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WRB Documentation Centre

Vertisols

Alemtsehay Tsegay, J. Deckers*, S. Mantel, F. Nachtergaele, K. Vancampenhout
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* Lead author

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WRB Documentation Centre

Abstract

This text is a contribution to develop a WRB Documentation Centre website that illustrates the Reference Soil Groups (RSG) and all their principal qualifiers in the World Reference Base for Soil Resources (IUSS Working Group WRB, 2022).

This example deals with the RSG of Vertisols. It provides the soil forming factors and the main characteristics of this RSG and reviews its classification at RSG and qualifier level. Examples of fully documented Ferralsols with their principal qualifiers derived from the soil reference collection of ISRIC World Soil Information are given in an Annex. A second Annex describes the changes in the evolving classification criteria for Vertisols since the FAO-Unesco Legend of the Soil Map of the World.

The WRB soil classification system will benefit from a core set of documented occurrences of Reference Soil Groups with their principal qualifiers as illustrated here. However, not all qualifiers could be documented and a call for contributions is made to fill the gaps in the present Vertisols collection.

Call for contributions:

Examples of fully documented (Photograph with tape, soil profile description, analytical data), with specification of the description protocol used, the methods for analyses applied and the units of the data), for **Salic, Duric, Petroduric, Gypsic Petrocalcic, Chromic, Anthraquic, Hydragric, Anthraquic and Irragric** principal qualifiers in Vertisols will be gratefully acknowledged (Name, title, Institution).

Please contact:

ISRIC, c/o Stephan Mantel: wrbwgsecretariat@gmail.com

and / or

KU Leuven, c/o Seppe Deckers: https://ees.kuleuven.be/en/soil-monoliths/contact

VERTISOLS

Introduction

Vertisols are heavy clay soils that form deep polygonal cracks upon drying.
The characterization of Vertisols in this text was based on of information from various sources, among others Driessen et al. (2001), Deckers et al. (1998) and Deckers (2001). The classification of Vertisols is discussed as given in the World Reference Base for Soil Resources (IUSS Working Group WRB, 2022). The findings are illustrated in fully documented monoliths from ISRIC's soil reference collection[1]. Attention is paid to the evolution of classification of Vertisols in different editions of the World Reference Base for Soil Resources (Deckers et al, 1998; ISSS/ISRIC/FAO 1998; IUSS Working Group WRB 2006, 2007, 2010, 2015) in a separate Annex.

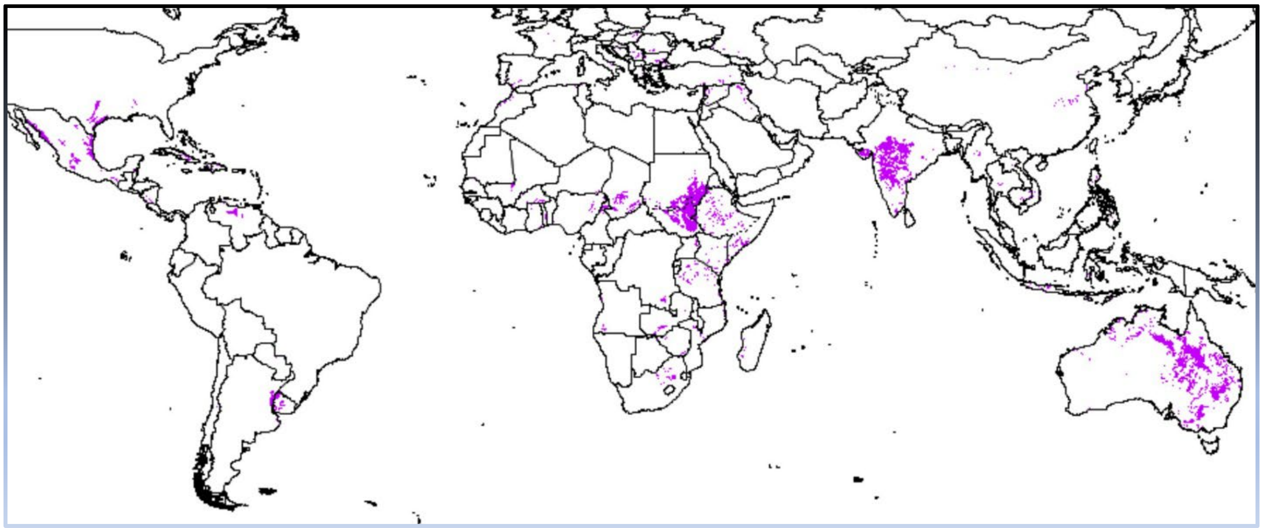
Summary description of Vertisols

The name Vertisols (from Latin vertere, to turn) refers to the constant internal turnover (churning) of soil material. Vertisols are relatively deep soils with a high (> 30%) proportion of swelling clays that expand upon wetting and shrink upon drying. Vertisols form deep wide cracks from the soil surface downwards when drying out. Common local names for Vertisols are Black cotton soils and Regur (India), Black turf soils (South Africa) or Margalites (Indonesia). In national soil classification systems they are called Slitozems or Dark vertic soils (Russia), Vertosols (Australia), Vertisolos (Brazil) and Vertisols (United States of America).

Geographic distribution of Vertisols

Most Vertisols occur in the semi-arid tropics with an average annual rainfall of 500–1 000 mm and the Mediterranean (400-900 mm annual rainfall), but Vertisols are also found in the wet tropics, e.g. Trinidad (where annual rainfall amounts to 3000 mm). The largest Vertisol areas are in Australia, India, Sudan (Gezira) and South Sudan. They also occupy important areas in Ethiopia, China, southern United States of America (Texas), Uruguay, Paraguay, Argentina and South Africa. Vertisols are commonly associated with sediments that have a high content of smectite clays or that produce such clays upon post-depositional weathering (e.g. in South Sudan and Australia) and on extensive basalt plateaus (e.g. in India and Ethiopia). Vertisols are often found in lower landscape positions such as dry lake bottoms, river basins, lower river terraces (e.g. along the Blue Nile River), and other lowlands that are periodically wet in their natural state. Small areas of Vertisols occur in southern European Russia and in Hungary.
The total extent of Vertisols has been estimated at 335 million hectares, of which 50% is considered as potential crop land (Map 1).

[1] https://isis.isric.org/ and https://wsm.isric.org/gallery.html



Map 1: Distribution of Vertisols worldwide. (FAO/IIASA, 2022)

Soil Forming factors in Vertisols

Parent material: Vertisols are conditioned by the parent material that is derived from fine-grained mafic rocks such as basalt, dolerite, tuff, basic metamorphic rocks, limestone, marl, and from fine-textured riverine, marine or lacustrine fluviatile materials.

