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Challenges of Soil Taxonomy and WRB in classifying soils: some examples from Iranian soils

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Abstract. The two most widely used soil classifications are the Soil Taxonomy (ST) and the World Reference Base for Soil Resources (WRB). The purpose of this paper is to clarify the differences and the similarities between ST and WRB in their current state, with some examples for representative soils in arid and semi-arid regions of Iran. Four representative pedons were classified and soil units from WRB were compared to those obtained by using ST at the family level. WRB could show the status of soils polluted by heavy metals through the Toxic qualifier and its subqualifiers. On the other hand, ST could indicate the status of shallow soils in our studied soils but it was not able to show gleyic conditions and the existence of a salic horizon because of the differences in its criteria compared to those of WRB. Special effort should be made to quantify various anthropogenic activities in upcoming editions of both classification systems.

Key words:
Arid and semi-arid regions,
poorly drained soils,
polluted soils,
Soil Taxonomy,
WRB

Introduction

Soil classification systems generally aim to establish a taxonomy based on breaking the soil continuum into more or less homogeneous groups (Guo et al. 2003). Furthermore, most modern soil classification systems are developed to complement and support soil survey activities (Ahrens et al. 2003). Classification systems are conceptual frameworks that enable the assimilation of information and the delivery of information to a user (Blum and Laker 2003). Since the earliest days of soil science, attempts have been made to develop a universal soil classification system. Most early soil classification systems were based on the recognition of soil-forming processes, whereas modern systems classify soils based on quantitative characteristics defined as diagnostic horizons, properties, and materials. This allows pedologists with different experiences to classify soils in much the same way.

The two most widely used modern soil classification schemes are American Soil Taxonomy, or ST (Soil Survey Staff 2014) and the World Reference Base for Soil Resources, or WRB (IUSS Working Group WRB 2015). After years of intensive worldwide testing and data collection, new versions of the ST and WRB systems have been released. In its current state, ST has a strong hierarchy with six categorical levels, i.e., order, suborder, great group, subgroup, family, and series (Soil Survey Staff 2014), whereas the WRB has a flat hierarchy with only two categorical levels, i.e., reference soil groups and soil units (IUSS Working Group WRB 2015). Rossiter (2001) stated that the reference soil group level of WRB is an intermediate in the conceptual level between ST orders and suborders, while the second-level subdivisions, i.e., soil units, which are defined by combinations of qualifiers, are similar to ST great groups (one qualifier) or subgroups (multiple qualifiers).

Some scientists have tried to compare the advantages and disadvantages of these soil classification systems and give comments for their improvement (e.g., Deckers et al. 2003; Esfandiarpor et al. 2013). Toomanian et al. (2003) focused on gypsiferous soils in Central Iran and argued that the WRB seems to be the most appropriate system for the classification of these soils. Dazzi et al. (2009) proposed a new diagnostic horizon for Anthrosols in WRB as a "*geomiscic*" horizon which can be succinctly defined as a horizon that develops when a layer of at least 30 cm thick and of different kinds of earthy materials is added to the soil using earthmoving equipment. Charzyński et al. (2013) proposed that new qualifiers of Edific, Nekric, Misceric, Artefactic, Radioactivic and new specifier of Technic be added to Technosols in WRB. They also recommended that Salic and Sodic qualifiers should be available for Technosols. Hulisz et al. (2010) suggested that two new qualifiers (Anthrosalic and Anthrosodic) be used with the Technosols Reference Soil Group of WRB. Charzyński et al. (2018) studied the soils of gardens in Toruń and stated that none of the studied mineral surface horizons meets the criteria for hortic horizon according to WRB 2015, due to the phosphorus content being too low. They suggested that the research on classification issues of garden soils should be continued on a larger scale to evaluate whether WRB criteria are not too strict in taking into account only the features of the most typical, few-decades-old garden soils.

