
Silty clay loam from 0 to 60 cm	Anoloamic subqualifier
Silty clay from 60 cm to at least 100 cm	Endoclayic subqualifier

Abbreviations: CEC, cation exchange capacity; RSG, Reference Soil Group.
Source: Modified from IUSS Working Group WRB (2022).

- A soil layer is a zone in the soil, approximately parallel to the soil surface, with properties different from layers above and/or below it. If at least one of these properties is the result of soil-forming processes, the layer is called a soil horizon.
- The diagnostic criteria must be fulfilled throughout the specified depth range, unless stated otherwise. If a diagnostic horizon consists of several subhorizons, the diagnostic criteria (except thickness) must be fulfilled in every subhorizon separately (averages are not calculated).
- On a slope, the soil is described as a vertical profile. The thickness and depth values are calculated by multiplying the vertically measured values by the cosine of the inclination angle (Prietzel & Wiesmeier, 2019). This is especially important on steep slopes.

2.10 | Field characteristics

In the past, the WRB gave no recommendations, how to survey and describe the needed field characteristics. For the third edition (IUSS Working Group WRB, 2015), the WRB recommended to use the fourth edition of the FAO (Food and Agriculture Organization of the United Nations) Guidelines for Soil Description (FAO, 2006). Now and for the first time, WRB has its own Field Guide, which is given as Annex 1. This solves several problems:

First, the WRB used many terms for field characteristics that are not common sense (e.g., 'soil matrix' or 'cracks' are common sense for soil scientists) but were not defined in the respective documents, neither in the WRB, nor in the FAO Guidelines. They were taken long time ago from US publications: the Seventh Approximation to Soil Classification (Soil Survey Staff, 1960), the first edition of Soil Taxonomy (Soil Survey Staff, 1975) and the Soil Survey Manual (Soil Survey Staff, 1951). Examples are cementation classes ('weakly cemented to indurated'), concentrations ('mass', 'concretion') and redox features ('redox depletions', 'concretions'). These and other field characteristics are now defined in the WRB Field Guide. Many of these definitions are close to the definitions in current US field documents, the Soil Survey Manual (Soil Science Division Staff, 2017) and the Field Book for Describing and Sampling Soils (Schoeneberger et al., 2012), which brings WRB and Soil Taxonomy closer together.

Second, some field characteristics in the FAO Guidelines had limit values different from those needed in WRB. Some characteristics were missing at all. They are now added and use the limit values needed.

Third, many WRB criteria require weighted averages of percentages (e.g., redox features for Gleysols, Planosols and Stagnosols; coarse fragments for the Skeletic qualifier), but the FAO Guidelines use classes, and calculation is impossible. The new Field Guide always asks to report percentages and not classes.

The Field Guide provides many new illustrations, for example, for structure or for the location of redox features, and offers a flow chart for hand-texturing.

2.11 | Horizon and layer designations

As stated before, WRB uses diagnostic horizons. Different from that, is a system of designations for all horizons and layers, which is provided in Annex 3. They are a further elaboration of the designations given in the FAO Guidelines for Soil Description (FAO, 2006). They are based on the general definitions of 'soil layer' and 'soil horizon' given before. The designation consists of a capital letter (master symbol), which, in most cases, is followed by one or more lowercase letters (suffixes). The master symbols are given in Table 5 and the suffixes in Table 6. In the FAO Guidelines, for the suffixes, the Latin alphabet was used up. To satisfy the needs for new designations, suffixes with Greek letters were introduced. Examples of new suffixes are β for low bulk density, γ for volcanic glasses, and τ for human-transported natural material. The WRB provides rules for the combination of suffixes, for the denomination of transitional layers (two or more master symbols) and for the

TABLE 3 Detection of dominant, codominant and associated soils (IUSS Working Group WRB, 2022)

Area	Complete soil name	Result
1	Haplic Luvisol (Episiltic, Katoclayic, Aric, Cutanic, Differentic, Epic, Ochric)	Dominant soil
2	Eutric Stagnic Leptic Cambisol (Loamic, Humic)	Codominant soil
3	Albic Stagnic Luvisol (Anosiltic, Endoclayic, Cutanic, Differentic, Endic, Humic)	Associated soil
4	Thyric Technosol (Loamic, Calcaric, Skeletic)	Ignored
5	Eutric Luvic Stagnosol (Episiltic, Katoclayic, Humic)	Ignored
6	Hortic Anthrosol (Loamic, Eutric)	Ignored

TABLE 4 Denomination of the map unit depending on the map scale level (IUSS Working Group WRB, 2022)

Map scale level	Dominant soil	Codominant soil	Associated soil
First	Luvisols	Cambisols	
Second	Haplic Luvisols	Leptic Cambisols	Stagnic Luvisols
Third	Haplic Luvisols	Stagnic Leptic Cambisols	Albic Stagnic Luvisols

layer sequences in a soil profile. For every RSG, examples for layer sequences are given.