Climate: Vertisols form mainly in tropical and subtropical, semi-arid to subhumid and humid climates with an alternation of distinct wet and dry seasons (Aw, As and Bs Köppen climates, Ustic moisture regimes in Soil Taxonomy). Minor occurrences outside these climates zones are considered to be relics from past eras with a different climate than today.

Age/Time: Vertisols are relatively young soils of late Holocene age or younger;

Fauna and Flora: The climax vegetation is savannah, natural grassland and/or woodland. The seasonally dry savannah woodland comprises acacia species such as whistling thorn (*Vachellia drepanolobium) or eucalyptus forest (Eucalyptus globulus*)

Topography: Vertisols occur on flat to gently undulating plateaus and river terraces with gentle a slope of usually not more than 3%

Human influence: As Vertisols are rather fertile, they may form good farm land under an adjusted land management system, including mechanization, geared to cope with challenging vertic properties. However in absence of soil conservation measures they may be subject to severe soil erosion to chemical degradation such as salinization and/or alkalinization.

Soil characteristics of Vertisols

Morphology

Vertisols are relatively shallow (less than 2 m deep), black or brownish soils that contain > 30% clay. Seasonal polygonal cracks may protrude down to +- 50 cm depth. The structure of the topsoil typically is small-medium prismatic blocky. The subsoil is characterized by wedge-shaped structural aggregates with shiny curved ped faces. Due to seasonal wet-dry cycles, Vertisols develop slanted shiny shear planes with striations (slickensides) in the subsoil, along which pressure is released to the surface through chimneys of coarse (often lime-rich) soil material that reaches the soil surface, leading to the ups in the wavy soil surface (gilgai). The lows in the gilgai-microtopography of Vertisols are relatively higher in clay than the ups and usually waterlogged during the rainy season. As gilgai surface microrelief originates from wet-dry cycles in the subsoil, it is re-installing itself even after surface levelling (e,g. for surface irrigation purposes). The driving force of gilgai is extremely strong and will cause cracks in constructions such as roads, buildings and runways of airports (e.g. in Addis Ababa international Airport in the old days).

Mineralogical characteristics

The high swell-shrink in Vertisols is due to the presence of high quantities of 2-1 clay minerals such as smectites and/ or mixed-layered clay minerals. Smectite is the first secondary mineral to form upon rock weathering in the semi-arid to sub-humid tropics. Smectite retains most of the (Ca++ and Mg++) released from weathering primary silicates, and becomes stable as long as the pH of the soil remains above neutral. This condition is often the case in lower reaches of the weathering soilscape where the content of fine clay is higher than in upslope positions and where drainage/leaching of soluble components is reduced due to lower infiltration rates. Smectite clays can be formed in the presence of silica and basic cations under rather specific environmental conditions: 1) annual rainfall must be sufficient to enable weathering but not so high that leaching of bases occur; 2) dry periods must allow crystallization of clay minerals that form upon rock or sediment weathering; 3) drainage must be impeded to the extent that leaching and loss of weathering products are curbed; 4) high temperatures promoting the weathering process.

Hydrological characteristics

Intake rate of water in dry (cracked) Vertisols with surface mulch or a fine tilth is initially rapid. However, once the topsoil is thoroughly wetted and cracks have closed, infiltration rate of water becomes almost zero. From then onwards rain or irrigation water remains on the soil surface, filling up localized dips in the gilgai soil surface, or run downslope from the field, causing soil erosion. In view of their high clay content, Vertisols have a relatively high (± 150 mm/m soil depth) water holding capacity. Water is adsorbed at the clay surfaces and retained between crystal lattice clays layers. Residual moisture after the rainy season may support lay-crops that grow through the dry season.

Physical characteristics

Vertisols get very hard upon drying and very sticky and plastic when wet. In general, Vertisols are friable over a narrow moisture range, however, their physical properties are greatly influenced by soluble salts and/or adsorbed sodium. Vertisols on gently sloping terrain may be subject to severe soil sheet, rill, gully, or pipe erosion. Annual cropping on slopes > 5 degrees is therefore not recommended. Vertic soil materials accumulated in concave land surfaces commonly develop landslides that may move downslope over great distances covering neighboring downslope soilscapes as has occurred near Hagere Selam in the north Ethiopian Highlands.

Chemical characteristics

Vertisols are chemically relatively rich and fertile. They have a large reserve of weatherable minerals. Paradoxically, dark-colored (Pellic) Vertisols may still be low in organic carbon. Vertisols generally have a high cation exchange capacity and in view of a high base saturation, their pH is usually neutral to slightly alkaline. High contents of soluble salts and/or sodium may cause problems for sensitive crops such as citrus species. The only option to control topsoil salinity is to evacuate excess salts by surface leaching.

Biological characteristics

In view of their high fertility, Vertisols support a rich savanna woodland which is home to large grazing wildlife. The onset of the rainy season boosts bacterial populations in the soil, causing a rapid breakdown of straw mulch, eventually inducing nitrogen deficiency in crops through competition for nitrate. Furthermore, a natural denitrification may enhance the stress for nitrogen especially on the more alkaline Vertisols.

Soilscape-relationships of Vertisols with some other Reference Soil Groups

The combination of topographic position, climatic conditions and parent material determines the spatial and temporal linkages of Vertisols with other soils. Vertisols normally occupy either the high plateaus or the lower parts of the landscape, comprising near-level to gently undulating river terraces and piedmont, flood and coastal plains in association with Calcisols, Gypsisols and Solonchaks. On the more humid 'plateau' side of the 'Vertisol environmental niche', high levels of biomass production is leading to associations with Phaeozems and Chernozems. In basalt plateaus of the Tropical highlands under a cool subhumid climate, typical red-black topo-sequences occur with Nitisols/Luvisols dominating the upper reaches of the soilscape and Vertisols/Phaeozems/Planosols in the lower topographic positions. On the 'lower' edge of the 'Vertisol spectrum', where parent material often is salt/sodium-rich (e.g. on marine or lacustrine terraces), Vertisols are associated with Solonchaks and Solonetz.

