THE WORLD REFERENCE BASE FOR SOIL RESOURCES (WRB) AND ITS APPLICATION TO SOME SOILS OF ARGENTINA

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ABSTRACT – In response to recommendations of the 7th International Congress of Soil Science (Madison, USA, 1960), a project was undertaken by FAO and UNESCO to elaborate a world soil map at scale1:5,000,000 and the corresponding classification, which was published in ten volumes between 1971 and 1981. A new project was later conducted to improve the system, including the latest advances of soil science. This resulted in the World Reference Base for Soil Resources (WRB) which appeared in 1998. A new version was published in 2006, updated in 2007. This system was adopted by the International Union of Soil Science as the official system for soil correlation. This paper describes the structure of the system and its application to four soils of Argentina, classified as 1) *Calcic Stagnic Solonetz (Episiltic, Endoclayic)*, 2) *Luvic Stagnic Vertic Phaeozem (Abruptic, Episiltic, Endoclayic)*, 3) *Haplic Phaeozem (Tephric) over Calcic Stagnic Solonetz;* and 4) *Calcic Solonetz (Yermic)*. The correlation with the Soil Taxonomy system is included. The classification proved to be useful to reflect the main processes acting in the soils and the presence of buried soils (soil No. 3), not totally contemplated by Soil Taxonomy.
Keywords: soil classification; WRB system; buried soils; Argentina.

RESUMEN – *J.E. Giménez -La Base Referencial Mundial del Recurso Suelo (Sistema WRB) y su aplicación a algunos suelos de la Argentina*. Respondiendo a recomendaciones del 7º Congreso Internacional de la Ciencia del Suelo (Madison, EE.UU., 1960), la FAO y UNESCO emprendieron un proyecto para elaborar un mapa de suelos del mundo en escala 1:5.000.000 y la correspondiente clasificación, plasmados en diez volúmenes publicados entre 1971 y 1981. Un nuevo proyecto se emprendió luego para perfeccionar el sistema, incluyendo los últimos avances de la ciencia del suelo. Ello dio como resultado la Base Referencial Mundial del Recurso Suelo (World Reference Base for Soil Resources ,WRB) aparecido en1998. En 2006 se publicó una nueva versión actualizada en 2007. Este sistema fue adoptado por la Unión Internacional de la Ciencia del Suelo como sistema oficial de correlación de suelos. El objetivo del trabajo es describir la estructura del sistema y su aplicación a cuatro suelos de la Argentina, clasificados como: 1) *Solonetz Estágnico Cálcico (Epilímico, Endoarcíllico)*, 2) *Phaeozem Vértico Estágnico Lúvico (Abrúptico, Epilímico, Endoarcíllico)*, 3) *Phaeozem Háplico (Téfrico) sobre Solonetz Estágnico, Cálcico* y 4) *Solonetz Cálcico (Yérmico)*. Se incluyó también la correlación con el sistema Taxonomía de Suelos. La clasificación permitió reflejar los principales procesos que actúan en los suelos y la presencia de suelos enterrados (suelo No. 3) no contemplados totalmente por Taxonomía de Suelos.
Palabras clave: *clasificación de suelos; sistema WRB; suelos enterrados; Argentina.*

INTRODUCTION

The origins of the *World Reference Base for Soil Resources*, usually known as “WRB”, should be traced back to 1961, when a project to elaborate a world soil and its legend was launched. The project was undertaken jointly by two United Nations organizations: the Food and Agriculture Organization (FAO) and the Education, Science and Culture Organization (UNESCO) in response to the following recommendations of the Seventh World Congress of the International Soil Science Society (ISSS) held in Madison, USA, in 1960:

- To establish a global soil inventory;
- To provide a scientific basis for the exchange of experiences between regions with similar environmental characteristics;
- To promote the establishment of a generally accepted soil classification and nomenclature;
- To constitute a basic document for education, research and development activities; and
- To strengthen the international links between workers in soil science.