3 | THE MAJOR CHANGES FROM THE THIRD TO THE FOURTH EDITION

The WRB Manual lists the major changes:

1. The contents of the Manual were rearranged. The former Annex 1 (Descriptions) was deleted. The descriptions were not fully up to date. Annex 2 (Laboratory methods) was maintained. The former Annex 3 (Codes) is now Chapter 6. This reflects that the codes are part of the classification system itself and neither a preparation work nor a further elaboration. The former Annex 4 (Texture triangle) is integrated in the new Annex 1. The new Annex 1 is a Field Guide. It replaces the FAO Guidelines (FAO, 2006) for the use with WRB. The new Annex 3 provides brief definitions of layer symbols further developing the definitions of the FAO Guidelines. The new Annex 4 explains a soil description sheet that is provided online. The new Annex 5 gives guidance on database set-up that is also provided online. The new Annex 6 presents recommendations for colour symbols for RSG maps.
2. In Chapter 2 of the WRB Manual (General rules and definitions), several definitions were added for WRB: fine earth, whole soil, litter layer, soil surface, mineral soil surface, soil layer and soil horizon. These definitions are of fundamental importance for the use of WRB. Additionally, some new general rules were formulated to enable an easier wording of the diagnostic criteria.
3. All RSGs are maintained. There are some changes of the sequence in the key: Planosols and Stagnosols are now before Nitisols and Ferralsols, giving the current water influence preference over the clay and oxide mineralogy. Fluvisols are now before Arenosols. In the third edition, recent alluvial soils, dominated by sand, were Arenosols. All others, dominated by clay, silt or coarse fragments, belonged to the Fluvisols. The new sequence allocates them all as Fluvisols.
4. Some diagnostics were deleted. The fulvic and the melanic horizon, only foreseen for Andosols, belonged to an outdated concept of soil organic matter. The aridic properties combined various characteristics in a non-systematic manner (the only important one of these, the wind deposition, is now characterized by the newly introduced aeolic material, see next). Geric properties were a combination of a very low CEC with a positive ΔpH, which do not always occur together and can be better expressed by two separate qualifiers. The sulfidic material was defined in WRB since the beginning, but in the third edition, the hypersulfidic and the hyposulfidic materials were introduced making the sulfidic material obsolete.
5. The following diagnostics were introduced:
   a) Albic horizon: In the first and the second edition of the WRB, the albic horizon was already defined. However, it was defined only by colour, and results of soil-forming processes were not required. Consequently, it was changed into albic material in 2014. But this made the definition of the Albic qualifier difficult. Now, the albic horizon was reintroduced, explicitly requiring characteristics resulting from soil-forming processes. The albic material was maintained (just defined by colour) and renamed claric material (see next).
   b) Cohesic horizon: Dense subsurface horizon, dominated by kaolinite. It is found in tropical regions with seasonal climate and was not considered so far in the WRB.
   c) Limonic horizon: Accumulation of Fe by capillary rise in groundwater soils, so strong that Fe oxides cause a cementation. It is traditionally referred to as bog iron. The horizon was introduced to differentiate this type of Fe oxide accumulation from

TABLE 5 Horizon designations – master symbols (IUSS Working Group WRB, 2022, shortened)