Land use and management of Vertisols

Though Vertisols have great agricultural potential, they are difficult to work, being hard when dry and very sticky when wet. Therefore many Vertisol areas in the semi-arid tropics still remain unused or are used extensively for rough grazing, firewood production charcoal burning or as wildlife conservation reserve. Under the pressure of increasing human population, farmers are starting to develop some of Vertisol land for post-rainy season crop production, growing millet, sorghum, cotton or chickpeas on residual soil moisture. Management practices for crop production on Vertisols ought to be primarily directed to control water dynamics besides maintaining or improving soil fertility. As Vertisols have very low infiltration rates, excess water during the rainy season has to be drained and/or possibly stored in the soil for post-rainy season use (water harvesting). Several water management practices have been devised to improve water dynamics. Surface drainage can be achieved by shaping the land in broad beds and furrows. These protect field crops from waterlogging in the rooting zone. The drained water may be stored in the lower part of the catchment in small ponds for other uses, such as watering livestock, growing vegetables of nursing fish. In the Ethiopian Highlands traditionally one crop (e.g. teff or barley) is grown on Vertisols towards the end of the rainy season, hence growing after the seasonal floods on residual soil moisture. With improved surface drainage by beds and furrows two sequential crops become possible: barley or wheat during the full rainy season, followed by chick pea or teff on residual soil moisture. Beyond higher physical crop yields another big advantage of such crop intensification is that the soil is better conserved in line with a longer-term crop-cover, protecting the soil against soil erosion. Minimum-till conservation agriculture practicing contour cultivation and bunding on gently sloping land is widely used on Vertisols of the north Ethiopian highlands to improve infiltration, which also leads to less soil erosion. Gully erosion is controlled by sub-surface dam construction in the lower parts of the landscape, designed to keep up the groundwater table so as to maintain the subsoil moisture condition. In this way, swell-shrink is inactivated and many processes related to gully formation (slumping, pipe erosion, subsoil cracking) are curbed. Vertical mulching by inserting organic crop residues (e.g. sorghum stubbles) into the cracks is sometimes used to enhance infiltration and moisture uptake in the subsoil. Irrigating Vertisols by flood irrigation poses its own problems especially on the ones with gilgai microrelief. The closure of the soil in wet conditions favors the cultivation of rice on level Vertisol lands. A practical solution to this is small-scale basin irrigation. Vertisols are usually N-deficient due to the generally low amount of organic matter. Nitrogen fertilizers have to be applied carefully in order to avoid losses through volatilization, throughflow in the cracks or denitrification during inundation. Other nutrients which may need correction are phosphorus and, occasionally, sulphur and zinc. Cotton is known to perform well on Vertisols because it has a vertical rooting system which is not much affected by swell-shrink activity in the subsoil. Other common crops on Vertisols are: sugar cane, wheat, barley, teff, sorghum, chickpeas, field peas, horsebeans and noug (Guizotia abyssinica).

The classification of Vertisols

Vertisols definition as a Reference Group

Vertisols are churning heavy clay soils with a vertic horizon starting ≤ 100 cm from the mineral soil surface and having ≥ 30 % clay from the surface until the vertic horizon throughout with shrink-swell cracks, which open and close periodically.

The Reference Soil Group of Vertisols in WRB 2022 corresponds to the Vertisols in Soil Taxonomy (Soil Survey Staff, 2022). There is a broad consensus on the concept of Vertisols in all major classification systems.

In the key of the Reference Soil Groups, Vertisols are placed in 7th position, after Histosols, Anthrosols, Technosols, Cryosols, Leptosols and Solonetz.

Given the characteristics of Vertisols and the environment in which they develop, most of the other Reference Soil Groups preceding them in the key have characteristics that are incompatible with Vertisols. This is the case for Histosols (organic not mineral soil material), Leptosols (very shallow or very stony), Cryosols (permafrost). The Solonetz (high exchangeable Na content mainly occurring in dry climates) is an exception and is recognized in the principal qualifier Sodic.

Definition of the Vertic horizon

A vertic horizon (from Latin vertere, to turn) is a clay-rich subsurface horizon that, as a result of shrinking and swelling, has slickensides and wedge-shaped soil aggregates.

A vertic horizon should have:

(a) ≥ 30% clay and one or both of the following

(b) (1) in ≥ 20% (by volume), wedge-shaped soil aggregates with a longitudinal axis tilted between ≥ 10° and ≤ 60° from the horizontal; or
(2) slickensides on ≥ 10% of the surfaces of soil aggregates;
And:

(c) be more than 25cm thick and;
(d) Shrink-swell cracks

WRB (2022) goes through great length specifying that cracks should be deep (protruding down to the Vertic horizon. They should start at the mineral soil surface or at the base of a plough layer, or directly below a layer with strong granular structure or strong angular or subangular blocky structure with an aggregate size of ≤ 1 cm (self-mulching surface), or directly below a surface crust. This in the understanding that the cracks are assessed during the dry season when the soil is in dry condition, in absence of irrigation.

Definition of the Protovertic horizon

A protovertic horizon consists of mineral material and has:

1. ≥ 30% clay; and

2. One or more of the following:
    a. wedge-shaped soil aggregates in ≥ 10% (by volume); or
    b. slickensides on ≥ 5% of the surfaces of soil aggregates; or
    c. shrink-swell cracks; or
    d. a coefficient of linear extensibility (COLE) of ≥ 0.06;

    And:
3. a thickness of ≥ 15 cm

Note that the protovertic horizon is only used as a supplementary qualifier in Leptosols, Fluvisols and Regosols.

Definition of shrink-swell cracks

Shrink-swell cracks occur in mineral material and:
1. Open and close with changing water content of the soil; and
2. Are ≥ 0.5cm wide, when the soil is dry, with or without infillings of material from the surface

Principal qualifiers of Vertisols

The principal qualifiers are the main subdivisions of the Vertisols that are used for mapping and reflect the major occurrences of the Reference Soil Group regionally and globally.

In WRB2022 the following principal qualifiers have been recognized:

Salic: indicator of accumulation of high concentrations of soluble salts (i.e. salts more soluble than gypsum) at shallow depth at ≤ 100cm (salic horizon).

Sodic: indicator of high (≥ 15%) exchangeable Na + Mg on the exchange complex, which makes the soil unstable and extremely vulnerable to structure decay with high risk of severe soil erosion

Leptic: refers to shallowness with a solum of ≤ than 100 cm.

Petroduric/Duric: indicator of shallow at ≤ 100 cm presence of high (≥ 10 vol%) concentrations of silica in the form of nodules or concretions (durinodes) and/or remnants of a broken-up petroduric horizon; duric and petroduric horizon.

Gypsic: indicator of the non-cemented accumulations (≥ 5% gypsum content) of secondary gypsum at shallow (≤ 100 cm) depth (gypsic horizon).