The first draft of the classification was presented at the ISSS World Congress in Adelaide (Australia) in 1968, where the legend, the definitions of the classes and the nomenclature were approved. The "Soil Map of the World" at scale 1:5,000,000 was published in 18 sheets included in 10 volumes between 1971 (South America) and 1981 (Europe).

In the early 1980's a new program, known as *International Reference Base for Soil Classification (IRB)*, renamed *World Reference Base for Soil Resources (WRB)* in 1992, was launched to deepen and giving more scientific support to the system, including the more recent advances. This program was elaborated by the FAO, the ISSS and the International Soil Reference and Information Centre (ISRIC). The first official version of WRB was released in 1998 at the World Congress of Soil Science in Montpellier (France), which approved and adopted it as the soil correlation and international communication system of the ISSS (now renamed International Union of Soil Science, IUSS). A new version was published in 2006 (IUSS Working Group WRB, 2006), which was updated and corrected in 2007 (IUSS Working Group WRB, 2007a). A Spanish translation based on the 2007 version is also available (IUSS Working Group WRB, 2007b).

Even though the official classification system in Argentina is Soil Taxonomy (ST), the importance of WRB as a world soil correlation system and its use by many countries should be emphasized. The objective of this paper is to make a review of the evolution and structure of the system, within the framework of other classification systems. Finally, some examples of WRB application to soils and paleosols of Argentina are included, presenting its advantages and limitations and the main differences with ST.

SOIL CLASSIFICATIONS

Soil classifications are usually differentiated into two classes: genetic (also called process-oriented by Bockheim and Genndiyev, 2000) and property-oriented. The first soil classifications were mainly genetic and originated in Russia between late 19th and early 20th centuries. They were based on the new concept of formation factors conceived by Dokuchaiev, who also presented a classification in 1879 before exposing his thesis on the Russian Chernozem in 1883. According to Fanning and Fanning (1989), Dokuchaiev modified his system in 1886 and 1900. These were followed in Russia by other classifications also based on genetic aspects such as Sibirtsev's (1901) and Glinka's (1921), which also circulated outside Russia. Sibirtsev's scheme was very similar to Dokuchaiev's and included at the highest level three classes still used, not as formal categories but as genetic concepts: zonal (or complete), intrazonal and azonal (or incomplete) soils.

In the United States, one of the first classifications was elaborated by Coffey in 1912, which was influenced by the Russian school. Other classifications, also based on genetic concepts, appeared later in USA, such as those of Marbut (1921, 1928) and Baldwin et al. (1938) modified by Thorp and Smith (1949). Other genetic classifications such as those of France, Australia, Canada, for example, should be mentioned

Growing difficulties were felt in USA in the1940´s to classify at higher levels the great number of series (about 5000) existing at that time. This was mainly due to the fact that the upper categories (for example, great groups) were not defined precisely. These uncertainties prompted to build a totally new system with strictly defined taxa based mainly on soil properties. The new system was refined through successive "approximations", from the First Approximation in 1951 to the *Seventh Approximation* presented in 1960 at the 7th Congress of the ISSS (Madison, USA) which had wider diffusion; later, there appeared "*Soil Taxonomy*" (Soil Survey Staff, 1975) which can be considered as the consolidated system, although new updates were subsequently published. Smith (1983), one of the main authors of the system, says that rigorous definitions could only be made from measurable or observable properties because processes are not always known and they can rarely be observed or measured; on the other hand, if a given set of processes has been dominant for a significant time, they will have left their marks in the soil in the form of distinctive horizons or features. Anyway, Smith recognizes that soil genesis is important to the classification partly because it produces the observable or measurable differences that can be used as differentiae. Genesis does not appear in the definitions of the taxa but lies behind them. In this respect, Cline and Johnson (1963) suggest that the choice of morphological characteristics to define a category was based on an understanding of how these characteristics represented specific kinds or degrees of pedogenic processes.

In Argentina, the new US system began to be used since the Seventh Approximation and it is the official classification system since 1970. However, some criticisms have raised about certain limitations of the system to reflect the particularities of the Argentine soils, especially in the Pampean Region and in the case of buried soils.