Symbol	Criteria
H	Organic or organotechnic layer, not forming part of a litter layer; water saturation >30 consecutive days in most years or drained; generally regarded as peat layer or organic limnic layer
O	Organic horizon or organotechnic layer, not forming part of a litter layer; water saturation ≤30 consecutive days in most years and not drained; generally regarded as non-peat and non-limnic horizon
A	Mineral horizon at the mineral soil surface or buried; contains organic matter that has at least partly been modified in situ; soil structure and/or structural elements created by cultivation in ≥50% (by volume, related to the fine earth), i.e., rock structure, if present, in <50% (by volume)
E	Mineral horizon; has lost by downward movement within the soil (vertically or laterally) one or more of the following: Fe, Al and/or Mn species; clay minerals; organic matter
B	Mineral horizon that has (at least originally) formed below an A or E horizon; rock structure, if present, in <50% (by volume, related to the fine earth); one or more of the following processes of soil formation: formation of soil aggregate structure formation of clay minerals and/or oxides accumulation by illuviation processes of one or more of the following: Fe, Al and/or Mn species; clay minerals; organic matter; silica; carbonates; gypsum removal of carbonates or gypsum Nota bene: B horizons may show other accumulations as well
C	Mineral layer; unconsolidated (can be cut with a spade when moist), or consolidated and more fractured than the R layer; no soil formation, or soil formation that does not meet the criteria of the A, E and B horizons
R	Consolidated rock; air-dry or drier specimens, when placed in water, will not slake within 24 h; fractures, if present, occupy <10% (by volume, related to the whole soil); not resulting from the cementation of a soil horizon
I	≥75% ice (by volume, related to the whole soil), permanent, below an H, O, A, E, B or C layer
W	Permanent water above the soil surface or between layers, may be seasonally frozen

accumulations by other soil-forming processes like in spodic, plinthic and tsitelic horizons.

d) Panpaic horizon: This is a buried A horizon. It is different from the sombric horizon (de Almeida et al., 2015), which is not understood as buried.

e) Tsitelic horizon: Accumulation of Fe by subsurface flow, usually from Planosols and Stagnosols further up the landscape. As the limonic horizon, it was introduced to differentiate the various soil-forming processes leading to accumulations of Fe oxides.

f) Protogypsic properties: Accumulation of secondary gypsum, not sufficient for a gypsic or petrogypsic horizon, analogous to the protocalcic properties.

g) Aeolic material: Deposited by wind.

h) Mulmic material: Mineral material with a high content of soil organic carbon, derived from organic material. Drainage of organic material causes accelerated decomposition, and eventually the content of soil organic carbon sinks below the limit value of organic material, which transforms the organic material into mineral material.

i) Organotechnic material: Large amounts of organic artefacts and relatively small contents of soil organic carbon in the fine earth.

6. Two diagnostic materials received new names: The albic material was renamed claric material. After reintroducing the albic horizon, it had to be avoided that a diagnostic material and a diagnostic horizon have the same name. The colluvic material is now called solimovic material. The word colluvium has very different meanings in different countries (Miller & Juilleret, 2020). The new name solimovic material explains that at least parts of the accumulated material underwent soil formation before having been transported.
7. Many criteria in the diagnostics, the key and in the definitions of the qualifiers, were sharpened and refined. Special effort was undertaken to make sure that the same features are worded in the same way throughout the text, including the Annexes (Field Guide and the layer designations). Examples for a more concise wording are: spodic horizon, retic properties, gleyic properties, stagnic properties and yermic properties.
8. Some new qualifiers were defined, some existing ones deleted. The number of qualifiers increased from 185 to 202. The sequence of the supplementary qualifiers was changed. If qualifiers related to texture apply, they are placed first, followed by all other supplementary qualifiers in alphabetical order.

4 | THE HISTORY OF THE WRB

4.1 | The development of the US Soil Taxonomy

The first edition of the US Soil Taxonomy was published in 1975 (Soil Survey Staff, 1975), and the second in 1999 (Soil Survey Staff, 1999). Soil Taxonomy was preceded by seven approximations, the seventh published in 1960 (Soil Survey Staff, 1960). Later, a supplement to the seventh approximation was issued (Soil Survey Staff, 1967). All these publications use the concept of the diagnostic horizons, which are defined by a set of diagnostic criteria. Especially the seventh approximation influenced the FAO soil classification.

4.2 | The FAO Soil Classification System

The FAO developed a Soil Map of the World in 10 volumes with a scale of 1:5000,000. It was published in collaboration with the United Nations Educational, Scientific and Cultural Organization

TABLE 6 Horizon designations – suffixes (IUSS Working Group WRB, 2022)