Petrocalcic: indicative for presence of a horizon cemented by calcium carbonate and in some cases, magnesium carbonate at shallow depth at ≤100cm (petrocalcic horizon).

Calcic: indicative for large accumulations of secondary calcium carbonate (≥ 15%) at shallow depth (≤ 100 cm); a calcic horizon.

Hydragric/Anthraquic: a typical topsoil-subsoil horizon sequence that developed on or under paddy fields; Hydragric being the puddle layer and the plough pan and below those layers (anthraquic horizon and a directly underlying hydragric horizon), while Anthaquic has typical hydromorphic mottling and iron-depletion patches (having an anthraquic horizon and no hydragric horizon).

Irragric: indicative for sizeable (≥ 20 cm) surface accumulation of sediment caused by long-term surface-irrigation (irragric horizon).

Pellic: indicative for a dark-colored topsoil.

Chromic: indicative for a reddish-brown topsoil.

Haplic: means having none of the principal qualifiers mentioned above.

During the preparation of the WRB Documentation Centre a review was done of fully documented soil profiles in monolith collections at ISRIC and KU Leuven (Nachtergaele et al, 2023, 2024). All of the above principal qualifiers could be identified for Vertisols with the exception of Salic, Duric, Petroduric, Gypsic Petrocalcic, Anthraquic, Hydragric, Anthraquic Irragric and Chromic. Assistance is sought from soil experts to provide fully documented sets for these principal qualifiers of Vertisols.

There has been little change in the naming of the principal qualifiers of Vertisols, although over the years there have been some changes in their definition, selection and use.

Examples illustrating all Principal qualifiers of Vertisols present in the soil reference collection of ISRIC soil are given in Annex 1, while changes over the years in the classification of these soils are described in Annex 2.

Supplementary Qualifiers of Vertisols

It is not the intention at this stage to document all supplementary qualifiers in the WRB Documentation Centre, therefore these qualifiers are not discussed in great detail. Examples are given below applicable for Ferralsols. There are 35 different supplementary qualifiers foreseen in Ferralsols in WRB2022.

- Unlike other Reference Groups of WRB, Vertisols are always heavy clay soils, hence no further specification is required to qualify granulometry

Supplementary qualifiers allow further characterization of the soil unit at a local level specifically to:

- Indicate the occurrence, the depth of the Soil Reference Group diagnostic (the upper limit of the Vertic horizon can be specified as **Epic** (<50cm), **Endi**c (50-100cm);

- Indicate special chemical and physical characteristics of the soil: **Alcalic (**for presence of sodiumbicarbonate salts in the topsoil); **Dolomitic/Calcaric**: indicative for presence of small quantities of magnesium – or calcium carbonate; **Drainic:** indicative for presence of a surface drainage system; **Endodystric** (low nutrient supply in the subsoil); **Fractic**: containing fragments of a broken petrogypsic or petrocalcic horizon within 100 cm depth; **Gilgaic**: for an undulating microtopography; **Grumic:** strong granular or angular/subangular blocky structure at the surface; **Gypsiric**: indicating presence of small quantities of gypsum; **Humic** (≥1% SOC weighted averaged over 50 cm); **Hypereutric**: indicative for a neutral to high pH; **Magnesic**: having an exchangeable Ca to Mg ratio of <1; **Mazic**: indicative for a massive structure at the surface; **Ochric:** ≥ 0.2% soil organic carbon (weighted average) in the upper 10 cm and no mollic or umbric horizon are present; **Oxyaquic**: indicative for presence of seasonal oxygenated groundwater within 75 cm depth; **Pelocrustic**; indicative for a clay crust at the surface; **Raptic**: having a lithic discontinuity within 100 cm depth; **Skeletic**: having ≥ 40% stoniness; **Takyric:** indicating a platy or massive topsoil structure.

- Indicate an intergrade characteristic to another Reference Soil Group that seldom occurs (in the case of Vertisols this could be (in key-order): **Technic/Kalkaic**: (Technosols); **Gleyic:** (Gleysols); **Andic** (Andosols); **Stagnic** (Stagnosols); **Chernic** (Chernozems); **Mollic**: (Phaeozems/Kastanozems); **Fluvic** (Fluvisols).

- Indicate human interventions that have influenced the local characteristics of the Vertisol (e.g. **Aric:** indicative for the presence of a ploughed surface layer ≥ 10 cm thickness; **Pyric**: presence of charcoal; **Transportic:** an added layer intentional human activity, originating from outside the near vicinity; **Toxic:** toxic concentrations).

- Flag the occurrence of specific horizons or layers not typical for the Reference Soil Group (e.g. for Vertisols**; Ferric**: accumulation of Fe and Mn oxides; **Sulfidic**: containing sulfides; **Thionic**: presence of sulphuric acid.

- Indicate local pedogenetic processes, such as: **Novic**: overlying buried material, **Raptic**: having a lithological discontinuity; **Solimovic**: having transported material.

Conclusions

A summary description of the genesis, characteristics, geographic distribution and land use of Vertisols has been presented together with a detailed discussion of the classification of the Reference Soil Group with its qualifiers in WRB2022 (4th ed).

A full documentation of the RSG and its principal qualifiers was undertaken that included photographs, soil profile descriptions and associated laboratory analysis and was based on 38 monoliths of Vertisols present in ISRIC's soil reference collection.

Only a number of principal qualifiers of Vertisols could be documented. Examples are missing for Salic, Duric, Petroduric, Gypsic Petrocalcic, Chromic, Anthraquic, Hydragric, Anthraquic and Irragric principal qualifiers. Assistance is sought from soil experts to provide this missing documentation by accessing other source material they have access to.

Examples illustrating all principal qualifiers of Vertisols present in the soil museums of ISRIC and KU Leuven are provided in Annex 1, while changes over the years in the classification of these soils are described in Annex 2.

It is recommended to establish a WRB Documentation Centre that would collect similar descriptions for all reference soil groups and their principal qualifiers.