The FAO-UNESCO classification adopted some criteria of the new US classification, especially the "reference horizons", which largely reflected, with some simplifications, the "diagnostic horizons" of the Seventh Approximation. However, there are important differences between both systems: whilst the US system is a hierarchical system with successive taxonomic levels, the FAO-UNESCO system (and later WRB) only includes two levels. Besides, the WRB system does not use climate variables such as the moisture and temperature soil regimes adopted by the Seventh Approximation.

According to Bockheim and Genneyeiv (2000), the FAO-UNESCO system grouped the units at the first level according to soil-forming processes and considered it to be a mixed system based both on properties and processes. However, those authors deem that the new version (the WRB system) tends to increase the similarities with Soil Taxonomy, since more emphasis is given to properties.

STRUCTURE OF THE WRB SYSTEM

The WRB comprises only two tiers of categorical detail:

1. Tier 1, with 32 Reference Soil Groups (RSG), and
2. Tier 2, (also named qualifier level) in which the RSGs are combined with "qualifers" detailing the properties of the RSGs by adding a set of defined characteristics.

In the key of RSGs, these are allocated to the soil-forming factors or processes that most clearly condition the soil formation. The sequencing of the RSGs is done as follows:

- Organic soils: 1) Histosols.
- Soils greatly affected by human activity: 2) Anthrosols, 3) Technosols.
- Soils with severe limitations to rooting¨4) Cryosols, 5) Leptosols.
- Soils strongly influenced by water: 6) Vertisols, 7) Fluvisols, 8) Solonetz, 9) Solonchaks, 10) Gleysols.
- Soils in which iron and/or aluminium chemistry plays a major role in its formation: 11) Andosols, 12) Podzols, 13) Plinthosols, 14) Nitisols, 15) Ferralsols.
- Soils with perched water: 16) Planosols, 17) Stagnosols.
- Soils that occur mainly in steppe regions with humus-rich topsoils and high base saturation: 18) Chernozems, 19) Kastanozems, 20) Phaeozems.
- Soils from the drier regions with accumulation of gypsum: 21) Gypsisols, silica: 22) Durisols, calcium carbonate: 23) Calcisols.
- Soils with clay-rich subsoil: 24) Albeluvisols, 25) Alisols, 26) Acrisols, 27) Luvisols, 28) Lixisols.
- Relatively young soils or with little or no profile development: 29) Umbrisols, 30) Arenosols, 31) Cambisols, 32) Regosols.

At the second level, the WRB uses two kinds of qualifiers: *prefix qualifers* and *suffix qualifiers*. Prefix qualifiers are included before the name of the RSG and are differentiated as follows.

Prefix Qualifers

- *typically associated qualifers*: reflect specific characteristics of a RSG (*grumic* in Vertisols, *vitric* in Andosols, *vermic* in Phaeozems, etc.);
- *intergrade qualifers*: are those that reflect important diagnostic criteria of other RSG (*vertic, gleyic, stagnic, andic*, etc.); and
- *other qualifers*: are not typically associated to the RSG and do not link to other RSGs. They generally reflect physical and chemical properties (color, base status, etc.) not used as typically associated qualifier in a particular RSG.

Suffix Qualifiers

They correspond to additional characteristics related mainly to diagnostic horizons or chemical, 'physical, mineralogical, textural and color properties; for example: *anthric, albic, glossic, calcaric tephric, sodic, oxyaquic, skeletic, arenic, siltic, clayic, chromic.* These qualifiers are placed between brackets following the RSG name.

Each RSG has a specific list of prefix and suffix qualifiers, although many of them are common to several RSGs. In some cases, *specifiers* are used to indicate depth or expression of the qualifier, for example *epi-* (epidystric), *endo-* (endosalic), *hyper-* (hyperskeletic), *hypo-* (hypocalcic).

The presence of buried layers related with diagnostic horizons, properties or materials within 100 cm of the surface is indicated with the specifier *Thapto,* which can be used with any of the qualifers. and is added as the last suffix qualifier (for example: *Thaptomollic*)

The presence of buried soils is indicated according to the rules given in Table 1.