Symbol	Criteria	Combination with
a	Organic material in an advanced state of decomposition; after gently rubbing, ≤ one sixth of the volume consists of recognizable dead plant tissues [a like **a**dvanced]	H, O
b	Buried horizon; first, the horizon has formed, and then, it was buried by mineral material [b like **b**uried]	H, O, A, E, B
c	Concretions and/or nodules (only used if following another suffix (k, q, v, y) that indicates the accumulated substance) [c like **c**oncretion]	
d	Drained [d like **d**rained]	H
e	Organic material in an intermediate state of decomposition; after gently rubbing, ≤ two thirds and > one sixth of the volume consist of recognizable dead plant tissues [e like interm**e**diate]	H, O
	Saprolite [e like saprolit**e**]	C
f	Permafrost [f like **f**rost]	H, O, A, E, B, C
g	Accumulation of Fe and/or Mn oxides predominantly inside soil aggregates, if present, and loss of these oxides on aggregate surfaces (A, B and C horizons), or loss of Fe and/or Mn by lateral subsurface flow (pale colours in ≥50% of the exposed area; E horizons); transport in reduced form [g like sta**g**nic]	A, B, C E
h	Significant amount of organic matter; in A horizons at least partly modified in situ; in B horizons predominantly by illuviation; in C horizons forming part of the parent material [h like **h**umus]	A, B, C
i	Organic material in an initial state of decomposition; after gently rubbing, > two thirds of the volume consist of recognizable dead plant tissues [i like **i**nitial]	H, O
	Slickensides and/or wedge-shaped aggregates [i like sl**i**ckenside]	B
j	Accumulation of jarosite and/or schwertmannite [j like **j**arosite]	H, O, A, E, B, C
k	Accumulation of secondary carbonates, evident by one or both of the following: visible even in moist state has a calcium carbonate equivalent of ≥5% higher (absolute) than that of an underlying layer and no *lithic discontinuity* between the two layers [k like German ***K**arbonat*]	H, O, A, E, B, C
l	Accumulation of Fe and/or Mn in reduced form by upward-moving capillary water with subsequent oxidation: accumulation predominantly at soil aggregate surfaces, if present, and reduction of these oxides inside the aggregates [l like capi**ll**ary]	H, A, B, C
m	Pedogenic cementation in ≥50% of the volume; cementation class: at least moderately cemented (only used if following another suffix (k, l, q, s, v, y, z) that indicates the cementing agent) [m like ce**m**ented]	
n	Exchangeable sodium percentage ≥6 [n like **n**atrium]	E, B, C
o	Residual accumulation of large amounts of pedogenic oxides in strongly weathered horizons [o like **o**xide]	B
p	Modification by cultivation (e.g., ploughing); mineral layers are designated A, even if they belonged to another layer before cultivation [p like **p**lough]	H, O, A
q	Accumulation of secondary silica [q like **q**uartz]	A, E, B, C
r	Strong reduction [r like **r**eduction]	A, E, B, C
s	Accumulation of Fe oxides, Mn oxides and/or Al by vertical illuviation processes from above [s like **s**esquioxide]	B, C
t	Accumulation of clay minerals by illuviation processes [t like German ***T**on*, clay]	B, C
u	Containing artefacts or consisting of artefacts [u like **u**rban]	H, O, A, E, B, C, R
v	Plinthite [the suffix v has no connotation]	B, C
w	Formation of soil aggregate structure and/or oxides and/or clay minerals (layer silicates, allophanes and/or imogolites) [w like **w**eathered]	B

(Continues)

TABLE 6 (Continued)

Symbol	Criteria	Combination with
x	Fragic characteristics (soil aggregates with a rupture resistance of at least firm and a brittle manner of failure, not allowing roots to enter the aggregates) [the x refers to the impossibility to enter the aggregates]	E, B, C
y	Accumulation of secondary gypsum [y like g**y**psum or Spanish ***y****eso*]	A, E, B, C
z	Presence of readily soluble salts [z like Dutch ***z****out*]	H, O, A, E, B, C
@	Cryogenic alteration	H, O, A, E, B, C
α	Presence of primary carbonates (in R layers related to the rock, in all other layers related to the fine earth) [α like c**a**rbonate]	H, A, E, B, C, R
β	Bulk density $\leq$0.9 kg dm^{-3} [β like **b**ulk density]	B
γ	Containing $\geq$5% (by grain count) volcanic glasses in the fraction between >0.02 and $\leq$2 mm [γ like **g**lass]	H, O, A, E, B, C
δ	High bulk density (natural or anthropogenic – not due to cementation (symbol ..m), not in fragic horizons (symbol x), not in layers with retic properties (symbol Bt/E)), so that roots cannot enter, except along cracks [δ like **d**ense]	A, E, B, C
λ	Deposited in a body of water (limnic) [λ like **l**imnic]	H, A, C
ρ	Relict features (only used if following another suffix (g, k, l, p, r, @) that indicates the relict feature) [ρ like **r**elict]	
σ	Permanent water saturation and no redoximorphic features [σ like **s**aturation]	A, E, B, C
τ	Human-transported natural material [τ like **t**ransported]	H, O, A, B, C
φ	Accumulation of Fe and/or Mn in reduced form by lateral subsurface flow with subsequent oxidation [φ like **f**low]	A, B, C

Note: The table is shortened: For the reference values of the volume percentages, please refer to the WRB Manual.