Acknowledgment

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ANNEX 1 Fully documented Vertisols with Principal Qualifiers

WRB Documentation Centre

Cuba CU021 Calcic Sodic Vertisol
Nicaragua NI009 Pellic Leptic Vertisol
Zimbabwe ZW006 Haplic Vertisol

Vertisols and Principal Qualifiers Hyperlinks

Principal Qualifiers	Monolith
Salic	
Sodic	CU021
Leptic	NI009
Petroduric/Duric	
Gypsic	
Petrocalcic	
Calcic	CU021
Hydragric/Anthraquic/Irragric	NI009
Pellic	
Chromic	ZW006
Haplic	

INVITATION: We welcome examples of fully documented Salic, Duric, Petroduric, Gypsic Petrocalcic, Chromic, Anthraquic, Hydragric, Anthraquic and Irragric Vertisols
We shall gratefully acknowledge the provider/authors (Name, title, Institution).
Please submit to: ISRIC, c/o Stephan Mantel: wrbwgsecretariat@gmail.com
and/or
KU Leuven: https://ees.kuleuven.be/en/soil-monoliths/contact

Monolith CU021 Cuba Lat/Lon 20.6667, -75.8333

Calcic Sodic Vertisol

I. Soil Profile Description / Monolith Sampling: ISRIC, Marin, R., Chang, R. and Montero, B. (1991)

I.1. Environmental information

Koppen Climate: As

Parent material: Mid-early Miocene clays, sands, marl, limestone and conglomerate

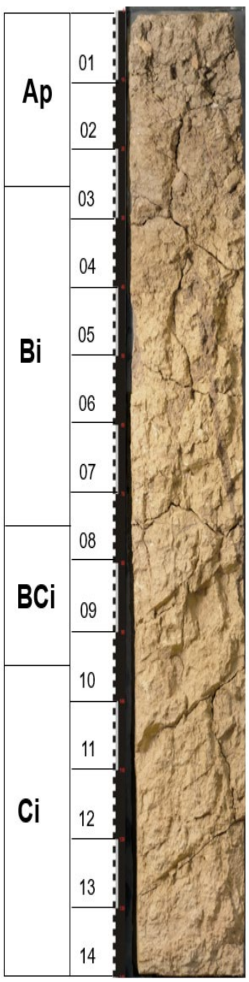
Physiography: Low hill (2% slope) (20m ask)

Hydrology: Groundwater table at 300 cm Stagnating at 120cm. Never flooded

Land use: High inputs and management of sugar cane

Surface characteristics: Cracks>1cm wide until 50cm

I.2 Soil Profile Description



Ap 0 -27cm: brown (10YR 5/3, moist), clay, moderate fine subangular blocky, slightly sticky, slightly plastic, no cutans, few fine pores and few pores slightly porous (<40 vol%),very frequent large irregular hard calcareous unspecified inclusions, no fragments, frequent channels, clear irregular boundary to,

Bi 27 – 75cm: yellowish brown (10YR 5/4, moist), clay, moderate medium angular blocky and moderate medium prismatic, sticky, plastic, common coarse distinct clear mottles (10YR 6/6), patchy distinct slickensides throughout cutans, few medium pores and few pores slightly porous (<40 vol%),very frequent large irregular hard manganiferous unspecified inclusions, very frequent large irregular hard calcareous unspecified inclusions, no fragments, frequent channels, gradual wavy boundary to,

BCi 75 – 95cm: brownish yellow (10YR 6/6, moist), clay, moderate coarse angular blocky and moderate coarse prismatic, sticky, plastic, few coarse distinct clear mottles (10YR 5/8),continuous distinct slickensides throughout cutans, common fine pores and common pores moderately porous (40-60 vol%), few medium irregular soft calcareous nodules, no fragments,continuous weakly cemented petroferric pans, gradual irregular boundary to,

Ci 95 -150cm : brownish yellow (10YR 6/8, moist), clay, structureless massive, stony, plastic, few distinct clear mottles (10YR 5/8), patchy moderately thick slickensides on pedfaces cutans, few common fine pores slightly porous (<40 vol%), frequent small irregular hard manganiferous concretions,

II. Analytical Results (ISRIC)

Horizon	Depth	pH (H2O)	OC	Exch Ca	Exch Mg	Exch K	Exch Na	Sum Cations	ESP
	cm		%	cmol(c)/kg	cmol(c)/k	cmol(c)/kg	cmol(c)/kg	cmol(c)/kg	%
Ap	0 -27	8.1	1.60	60.9	7.5	1.0	0.6	70.0	1
Bi	27 - 75	8.7	0.32	56.0	11.0	0.4	4.7	72.1	10
Bci	75 - 95	9.0	0.19	53.9	12.8	0.4	11.2	78.3	25
Ci	95 - 150	8.8	0.06	47.9	12.6	0.4	19.0	79.9	41
Horizon	**Depth**	**Clay**	**Silt**	**Sand**	**TXT Class**	**CEC**	**CECclay**	**CaCO3**	**BS**
	cm	% w/w	% w/w	% w/w		cmol(c)/kg	cmol(c)/kg	% w/w	%
Ap	0 -27	53.0	22.9	24.1	C	49.7	93	7.0	100+
Bi	27 - 75	60.3	19.3	20.4	Ch	45.3	87	15.0	100+
Bci	75 - 95	64.8	23.6	11.6	Ch	44.1	83	18.4	100+
Ci	95 - 150	67.7	30.3	2.0	Ch	45.9	78	13.0	100+
Mineralogy: : **Smectite** Very Strong									

III Soil Classification (F. Nachtergaele, S. Deckers, S. Mantel)

III.1 Horizons and major soil characteristics.

0 – 27 cm : **Ochric horizon** (10 YR 5/3 moist)

27 – 95 cm: **Vertic horizon** (Clay > 30%, shrink-swell cracks, slickensides)

27 – 95 cm **Calcic horizon** (CaCO3%>15, secondary carbonates, >15 cm thic, > 5% more CaCO3 than underlying horizon)

27 - 95 cm **Ferric horizon** ≥ 5% of its exposed area (related to the fine earth plus concretions and/or nodules of any size and any cementation class) occupied by concretions and/or nodules with a cementation class of at least weakly cemented, a reddish and/or blackish colour and a diameter of > 2 mm;

Reference Soil Group: **Vertisols** (Soils with a Vertic horizon within 100 cm, >30% clay above vertic horizont), shrink-swell cracks)

Principal Qualifiers

Sodic (ESP>15); Calcic (Calcic horizon);

Supplementary Qualifiers

Alcalic (PH>8.5); Epic (Top vertic horizon within 50 cm from the surface); Ferric (Ferric horizon);Humic (>1% OC in top 50cm); Stagnic (mottles with higher chroma)

III.2 Classification systems:

WRB 2022: Calcic Sodic Vertisol (Alcalic, Epic, Ferric, Humic, Stagnic)

Soil Taxonomy (2022): Sodic Calciusterts

FAO 1974: Chromic Vertisols, sodic phase.