As indicated above, WRB does not contemplate the use of climate variables, but their influence is indirectly considered in the case of dry climates with the *aridic* diagnostic properties defined by low organic matter, evidences of eolian activity, light colors and high base saturation (>75 %) and the *yermic* surface diagnostic horizon, which should have aridic diagnostic properties and accumulation of rock fragments (desert pavement) or a vesicular layer below a platy surface layer.

TABLE 1. Rules that apply to classify buried soils.

Characteristics of the overlying new material	Classification	Examples
1) ≥50 cm thick or not classified as a Regosol	New material classified at the first level. Buried material placed after the name of the new material adding "over" in between.	Haplic Phaeozem over Gleyic Solonetz
2) ≥5 to <50 cm thick or classified as a Regosol	Buried soil classified at the first level. Overlying material indicated with the suffix qualifier "novic" (*)	Gleyic Solonetz, Haplic Regosol (Novic)
3) The overlying new material and the buried soil are classified as one soil if both qualify as Histosol, Technosol, Cryosol, Leptosol, Vertisol, Fluvisol, Gleysol, Andosol, Planosol, Stagnosol or Arenosol.		

APPLICATION OF THE WRB SYSTEM

In Argentina, the FAO-UNESCO system was used occasionally in some regional soil surveys; for example, in the Lower Basin of Bermejo River (OEA, 1977), the Pilcomayo River Basin (OEA, BID, PNUD, 1977) and Santa Cruz River Basin (Ferrer et al., 1978). More recently, correlations with Soil Taxonomy were made for soils of the Pampean Region and Catamarca province (Pazos, 1996; Pazos and Moscatelli, 1998; Roca Pascual and Pazos, 2002).

In order to make a preliminary application of the new version of WRB (IUSS Working Group WRB, 2007a) and assess its usefulness to detect local situations, four soils originally classified by Soil Taxonomy (Table 2) were used.

The two first examples (Profiles 1 and 2) correspond to present soils of a toposequence in Samborombón River basin, northern Buenos Aires province. Profile 1 is located in a depression subject to frequent ponding, and was classified by ST as *Typic Natraqualf*. According to WRB, it was classified as *Calcic Stagnic Solonetz (Episiltic, Endoclayic)*. The RSG *Solonetz* indicates the presence of a natric diagnostic horizon; the prefix qualifiers refer to the presence of reducing conditions or a stagnic color pattern (mottles) and accumulation of secondary calcium carbonate., whilst the suffix qualifers, included between brackets, indicate high content of silt (textural classes silt, silt loam, silty clay loam or silty clay) in the upper part of the profile (above 50 cm depth) and clay texture in the lower part (50-100 cm depth).

Profile 2 corresponds to a moderately well drained soil located in an interfluve, classified by ST as *Aquertic Argiudoll*. According to WRB it was classified as *Luvic Stagnic Vertic Phaeozem (Abruptic, Episiltic, Endoclayic)*. The RSG *Phaeozem* refers to the presence of the mollic diagnostic horizon and high base saturation (≥ 50 % in the upper 100 cm). The prefix qualifiers indicate the presence of an argic diagnostic horizon, reducing conditions or a stagnic color pattern and a vertic horizon, respectively. The suffix qualifier *Abruptic* indicates the presence of an abrupt textural change between the eluvial and illuvial sectors and the qualifiers *Episiltic* and *Endoclayic* indicate depth of textures, as in the previous example.

Profile 3 is an example of classification of buried soils. The soil is located in an interdune depression in the area of longitudinal dunes of the Sandy Pampa (Carlos Tejedor district, Buenos Aires province). Other examples of paleosols in this region are discussed by Imbellone (this issue).