Esfandiarpour-Borugeni et al. (2018) mentioned that the presence of lithologic discontinuity in taxon name was totally neglected by the ST system but the WRB system showed this property with the Raptic qualifier. They recommended the "Raptic" subgroup for all taxa in the ST system.

Láng et al. (2016) and Michéli et al. (2016) tested the distance calculation for comparing the great group of the ST and concluded that it was useful in determining differences between soil taxa and improving classification definitions. Hughes et al. (2017) compared the USDA Soil Taxonomy and the Australian Soil Classification System using their taxa centroids calculated via principal component analysis and concluded that this method opened the way for the possibility of comparing differing taxonomies and could open the way for a more comprehensive classification method.

In recent decades, the role of humans in soil formation has become a matter of great concern among soil scientists. Human influence is now considered as a soil-forming factor, and anthropogenisation is recognised as a soil-forming process that consists of a collection of geomorphic and pedological processes resulting from human activities. Industrial developments, mines and their activities and intensive agriculture have all led to soil changes in urban areas. The importance of human impact on soil properties is considered in soil classification systems and both soil classifications have experienced important enhancements which allow urban and industrial soils to be described and mapped. For instance, the new reference soil group of Technosols was introduced from the 2006 edition of the WRB onwards (IUSS Working Group WRB 2007). Ahrens and Engel (1999) reported that although a few categories in the ST distinguish anthropogenic soils, two soil reference groups, i.e., Anthrosols and Technosols, were distinguished in the WRB system at a higher level and it is also possible to account for different anthropogenic elements in other reference groups. On the other hand, from the 2010 edition onwards, the Soil Taxonomy tried to consider human effects in different ways, mainly by definition of a Master horizon, M, the horizon suffix, u, and recently (Soil Survey Staff 2014) by introducing "Human-altered and human-transported material classes" at family level.

Most soils around cities are intensively used and heavily influenced by humans. Processes in these soils often differ greatly from those in rural soils, with features such as contaminant loads, parent materials and chemical composition (Rossiter 2007). Soil classification should provide a method for planning agricultural output, allowing the application of new management techniques and supporting the use of environmentally sound land-use practices (Shi et al. 2010). The concept of soil security serves to make explicit the connections between soil and other global existential challenges. Therefore, a better understanding of the connections between the earth and its inhabitants is needed. Indeed, it is necessary to consider geologic, geographic, and climatic contributions to public health (Catherine and Skinner

2007). Therefore, soil classification systems should also explain the soil's pollutants and also their effects on human health. However, one of the important missions of soil classifications is still to identify important properties which have an effect on management purposes and health issues. The purpose of this study was to compare the efficiency of current editions of the American Soil Taxonomy and WRB soil classification systems in describing the management properties of some representative soils in arid and semi-arid regions of Iran.

Materials and Methods

Iran is located in the southwest of Asia, between 44° 02´ and 63° 20´ eastern longitudes and 25° 03´ and 39° 46´ northern latitudes (Fig. 1). About 85% of Iran's territory is located in the arid and semi-arid belt of the world (NCCO 2003). Some representative soils with different pedogenic processes from arid and semi-arid areas of Iran were selected: suburbs of Isfahan in Isfahan province in the centre of the country and suburbs of Shahrekord in Chaharmahal-Va-Bakhtiari province in the southwest, respectively (Fig. 1). Environmental characteristics of these areas are shown in Table 1.