References

https://rest-wsm.isric.org/monoliths/10per/png/CU-021-def.10per.png

https://isis.isric.org/monoliths/reference-soil-cu021#block-system-main

Monolith NI009 Nicaragua Lat/Lon 12.2500, -86.0333

Pellic Leptic Vertisol

I. Soil Profile Description / Monolith Sampling: ISRIC, Vogel, A.W. and Jimenez, M.

I.1. Environmental information

Koppen Climate: Aw

Parent material:Tuff alluvium

Physiography: Nicaraguan depression : flat (0% slope) plain (20m asl)

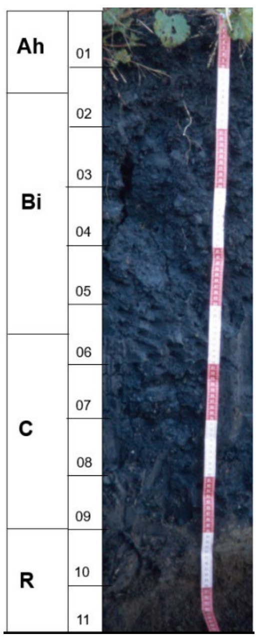
Hydrology:No groundwater table. Irregular flooding. Impermeable layer at 90cm

Surface characteristics: large cracks >1cm wide at 50cm. gilgai (20cm micro relief)

Land use: Grazed grassland.

I.2 Soil Profile Description

Moderately deep, imperfectly drained, very dark grey to black heavy clay developed from alluvium derived from tuff. The soil contains few pyroclastic fragments, is moderately to strongly structured (columnar) and moderately to slightly porous



Ah 0 -15cm: very dark grey (10YR 3/1, moist), clay, moderate to strong fine and medium granular and weak to moderate medium wedge-shaped angular blocky, slightly sticky, plastic, few medium distinct clear mottles (7.5YR 4/6), common fine oblique pores and common oblique pores moderately porous (40-60 vol%), very few fine gravel fresh pyroclastic fragments, clear wavy boundary to,

Bi 15 – 55cm: very dark grey (10YR 3/1, moist,)clay,strong medium columnar, slightly sticky, plastic, broken slickensides on pedfaces cutans, few fine oblique pores and few oblique pores slightly porous (<40 vol%), very few fine gravel fresh pyroclastic fragments, clear wavy boundary to,

C 55 – 90cm: very dark grey (10YR 3/1, moist), clay, strongly coherent, non-sticky, very plastic, few fine oblique pores and few oblique pores slightly porous (<40 vol%),clear smooth boundary to,

R 90cm + : Tuff (dark) brown (10YR 4/3, moist), silt loam,

II. Analytical Results (ISRIC)

Horizon	Depth	pH (H2O)	OC	Exch Ca	Exch Mg	Exch K	Exch Na	Sum Cations	ESP
	cm		%	cmol(c)/kg	cmol(c)/k	cmol(c)/kg	cmol(c)/kg	cmol(c)/kg	%
Ap	0 -15	6.4	1.11	48.2	34.8	0.2	0.6	83.8	1
Bi	15 - 55	6.5	0.86	43.8	29.0	0.2	0.8	73.8	1
C	55 - 90	6.5	0.90	46.5	30.6	3.8	1.2	82.1	2
Horizon	**Depth**	**Clay**	**Silt**	**Sand**	**TXT Class**	**CEC**	**CECclay**	**CaCO3**	**BS**
	cm	% w/w	% w/w	% w/w		cmol(c)/kg	cmol(c)/kg	% w/w	%
Ap	0 -15	78.9	17.3	3.8	Ch	77.2	98	ND	100+
Bi	15 - 55	81.3	15.6	3.3	Ch	74.2	91	ND	99
C	55 - 90	83.1	14.1	2.8	Ch	74.6	90	ND	100+
Mineralogy: : **Smectite** Very Strong									

III Soil Classification (F. Nachtergaele, S. Deckers, S. Mantel)

III.1 Horizons and major soil characteristics.

0 – 15 cm : **Ochric horizon**

15 – 55 cm: **Vertic horizon** (Clay > 30%, shrink-swell cracks, slickensides)

Reference Soil Group: **Vertisols** (Soils with a Vertic horizon within 100 cm, >30% clay above vertic horizont), shrink-swell cracks)

Principal Qualifiers

Pellic (having in the upper 30 cm of the mineral soil a Munsell colour value of ≤ 3 and a chroma of ≤ 2, both moist). **Leptic** (having continuous rock starting ≤ 100 cm from the soil surface)

Supplementary Qualifiers

Hypereutric (BS>100%) **; Epic** (Vertic starts within 50cm) **; Gilgaic** (gilgai microrelief 20cm); **Ochric** (OC<1% in upper 50cm)

III.2 Classification systems:

WRB 2022: Pellic Leptic Vertisol (HyperEutric, Epic, Gilgaic, Ochric)

Soil Taxonomy (2022): Leptic Haplustert

FAO 1974: Pellic Vertisol,

Local classification: San Nicolas series.

References

https://www.isric.org/sites/default/files/soilbrief_Nicaragua02.pdf

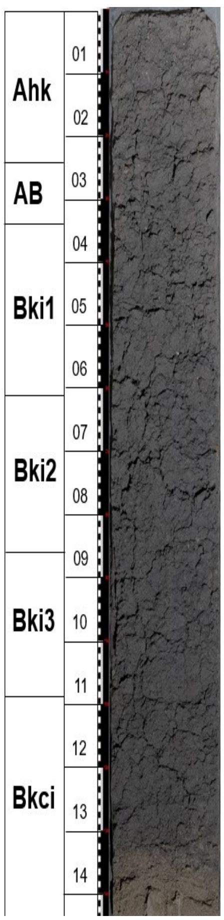
https://isis.isric.org/monoliths/reference-soil-ni009#block-system-main

https://isis.isric.org/monoliths/reference-soil-ni009#block-system-main

Monolith ZW006 Zimbabwe Lat/Lon -20.7972, 32.2375
Haplic Vertisol

Soil Profile Description / Monolith Sampling: ISRIC, Spurway, JKR (1991)

I.1. Environmental information
Koppen Climate: BSh
Parent material Fine grained basic igneous rock (Karoo basalt)
Physiography: Flat pediplain / 1% slope / 420m asl
Hydrology:No groundwater table observed .
Land use: sorghum currently under fallow
Surface characteristics: large cracks (1cm/50cm).. Gilgai with 10cm between high and low.
I.2 Soil Profile Description A moderately deep heavy clay soil with cracks 1 cm wide till 50 cm deep and gilgai.