This soil consists of two materials: a) an upper material with a slightly developed soil (A-AC-C) which includes a mollic A horizon and a thin tephra layer; and b) a buried soil which includes a natric horizon (Btnb-Btnkb) with redoximorphic features and accumulation of secondary carbonates. It was classified as *Thapto-natric Hapludoll* by ST; this subgroup is not contemplated in the system although it is commonly used in soil surveys of Argentina, as well as the subgroup *thapto-argic*. According to the rules of WRB

TABLE 2. Selected properties of the studied soils

Horizon	Depth (cm)	Structure (type)	Grain-size composition (%)			pH	CEC	Exchangeable cations (cmol kg^{-1})				Exch. Na	Org. C	$CaCO_3$
			clay	silt	sand	paste	cmol kg^{-1}	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	%	%	%
Profile 1. WRB: Calcic Stagnic Solonetz (Episiltic, Endoclayic). ST: Typic Natraqualf (Imbellone, 1980)														
A	0-17	sub. bl.	26,3	56.8	16.9	5.5	24.8	14.5	2.1	0.9	2.3	3.7	1.9	0.0
E	17-28	massive	20,6	60.7	18.7	6.0	15.9	7.4	1.8	0.6	1.6	3.8	0.7	0.0
Bt	28-42	prismatic	37.5	52.3	10.2	6.8	35.6	18.2	7.3	4.6	3.47	12.9	0.6	0.0
Btn1	42-51	prismatic	61.6	34.2	4.2	7.6	41.8	22.7	7.6	7.5	3.5	17.9	0.7	0.0
Btn2	51-71	prismatic	52.6	41.0	6.4	7.8	36.9	19.2	8.2	7.5	2.1	20.3	0.6	0.0
BCtnk	71-100	sub. bl.	43.6	42.0	14.4	7.9	33.1	-	-	9.4	2.0	28.4	0.3	3.4
BCnk	100-153	sub. bl.	33.6	50.0	16.4	7.4	28.4	-	-	5.3	2.2	18.7	0.1	3.6
Cnk	153+	massive	26.4	57.0	16.6	7.3	22.5	-	-	4.1	2.2	18.2	0.1	2.5
Profile 2. WRB: Luvic StagnicVertic Phaeozem (Abruptic, Episiltic, Endoclayic). ST: Aquertic Argiudoll (Imbellone, 1980)														
A1	0-15	granular	25.4	58.0	16.6	5.4	21.4	14.3	1.3	0.3	2.4	1.4	2.1	0.0
A2	15-25	sub. bl./gr.	26.4	56.4	17.2	5.3	19.8	11.7	1.1	0.4	1.7	2.0	2.1	0.0
E	25-45	sub. bl./m.	24.7	57.1	18.2	5.3	12.8	7.2	1.2	0.4	1.6	3.1	1.3	0.0
BA	45-52	prismatic	42.4	46.8	10.8.	5.3	17.8	9.7	3.0	0.4	2.5	2.2	1.6	0.0
Btss1	52-84	prismatic	56.4	38.0	5.8	5.3	24.6	15.8	5.8	0.5	2.4	2.0	1.1	0.0
Btss2	84-97	prismatic	44.4	44.0	11.6	5.5	21.4	12.9	6.2	0.5	2.2	2.3	1.1	0.0
BCt	97-147	sub. bl.	32.4	50.3	17.3	5.6	19.5	11.9	5.1	0.4	2.1	2.1	0.7	0.0
BC	147-196	sub. bl.	27.2	57.2	15.6	5.6	18.8	12.4	4.2	0.6	2.2	3.2	0.3	0.0
C	196+	massive	23.4	49.0	27.6	5.7	21.8	15.6	3.5	0.6	2.4	2.8	0.1	0.0
Profile 3. WRB: Haplic Phaeozem (Tephric) over Calcic Stagnic Solonetz. ST: Thapto-argic Hapludoll (Camilión and Imbellone, 1984).														
A1	0-18	sub. bl.	13.3	37.1	50.1	5.8	11.0	4.1	2.5	0.4	2.5	3.6	1.6	0.0
Tephr a	18-20	single gr.	12.4	47.4	40.2	6.2	3.1	0.8	0.7	0.1	0.5	3.2	0.8	0.0
A2	20-26	sub. bl.	15.5	33.3	47.6	6.4	12.0	4.3	2.8	1.4	2.2	11.7	1.2	0.0
AC	26-33	sub. bl.	12.1	33.7	54.0	6.7	10.5	3.4	2.9	1.6	1.9	15.2	0.8	0.0
C	33-43	massive	13.9	28.0	58.2	7.1	9.4	2.9	2.8	1.6	1.9	17.0	0.6	0.0
2Btnb	43-55	sub. bl.	23.9	29.7	46.4	7.3	15.4	4.5	5.2	3.8	2.4	24.7	0.5	0.0
2Btnkb	55-78	sub. bl.	10.4	25.6	63.9	8.1	17.3	-	-	8.0	2.9	46.2	0.2	3.4
2BCnk b	78-135	sub. bl.	7.7	25.9	65.3	7.9	18.6	-	-	3.8	1.7	20.4	0.1	2.0
2Cnk	135-194+	massive	8.2	27.4	64.5	8.0	15.8	-	-	6.3	1.5	39.9	0.1	5.2
Profile 4.WRB: Calcic Solonetz (Yermic). ST: Typic Natrargid (Bouza et al., 1992)														
Desert pavement (1 cm thick). Porphyritic subangular medium gravel.														
Av	0-2	platy	15	37	48	8.7	-	-	-	-	-	33.1	0.3	1.2
2Bt	2-12	prismatic	26	17	57	8.8	-	-	-	-	-	10.2	0.9	0.5
2Btk	12-29	prism./col.	28	14	58	8.9	-	-	-	-	-	24.1	0.4	5.4
2BCk	29-42	ang. bl.	28	15	57	8.9	-	-	-	-	-	32.3	0.4	7.1
3Ck	42-70+	massive	20	13	67	9.0	-	-	-	-	-	35.6	0.3	23.0