(FAO-UNESCO, 1971–1981). The process of its elaboration was led by D. L. Bramão (1961–1968), L. D. Svindale (1968–1970) and R. Dudal (1970–1981), see Blume and Schad (2015). The corresponding Legend (FAO-UNESCO, 1974) lists 106 soil units, which were grouped into 26 major units. Both were identified using a key. The key was based on diagnostic horizons and diagnostic properties. Many of the definitions were worded using concepts developed in Soil Taxonomy.

In 1988, the FAO published a Revised Legend (FAO, 1988) in cooperation with the UNESCO and the International Soil Reference and Information Centre (ISRIC). A new map was not produced, which indicates that the Legend has developed into a stand-alone soil classification system. Now, the major units received an official denomination: Major Soil Groupings. The Revised Legend has 28 Major Soil Groupings, 7 were newly introduced, and 5 of the 26 major units of the Legend were abolished. The sequence in the key was rearranged. Some new diagnostics were defined. The number of soil units increased from 106 to 153. The users were allowed to define subunits, and the text gives some guidelines how to do that but no strict rules.

4.3 | The activity of IUSS Working Groups

Some soil scientists considered the FAO Legend as too much focused on utilization and wanted to establish an international soil classification system, based on soil properties that reflect characteristics of parent material and effects of soil-forming processes (Blume & Schad, 2015). E. Schlichting, Chair of Commission V (Soil Genesis, Classification and Cartography) of the International Society of Soil Science (ISSS – now: International Union of Soil Sciences, IUSS) invited international experts to several meetings (Dudal, 1980; Schlichting, 1984). At the 12th World Congress of Soil Science 1982 in New Delhi, the ISSS established a Working Group named International Reference Base for Soil Classification (IRB) with E. Schlichting as chair to develop a new international soil classification system (Schlichting, 1984). The IRB Working Group developed definitions of 20 soil units and of several subunits as special forms or as transition forms (Schlichting, 1986), but due to missing financial support and Schlichting's death in 1988, a joint classification system was not evolved.

In 1992, a new approach was made during a meeting in Montpellier: The chair of ISSS Commission V, H. Eswaran, the chair of the IRB Working Group, A. Ruellan and other members of the IRB Working Group accepted a suggestion from R. Dudal. A new system should be developed, called WRB, based on the Revised Legend of the FAO classification but with systematic inputs from the IRB concept (Blume & Schad, 2015). FAO and ISRIC supported this idea and nominated two scientists to elaborate a draft: O. Spaargaren (ISRIC) and F. Nachtergaele (FAO). The draft was presented in 2014 at the 15th World Congress of Soil Science in Acapulco (FAO, 1994).

At the same congress, the WRB Working Group was formally established by the ISSS, replacing the IRB Working Group. The WRB Working Group had the following chairs:

Seppe Deckers (1994–2002)
Erika Michéli (2002–2006)
Otto Spaargaren (2006–2010)
Peter Schad (2010–2022)
Cezary Kabała (since 2022)

4.4 | First edition of the WRB (1998)

The first edition of the WRB (FAO, 1998) was presented at the 16th World Congress of Soil Science 1998 in Montpellier. Compared to the Revised Legend (FAO, 1988), there were three important changes:

1. The Major Soil Groupings were renamed Reference Soil Groups (RSGs). The system had 30 RSGs. The Greyzems were abolished (now mainly belonging to the Phaeozems) and the Cryosols, the Durisols and the Umbrisols introduced. The sequence in the key was rearranged.
2. The RSGs were identified using a key. At the lower classification level, however, the key was abolished and a qualifier system introduced. Qualifiers are adjectives to be combined with the names of RSGs. Each qualifier was given one unique meaning, applicable for all RSGs, in which it occurred. For every RSG, there was a list of the available qualifiers in the priority from top to down. There were in total 122 qualifiers. The Regosols had the longest list with 29, whereas Chernozems and Kastanozems had the shortest lists with 9 qualifiers, each. A maximum of two qualifiers was used before the name of the RSG, the first applicable in the list standing closer to the name of the RSG, and the second applicable added without the letter c and with a hyphen, for example, Geric Ferralsol, and then Acri-Geric Ferralsol. If more qualifiers applied, they were added in brackets behind the name of the RSG, for example, Acri-Geric Ferralsol (Abruptic and Xanthic). In addition, 10 prefixes were defined to indicate the depth of occurrence or to express the intensity of soil characteristics. They were combined to one word with the qualifier, for example, Hypercalcic. A double combination, like Epihypercalcic, was also allowed. The introduction of the qualifier system was a major revolution in the history of WRB, making the system easier and more concise (see Qualifiers, before).
3. Besides the diagnostic horizons and properties, diagnostic materials were introduced referring to materials that significantly influence soil-forming processes. Additionally, some new diagnostic horizons and properties were defined.