Ahk 0 -23 cm: dark grey (10YR 4/1, moist), clay, strong fine crumb, very friable very sticky very plastic, no cutans, many fine roots, no inclusions, very few fine gravel weathered quartz fragments, non-calcareous,clear smooth boundary to,
AB 23 – 33 cm: dark grey (10YR 4/1, moist), clay, moderate very coarse angular blocky, firm, very sticky, very plastic, broken thin pressure cutans on pedfaces, many fine roots, no inclusions, very few fine gravel, weathered quartz fragments, non-calcareous, gradual smooth boundary to,
Bki1 33 – 61 cm: dark grey (10YR 4/1, moist), clay, moderate very coarse angular blocky, firm, very sticky, very plastic, broken thin pressure cutans on pedfaces, many fine roots, no inclusions, very few fine gravel weathered quartz fragments, non-calcareous, gradual smooth boundary to,
Bki2 61- 87 cm: very dark grey (5Y 3/1, moist), clay, strong coarse angular blocky, extremely firm, very sticky, very plastic, continuous thin slickensides on pedfaces, few medium roots, very few small spherical soft calcareous concretions and few medium spherical soft calcareous concretions, very few fine gravel weathered quartz fragments, slightly calcareous (0-2%),diffuse smooth boundary to,
Bki3 87 – 109 cm: very dark grey (5Y 3/1, moist), clay, moderate coarse angular blocky, extremely firm, very sticky, very plastic, broken thin slickensides on pedfaces, few fine roots, very few small spherical soft calcareous concretions and few medium spherical soft calcareous concretions, very few fine gravel weathered quartz fragments, moderately calcareous (2-10%),diffuse smooth boundary to,
Bkci 109 – 132 cm: very dark grey (5Y 3/1, moist,), clay, medium subangular blocky, firm, very sticky, very plastic, broken thin pressure cutans on pedfaces, few fine roots,few medium spherical hard calcareous concretions and few medium irregular hard calcareous concretions, very few fine gravel weathered quartz fragments and very few fine gravel strongly weathered basalt fragments, moderately calcareous (2-10%),abrupt smooth boundary to,
CBk 132 -175 cm: light yellowish brown (2.5Y 6/4, moist), very gravelly loamy sand, patchy thin pressure cutans,f requent medium irregular hard calcareous concretions and frequent powdery thread-like calcareous soft segregations, very few fine gravel weathered quartz fragments, strongly calcareous (10-25%),

II. Analytical Results (ISRIC/CSIRO)

Horizon	Depth	pH (H2O)	OC	Exch Ca	Exch Mg	Exch K	Exch Na	Sum Cations	ESP
	cm		%	cmol(c)/kg	cmol(c)/k	cmol(c)/kg	cmol(c)/kg	cmol(c)/kg	%
Ah	0 -23	8.1	1.26.	49.4	26.0	2.5	0.1	78.0	0
AB	23 - 33	7.8	1.24	47.8	30.0	1.6	0.7	80.1	1
Bki1	33 - 61	7.8	1.21	45.3	30.0	1.8	1.2	78.2	2
Bki2	61 - 87	7.9	1.17	44.8	33.8	1.9	1.8	82.3	3
Bki3	87 - 109	8.1	1.24	44.6	33.8	2.0	2.3	82.7	3
Bkci	109 - 132	8.1	1.17	44.8	34.1	2.0	3.3	84.2	4
CBk	132 - 175	8.7	0.15	66.6	32.2	1.0	4.9	105.7	6
Horizon	**Depth**	**Clay**	**Silt**	**Sand**	**TXT Class**	**CEC**	**CECclay**	**CaCO3**	**BS**
	cm	% w/w	% w/w	% w/w		cmol(c)/kg	cmol(c)/kg	% w/w	%
Ah	0 -23	72.0	14.1	13.9	Ch	82.5	115	4.4	95
AB	23 - 33	74.8	12.1	12.9	Ch	71.4	95	4.1	100+
Bki1	33 - 61	76.2	11.8	11.9	Ch	72.4	95	4.5	100+
Bki2	61 - 87	74.0	13.5	12.4	Ch	71.4	96	3.7	100+
Bki3	87 - 109	73.5	14.8	11.7	Ch	83.3	113	4.7	99
Bkci	109 - 132	79.4	12.2	8.4	Ch	79.0	99	4.5	100+
CBk	132 - 175	21.0	11.0	68.0	SCL	84.1	400	8.0	100+
Mineralogy: Smectite Very Strong									

III. Soil Classification (F. Nachtergaele, S. Deckers, S. Mantel)

III.1 Horizons and major soil characteristics

0 – 33 cm **Ochric horizon** (Color 4/1 moist).

61 – 109 cm **Vertic horizon** >30% clay, slickensides, shrink-swell cracks>1cm wide at 50cm.

Presence of **secondary carbonates** throughout not enough for a calcic horizon.

Reference Soil Group: **Vertisols** Soils with a vertic horizon within 100 cm, >30 % clay throughout, shrink-swell cracks at the soil surface.

Qualifiers:

Calcaric (>2% CaCO3 throughout); **Endic** (Slickensides at 61 cm), **Gilgaic** (10cm height difference in micro-relief); **Grumic** (fine crumb in top horizon); **Humic** (>1% OC in upper 50cm)

III.2 Classification systems:

WRB 2022 Haplic Vertisol (Calcaric, Endic, Gilgaic, Grumic, Humic)

Soil Taxonomy (2022): Chromic Haplusterts

FAO 1974 Pellic Vertisol,

Local Classification: Chisumbanje 3B.2 Series

References

https://isis.isric.org/monoliths/reference-soil-zw006#block-system-main

https://rest-wsm.isric.org/monoliths/10per/png/ZW-006-def.10per.png

ANNEX II Changing classification criteria for Vertisols

WRB Documentation Centre

Background

Classification criteria, including definitions of diagnostic horizons, properties and materials have changed over time both in the FAO Legend and WRB. Principal and supplementary qualifiers definitions and rankings also have undergone changes, new ones have been created and some deleted. One of the names of the Reference Group changed, as is the case for Podzoluvisols (FAO74, FAO88) renamed Albeluvisols (WRB1998, WRB2006) to be finally christened Retisols (WRB2014, WRB2022). Last but not least the, ranking of Reference groups in the key may change considerably as was for instance the case for Fluvisols that ranked fourth in the FAO74 key and are now in WRB2022 relegated to rank 28.

This annex has been created to document these changes and, where known, to explain why a certain change was implemented.

Changes that have affected the classification and characterization of Vertisols

Change in Name and Place of Vertisols in the key.