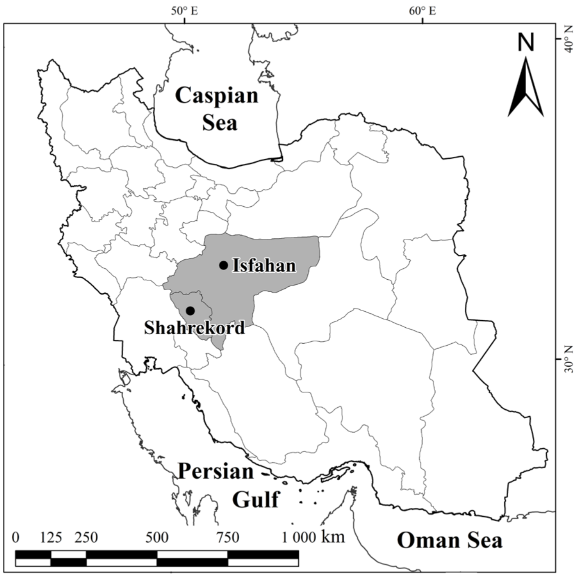

Fig. 1. Location of Isfahan and Chaharmahal-Va-Bakhtiari provinces in Iran.

The representative pedons were selected and described according to the "Field Book for Describing and Sampling Soils" (Schoeneberger et al. 2002). Then, soil samples from different genetic horizons of all pedons were taken, and were analyzed to determine: particle size distribution by hydrometer method); calcium carbonate equivalent (CCE) by HCl treatment or titrimetric method; cation exchange capacity (CEC) by NH4Ac method (at pH 7.0); organic matter (OM) by Walkley–Black method; gypsum percentage by acetone method; and percentage of rock fragments (RF) (by volume). Saturated paste extracts were prepared to evaluate soil salinity. Reaction (pHe), electrical conductivity (ECe) and ion content (Na^+, Ca^{2+} and Mg^{2+}) were determined (van Reeuwijk 2006). Based on the obtained results, the sodium adsorption ratio (SAR) was calculated. After that, soils were classified according to the ST (Soil Survey Staff 2014) and WRB (IUSS Working Group WRB, 2015) soil classification systems. Finally, the soil units according to WRB were compared with those obtained by applying ST at the family level.

Results from agricultural lands from different parts of Lenjanat region from the Isfahan suburbs have been considered. Lenjanat is an industrial region in which intensive agriculture is surrounded by different industries, such as steel- and cement-making factories and lead mining. The total amount of heavy metals (Cd and Pb) was determined in topsoil samples (0–20 cm depth), agricultural crops including turnip, onion, beetroot, cabbage and lettuce, and also muscles of sheep and cow grazed and/or nourished in the region (Mohajer et al. 2012).

Table 1. Environmental characteristics of two study sites

Site study	MAP[a] (mm)	MAT[b] (°C)	Altitude (m)	SMR[c]	STR[d]
Site 1: Shahrekord	321.5	11.8	2200	Xeric	Mesic
Site 2: Isfahan	100.0	15.7	1600	Aridic	Thermic

[a] Mean annual precipitation, [b] Mean annual temperature, [c] Soil moisture regime (Soil Survey Staff 2014), [d] Soil temperature regime (Soil Survey Staff 2014)

Results and Discussion

Tables 2 and 3 show a summary of the morphological and physicochemical properties of the representative pedons for the study sites.

Pedon 1 at site 1 has a *saprolite* horizon which begins at 27 cm from the soil surface. This layer is considered as a root-limiting layer. Although both soil classification systems imply an undeveloped soil (Entisols in ST and Regosols in WRB), the presence of a root-limiting layer (saprolite) within 50 cm of the soil surface could be mentioned as "shallow" at the family level of ST as the soil depth class (Table 4). Although in the WRB soil classification system, Leptosols as a reference soil group and Leptic as a qualifier level are defined for soils with a continuous rock, WRB was not able to describe this feature. To solve the problem, it is suggested that the definition of Paralithic as a prefix and its subqualifiers, as below, be added to the diagnostic properties of WRB and to the list of qualifiers of Regosols:

- Paralithic: soils having paralithic contact starting within 100 cm of the soil surface,
- Endoparalithic: having paralithic contact starting between 50 and 100 cm of the soil surface,
- Epiparalithic: having paralithic contact starting within 50 cm of the soil surface.