4.5 | Second edition of the WRB (2006, update 2007)

The second edition (IUSS Working Group WRB, 2006) was issued in 2006 at the 18th World Congress of Soil Science in Philadelphia. In 2007, an update was published (IUSS Working Group WRB, 2007). Two new RSGs were added, Technosols and Stagnosols, and the sequence in the key was rearranged. Many definitions of diagnostics, RSGs, and qualifiers were sharpened. Some new diagnostics were introduced, and the number of qualifiers increased from 122 to 215. The formative elements, called prefixes in 1998, are now named specifiers. There were 10 specifiers to indicate the depth of occurrence or to express the intensity of soil characteristics. A new chapter was added: 'Description, distribution, use and management of RSGs'. It is a shortened and updated version of the 'Lecture notes on the major soils of the world' (FAO, 2001).

A very important change refers to the position of the qualifiers. For every RSG, the list of available qualifiers was divided into prefix qualifiers and suffix qualifiers. Prefix qualifiers were placed before the name of the RSG from right to left, the uppermost one closest to the name of the RSG. Suffix qualifiers were placed behind the name of the RSG, in brackets and with commas in between. The prefix qualifiers were typically associated qualifiers (e.g., Lamellic, Cutanic, Albic, Escalic for Luvisols) and intergrade qualifiers (intergrading to other RSGs). All others were suffix qualifiers, added in the following sequence: related to (1) diagnostic horizons, properties and materials; (2) chemical characteristics; (3) physical characteristics; (4) mineralogical characteristics; (5) surface characteristics; (6) textural characteristics, including coarse fragments; (7) colour; (8) other characteristics. The limitation of the number of qualifiers was suspended, and the rule was now that all applicable qualifiers have to be added.

This worked well for naming a soil but not for creating map legends. Example: If the scale allows just the RSG plus one qualifier, and the dominant soil of the map unit is a Luvisol, it will be most probably a Cutanic Luvisol. The only available qualifier's place at that scale level is taken by a qualifier most Luvisols have. A differentiation by prefix qualifiers further down the list (e.g., Albic and Stagnic) or suffix qualifiers (e.g., Rhodic and Chromic) could not be achieved.

To satisfy the demand to use WRB for map legends, the 'Guidelines for constructing small-scale map legends using the WRB' (IUSS Working Group WRB, 2010) were published. They rearranged the qualifiers into 'main map unit qualifiers' and 'optional map unit qualifiers'. Looking at the example of Luvisols: Informative suffix qualifiers like Rhodic, Chromic, Skeletic, Ferric shifted to the main map unit qualifiers. Less informative prefix qualifiers like Cutanic shifted to the optional map unit qualifiers. However, we now had two different qualifier distributions, one for naming soils and the other for creating legends for soil maps.

4.6 | Third edition of the WRB (2015)

The third edition (IUSS Working Group WRB, 2015) was first published in 2014 at the 20th World Congress of Soil Science in Jeju and then updated in 2015. It maintains the 32 RSGs but replaces the Albeluvisols by Retisols. The definition of the Albeluvisols was so narrow, that they covered only very small areas, worldwide. The Retisols have a broader definition and resemble more the Podzoluvisols of the Soil Map of the World (FAO-UNESCO, 1974). Again, some adjustments of the sequence in the key were made, some new diagnostics introduced, and many definitions made more precise. A new chapter was added: 'The rules for classifying soils and creating map legends'. This chapter helps correctly apply WRB.