Vertisols have not changed names since the 7th Approximation (Soil Survey Staff, 1960). Their place in the key has always been high: they were in third place in FAO74 (after Histosols and Litosls), they dropped to fourth place when Anthrosols were introduced in the Revised Legend (FAO/UNESCO/ISRIC, 1997). They were in fifth place in the first edition of WRB when Cryosols were introducd. In WRB2006 they dropped a place when the and Technosols were introduced. In WRB2014 Solonetz were placed before Vertisols in the key, presumably because a natric horizon is a more severe constraint for land use than a vertic one. This seventh position remained unchanged in the WRB2022 version.

Changes in the criteria for the Vertic horizon (Vertic properties?)

Vertisols are probably the only Reference Soil Group that has a near identical definition of the one in Soil Taxonomy. Although the FAO74 definition differed slightly (gilgai was an optional alternative for slickensides or wedge shaped aggregates and vertic characteristics had to occur within 50, not 100 cm), there has been nearly no change in criteria to define Vertisols over the last 50 years (Table 1).

Vertisol criteria	FAO74	FAO88	WRB98	WRB2006	WRB2015	WRB2022	ST2022
Clay content >30% in/above vertic	V	V	V	V	V	V	V
Slickensides or wedge shaped aggregates	V	V	V	V	V	V	V
Cracks 1cm / 50cm	V	V	V				
Shrink-swell cracks				V	V	V	V
Vertic within 50cm	V						
Vertic within 100cm		V	V	V	V	V	V
Thickness > =25cm	implicit	implicit	V	V	V	V	V
Gilgai	V (alternative)						

Table 1 The criteria used in Vertisols for defining these soils at the highest level.

The same cannot be said of the subdivisions of Vertisols because those have been changing quite frequently over the various editions of WRB at Principal Qualifier level (Table 2)

FAO74	FAO88	WRB98	WRB2006	WRB2015	WRB2022	ST2022
		Grumic	Grumic			
		Mazic	Mazic			
			Technic			
			Leptic	Leptic	Leptic	
		Salic	Salic	Salic	Salic	Sal
			Gleyic			Aquert
			Sodic	Sodic	Sodic	
			Stagnic			Aquert
			Mollic			
	Gypsic	Gypsic	Gypsic	Gypsic	Gypsic	Gyps
		Duric	Duric	Duric/Petroduric	Duric/Petroduric	Dur
	Calcic	Calcic	Calcic	Calcic/Petrocalcic	Calcic/Petrocalcic	Calci
		Haplic	Haplic	Haplic	Haplic	Hapl
Pellic		Pellic		Pellic	Pellic	
Chromic		Chromic		Chromic	Chromic	
		Thionic				Sulf
		Natric				Natr
		Alic				
		Gypsiric				
		Mesotrophic				
		Hyposodic				
	Eutric	Eutric				
	Dystric					Dystr
				Hydrargic/Irragric	Hydrargic/Irragric	
				Anthraquic	Anthraquic	

Table 2: Soil units (FAO), Principal Qualifiers (WRB), Suborders and Great Groups (ST) in Vertisols

There has been no less than 26 different principal qualifiers proposed since WRB98. Few of these were present in all editions (with the exception of Salic, Calcic, Gypsic, Duric and Haplic). Differences with Soil Taxonomy are also striking. For instance in WRB2022 the acid Vertisols (Dystrudepts in ST, Mesotrophic in WRB98) only endodystric at supplementary qualifier level is foreseen, while they key out as a Great Group in ST. Stagnic and Gleyic Vertisols are only defined at supplementary qualifier level in WRB2022, while there is a suborder of Aquerts in ST. Pellic and Chromic referring to topsoil color values in FAO74 and the Seventh Approximation had been abandoned both by FAO as USDA in the early eighties, but were reintroduced by WRB with different definitions:

Pellic (FAO74): Vertisols having moist chromas of less than 1.5 dominant in the soil matrix throughout the upper 30 cm

Pellic (WRB2022): : Vertisols having in the upper 30 cm of the mineral soil a Munsell colour value of ≤ 3 and a chroma of ≤ 2, both moist

Chromic (FAO74): Vertisols having moist chromas of 1.5 or more dominant in the soil matrix throughout the upper 30 cm.

Chromic (WRB2022): having between 25 and 150 cm of the mineral soil surface a layer, ≥ 30 cm thick, that shows evidence of soil formation as defined in criterion 3 of the cambic horizon and that has, in ≥ 90% of its exposed area, a Munsell colour hue redder than 7.5YR and a chroma of > 4, both moist, and that does not meet the set of diagnostic criteria of the Rhodic qualifier.

Chromic (ST2022) in Vertisols stands for a subgroup with a color value moist of 4 or more or a color value dry of 6 or more. So while WRB defines chroma in hue and chroma terms, Soil Taxonomy defines it in value or chroma terms that do not correspond with the WRB ones.

The analysis of the Vertisol monoliths in the ISRIC collection showed 39 monoliths from 20 different countries that could be classified as Vertisols, in which the 5 following principal qualifiers were identified: Pellic, Sodic, Calcic, Leptic and Haplic. There was no chromic qualifier in the set, but there occurred several Vertisols in which the Rhodic qualifier applied. Typifying pedons for those that could be documented are given in the Annex.

The number occurrences of these Principal Qualifiers is given in Table 3.

It means that quite a number of PQ's have not been documented so far: Salic, Duric, Petroduric, Petrocalcic, Chromic, Anthraquic, Irragric, and Hydrargic. Those will need documentation from contributors.

The Supplementary qualifiers present in the ISRIC collection are given in Table 4. Compared with the list of supplementary qualifiers in WRB2022 there are quite a number that are not yet documented: Endodystric, Aric, Chernic, Dolomitic, Drainic, Fractic, Mazic, Pelocrustic, Gypsiric, Novic, Oxyaquic, Pyric, Raptic, Skeletic, Sulfidic, Takyric, Technic/Kalaic, Thionic, Toxic and Transportic.

Principal Qualifiers	Number in ISRIC collection
Pellic	16
Leptic	1
Sodic	10
Calcic	10
Haplic	8
(Rhodic)	3

Table 3 Name and Number of occurrences of principal qualifiers of Vertisols in the ISRIC collection

Principal Qualifiers	Number in ISRIC collection
Alcalic	7
Calcaric	15
Epic	38
HyperEutric	9
Ferric	4
Gilgaic	8
Grumic	4
Humic	12
Mollic	13
Magnesic	2
Ochric	12
Reductigleyic	5
Stagnic	10

Table 4 Name and Number of occurrences of supplementary qualifiers of Vertisols in the ISRIC collection