There is a *gypsic* horizon with a considerable amount of gypsum in pedon 1 of site 2 within 100–150 cm of the soil surface (Tables 2 and 3) below the *calcic* horizons, but neither of the soil classification systems could show the presence of this horizon, even at lower levels (Table 4). This is a serious fault, especially if the soils are to be used for cultivation of long-rooted plants or for gardening activities. Therefore, Gypsicalcids as a great group should be defined for these soils (Calcids suborder) as: calcids with a *gypsic* horizon within 150 cm of the soil surface. An arbitrary qualifier like "Bathygypsic" should be defined for Calcisols in WRB having a *gypsic* horizon between 100 and 150 cm of the soil surface. Although the "gypseous" substitutes for particle size class are introduced for mineral soils (e.g., Aridisols) that have a high content of gypsum in the new edition of ST (2014), they cannot be used for pedon 1 of site 2 because the control section for particle-size classes and their substitutes are defined as between 25 and 100 cm below the mineral soil surface.

Pedon 2 at site 2 showed gleyic properties as a result of poor drainage (low water table) in different horizons. This soil has several cambic horizons below an *ochric* horizon (Tables 2 and 3). According to WRB (2015), this soil is classified as Gleysol whereas it is categorised into the Inceptisols order in ST (Table 4). Despite this soil being located in an arid region, the Aridisols order cannot be chosen because of the priority of the soil orders in ST. To make better sense, it is suggested that the "Aquids" suborder be defined for Aridisols in the American Soil Taxonomy for these soils.

Also, based on the Swiss Federal Office of Environmental, Forest and Landscape (FOEFL 2008), the amount of cadmium in these soils (Lenjanat region) was higher than the threshold limit (Table 5). Mohajer et al. (2012) indicated that all the crops in this region had a lead average higher than the maximum tolerance (FAO/WHO 2001) (Table 6). Additionally, the average of lead in cow and sheep livestock was also reported above Iran's and the European Union's permissible limit (0.1) (FAO/WHO 2011) (Table 6). Despite the last version of ST (2014) considering human-altered and human-transported material as a class at family level, it could not show the contamination of soils by heavy metals. However, the WRB soil classification system defined the qualifier Toxic (Zootoxic subqualifier in the case of our soils), which can be used in these conditions. The Toxic qualifier and its subqualifiers had been restricted to the Histosols, Technosols, and Gleysols in the previous version of WRB. However, after 2014, this qualifier can be used for all reference soil groups but, as mentioned already decade ago by Rossiter (2007), this phrase needs to be quantified. As mentioned by Mermut and Eswaran (2001), there are developments for the *in-situ* measurement of some soil properties and such instrumentation is essential for monitoring of critical parameters. Hartemink and Minasny (2014) argued that there has been progress in distinguishing soil horizons, texture and colour, mainly using vis–NIR, GPR, XRF and electrical resistivity. They believe that there is potential for *in-situ* digital morphometrics for all attributes of a soil profile and the combined use of in-situ digital morphometrics and continuous depth functions of soil properties may yield new insights in soil hori-

Table 2. Characteristics of morphological properties of the representative pedons in the different study sites[a]