The qualifier arrangement follows roughly the 'Guidelines for constructing small-scale map legends using the WRB' (IUSS Working Group WRB, 2010). The 'main map unit qualifiers' were renamed 'principal qualifiers' and the 'optional map unit qualifiers' 'supplementary

qualifiers'. This qualifier arrangement is suitable for both naming soils and creating legends for soil maps. The system of specifiers was thoroughly elaborated. The combinations of specifiers with qualifiers were called subqualifiers, for example, the specifier Epi- with the qualifier Arenic forms the subqualifier Epiarenic. Comprehensive rules for application were formulated. The elaboration of the subqualifiers reduced the number of qualifiers from 215 to 185.

The third edition was much more accepted by the scientific community than the previous versions. Textbooks applying the third edition were published, like Zech et al. (2022). A brief description was published by Schad and Dondeyne (2017).

4.7 | WRB and other soil classification systems

At the World Congress of Soil Science 1998, the ISSS Council endorsed the WRB as correlation system of the ISSS for soil classification. The same status was granted at the World Congress of Soil Science 2014 to the US Soil Taxonomy. The term 'correlation' led to the misunderstanding that a translation would be possible between soil names, for example, a Luvisol in WRB is an Alfisol in Soil Taxonomy, and an Alfisol in Soil Taxonomy is a Luvisol in WRB, a Luvisol in WRB is a Parabraunerde in the German system, and a Parabraunerde in the German system is a Luvisol in WRB. This is absolutely impossible! A correlation system is just a *lingua franca* for communication. Soil names have always to be derived from the original field and laboratory data. The architectures and the limit values are so different in the respective systems that a translation has very little chance to be correct.

4.8 | Codes

All editions of the FAO Legend and of the WRB provide codes.

The Legend of the Soil Map of the World (FAO-UNESCO, 1974) indicates the soil units with one capital and one lowercase letter, for example, Ag for a Gleyic Acrisol and Tv for a Vitric Andosol. The Revised Legend (FAO, 1988) uses two capital letters for the Major Soil Groupings, and the mentioned examples read as follows: ACg for a Gleyic Acrisol and ANz for a Vitric Andosol. As the Revised Legend allows the users to define subunits, two or even three lowercase letters may follow the code of the Major Soil Grouping, for example, ACgh for a Humi-Gleyic Acrisol or ACgha for an Alumi-Humi-Gleyic Acrisol. If a formative element is used in other soil units (e.g., Humi-), the respective symbol has to be used (h). Otherwise (e.g., Alumi-), the user chooses the symbol.

The first and the second edition of the WRB (FAO, 1998; IUSS Working Group WRB, 2006) use two capital letters for the RSGs and two lowercase letters for the qualifiers. The specifiers are indicated by an additional lowercase letter to be added at the end. However, no instructions were given how to combine them in soil names.

The third and the fourth edition of the WRB (IUSS Working Group WRB, 2015, 2022) follow the same scheme but explain how to use the codes in soil names and map unit names.

4.9 | Horizon and layer designations

The FAO Legends and WRB use diagnostic horizons. Different from diagnostic horizons, is a system of designations for all horizons or layers. The FAO Legends (FAO-UNESCO, 1974; FAO, 1988) and the first edition of the WRB (FAO, 1998) provided such designations. The second and the third edition (IUSS Working Group WRB, 2006, 2015) did not, and during that time, the designations of the FAO Guidelines for Soil Description (FAO, 2006) were recommended. The fourth edition (IUSS Working Group WRB, 2022) again provides designations, listed in its Annex 3. They are a further elaboration of the designations given in the FAO Guidelines.

5 | CONCLUSIONS

Twenty-four years have passed from the publication of the Legend of the Soil Map of the World to the first edition of the WRB. The Legend was designed primarily as a map legend but eventually became a soil classification system. The WRB was particularly a soil classification system but from the beginning also meant to be used for creating map legends. These two purposes require different capabilities: Naming a soil needs detailedness, whereas maps require a generalization. Since the third edition (IUSS Working Group WRB, 2015), the WRB is able to reasonably provide both. In the fourth edition (IUSS Working Group WRB, 2022), 24 years after the first edition, two new elements completed the system: First, the newly developed Field Guide provides the needed definitions of field characteristics and allows a precise survey and record of all the field characteristics required for the WRB criteria. Second, the horizon and layer designations permit a full soil description. The development of soil classification in general and of WRB in particular will go on – but with the current WRB, the soils of the world can receive a comprehensive description and classification.

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REFERENCES

Blume, H.-P., & Schad, P. (2015). 90 years of soil classification of the IUSS. *IUSS Bulletin*, *126*, 38–45.

De Almeida, J. A., Lunardi Neto, A., & Vidal-Torrado, P. (2015). Sombric horizon: Five decades without evolution. *Scientia Agricola*, *72*, 87–95.