CEC: cation exchange capacity; sub. bl.: subangular blocky; m: massive; single gr.: single grain; gran.: granular; prism.: prismatic; col.: columnar; ang. bl.: angular blocky.

for buried soils (see item 1, Table 1) , the soil has been classified as *Haplic Phaeozem (Tephric) over Calcic Stagnic Solonetz;* the new material is classified at the first level (Phaeozem) because it fits the requirements of a RSG different from Regosol and the buried soil (Calcic Stagnic Solonetz) is placed following the overlying soil.

In the case of non-buried paleosols (relict and exhumed soils) no particular specifications are given in WRB and the soils are classified as present soils. The same criterion is followed by ST in the case of *Argids* and some Oxisols (*Torrox*). With respect to Argids, ST says: "the presence of an argillic horizon commonly is attributed to a moister paleoclimate, although there is evidence that clay illuviation occurred during the Holocene in arid soils" (Soil Survey Staff, 1999). With respect to Oxisols, ST says that the wide range of climates under which these soils occur "indicates that changes have taken place since these soils formed or that highly weathered parent material has been transported to areas with a dry climate" (Soil Survey Staff, 1999). Profile 4 is an example of a soil from an arid region with argillic horizon. It is located at Bajo del Gualicho of Patagonia (northeastern Chubut province) and has been classified as *Typic Natrargid* by ST. According to WRB this soil has been classified as *Calcic Solonetz (Yermic)* because it has natric and calcic diagnostic horizons. The arid climate is indicated by the suffix qualifier yermic*,* which refers to the presence of the previously described yermic diagnostic horizon.

CONCLUSIONS

The WRB system has permitted to classify the present soils with acceptable precision because the main properties derived from different pedogenic processes have been indicated. The system has enough sensitivity to reflect in the examples properties such as presence of volcanic ash, textural differences in the upper and lower parts of the profiles, accumulation of secondary carbonates, etc. In the case of paleosols, WRB has sufficient flexibility to identify buried soils, unlike ST, which only recognizes the histic buried horizon (thapto-histic subgroup). The inclusion of different qualifiers at the second level may produce lengthy names in WRB, which contrasts with the more concise denominations of ST.

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