Dudal, R. (1980). Towards an international reference base for soil classification. *IUSS Bulletin*, *57*, 18–20.
FAO. (1988). *Soil map of the world. Revised legend*. World Soil Resources Report No. 60. FAO–UNESCO–ISRIC.
FAO. (1994). *World reference base for soil resources*. ISSS–ISRIC–FAO.
FAO. (1998). *World reference base for soil resources*. World Soil Resources Report No. 84. ISSS–ISRIC–FAO.
FAO (2001). *Lecture notes on the major soils of the world* (with CD-ROM), P. Driessen, J. Deckers, O. Spaargaren, & F. Nachtergaele (Eds.), World Soil Resources Report No. 94.
FAO (2006). *Guidelines for soil description*. Prepared by Jahn, R., Blume, H.-P., Asio, V. B., Spaargaren, O., & Schad, P. Fourth edition. FAO.
FAO-UNESCO. (1971–1981). *Soil map of the world 1:5 000 000* (10 Vol.). UNESCO.
FAO-UNESCO. (1974). *Soil map of the world 1:5 000 000* (Vol. 1, Legend). UNESCO.
IUSS Working Group WRB. (2006). *World reference base for soil resources 2006*. World Soil Resources Report No. 103. FAO.
IUSS Working Group WRB. (2007). *World reference base for soil resources 2006, first update 2007*. FAO.
IUSS Working Group WRB. (2010). *Guidelines for constructing small-scale map legends using the WRB*. FAO.
IUSS Working Group WRB. (2015). *World reference base for soil resources 2014, Update 2015. International soil classification system for naming soils and creating legends for soil maps*. World Soil Resources Report No. 106. FAO. https://www.fao.org/3/i3794en/I3794en.pdf
IUSS Working Group WRB. (2022). *World reference base for soil resources. International soil classification system for naming soils and creating legends for soil maps* (4th ed.). International Union of Soil Sciences (IUSS). https://www3.ls.tum.de/boku/?id=1419
Miller, B., & Juilleret, J. (2020). The colluvium and alluvium problem: Historical review and current state of definitions. *Earth-Science Reviews*, *209*, 103316. https://doi.org/10.1016/j.earscirev.2020.103316
Prietzel, J., & Wiesmeier, M. (2019). A concept to optimize the accuracy of soil surface area and SOC stock quantification in mountainous landscapes. *Geoderma*, *356*, 113922. https://doi.org/10.1016/j.geoderma.2019.113922
Schad, P., & Dondeyne, S. (2017). World reference base for soil resources. In R. Lal (Ed.), *Encyclopedia of soil science* (3rd ed., pp. 2650–2653). Taylor & Francis.
Schlichting, E. (1984). IUSS Working Group IRB. *ISSS Bulletin*, *65*, 22.
Schlichting, E. (1986). Diagnostic properties, horizons, soils and landscapes. *Zeitschrift für Pflanzenernährung und Bodenkunde*, *149*(4), 492–499.
Schoeneberger, P. J., Wysocki, D. A., Benham, E. C., & Soil Survey Staff. (2012). *Field book for describing and sampling soils, Version 3.0*. Natural Resources Conservation Service, National Soil Survey Center.
Soil Science Division Staff. (2017). *Soil survey manual* (4th ed.). Handbook No. 18. U.S. Department of Agriculture. U.S. Government Printing Office.
Soil Survey Staff. (1951). *Soil survey manual*. Handbook No. 18. U.S. Department of Agriculture. U.S. Government Printing Office.
Soil Survey Staff. (1960). *Soil classification, a comprehensive system, 7th approximation*. Soil Conservation Service, U.S. Department of Agriculture. U.S. Government Printing Office.
Soil Survey Staff. (1967). *Supplement to soil classification system (7th approximation)*. Soil Conservation Service, U.S. Department of Agriculture. U.S. Government Printing Office.
Soil Survey Staff. (1975). *Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys*. Handbook No. 436. Soil Conservation Service, U.S. Department of Agriculture. U.S. Government Printing Office.
Soil Survey Staff. (1999). *Soil taxonomy. A basic system of soil classification for making and interpreting soil surveys* (2nd ed.). Handbook No. 436. Soil Conservation Service, U.S. Department of Agriculture. U.S. Government Printing Office.
Zech, W., Schad, P., & Hintermaier-Erhard, G. (2022). *Soils of the world*. Springer.

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