Pedogenic processes	Cutans and/or concentration Redox-imorphic features	Effervescence	Structure	Consistency		Color	Depth (cm)	Horizon	Pedon No.	Site study
				Moist	Dry	Moist				
Calcification	-	2I	1fgr	lo	so	10YR 6/4	0–15	A	1	Site 1
	c, 1, CAC, MAT	3I	2cabk	fr	sh	7.5YR 4/4	15–27	Bkk		
	-	3I	m	-	-	-	27–110	Cr		
	-	3I	m	-	-	-	110+	R		
Calcification and Gypsification	-	2I	1vfgr	-	so	7.5YR 5/4	0–25	Ap	1	Site 2
	f,1, CAM, TOT	2I	1fabk	-	sh	7.5YR 5/6	25–55	Bk1		
	c,1, CAM, MAT	2I	1fabk	-	sh	7.5YR 6/4	55–75	Bk2		
	c, 2, CAM, MAT	3I	1fabk	-	h	7.5YR 7/4	75–95	Bk3		
	c, 3, CAC, MAT	3I	1fabk	-	h	7.5YR 7/4	95–110	Bk4		
	"c, 3, CAC, MAT" and "m, 2, GYX, MAT"	3I	1fabk	-	h	7.5YR 7/4	110–150	Bky		
Gleyzation	-	1I	2fgr	fr	sh	10YR 4/2	0–30	Ap	2	
	c,1,P ,FMM	1I	2cabk	fr	-	10YR 4/2	30–60	Bg1		
	m,1,P, FMM	2I	m	fi	-	10YR 4/2	60–100	Bg2		
	f,1,F ,FMM	2I	m	fi	-	10YR 5/2	100–140	Bg3		
Calcification Gypsification Gleyzation Lessivage Salinisation Alkalisation	-	2I	1fgr	fi	sh	10YR 5/4	0–18	Ap	3	
	c, 2, GYX, MAT	1I	2mpr	fr	-	10Y 5/1	18–60	Byg		
	"f, 3, CAC/CAN, MAT" and "m, 2, GYX, MAT"	3I	3mpr	vfr	-	5GY 2.5/1	60–130	Bkyg		
	f, D, CLF on PF	2I	3mabk	1o	-	10B 2.5/1	130–157	2Btg		

[a] Symbols are used based on Schoeneberger et al. (2002)

Table 3. Summary of physical and chemical properties of the representative pedons in the different study sites.

CEC[c] (meq/100gr soil)	SAR $(meql^{-1})^{0.5}$	EC_e (dSm^{-1})	pH	Soil Texture	%							Depth (cm)	Horizon	Pedon	Site
					OM	Gypsum	CCE[b]	RF[a] (2–75 mm)	Clay	Silt	Sand				
-	1.2	0.6	7.8	SiC	1.2	0	68	6	54	41	5	0–15	A	1	Site 1
-	1.0	0.4	7.9	SiCL	0.5	0	75	10	32	58	10	15–27	Bkk		
-	-	-	-	-	-	-	70	-	-	-	-	27–110	Cr		
-	-	-	-	-	-	-	82	-	-	-	-	110+	R		
-	2.6	1.0	7.4	SL	0.9	1	25	5	16	18	66	0–25	Ap	1	Site 2
10.7	1.9	0.7	7.5	SCL	0.8	2	33	12	20	16	64	25–55	Bk1		
9.3	1.8	0.9	7.8	SCL	0.6	2	35	14	21	12	67	55–75	Bk2		
12.3	2.0	0.8	7.9	SCL	0.5	5	37	10	24	14	62	75–95	Bk3		
13.9	2.6	0.8	8.0	SCL	0.5	8	38	16	28	15	57	95–110	Bk4		
-	3.3	1.9	8.2	SCL	0.3	27	43	8	28	26	46	110–150	Bky		
-	2.1	1.2	7.8	CL	1.3	5	44	32	34	35	31	0–30	Ap	2	
-	1.8	0.5	7.5	CL	1.0	3	43	40	35	34	31	30–60	Bg1		
-	2.3	0.3	7.5	CL	0.9	0	39	53	34	36	30	60–100	Bg2		
-	2.7	0.2	7.4	C	0.6	0	42	25	43	37	20	100–140	Bg3		
-	149	17.1	7.1	L	1.8	26	10	14	21	39	40	0–18	Ap	3	
-	130	26.3	7.3	L	0.6	44	7	12	24	47	29	18–60	Byg		
-	120	19.6	7.4	CL	0.9	38	18	13	29	45	26	60–130	Bkyg		
-	140	16.8	8.1	C	0.8	35	14	9	43	30	27	130–157	2Btg		

[a] Rock Fragments, [b] Carbonate Calcium Equivalent, [c] Determination of CEC was necessary to determine CEA class of control section for some pedons at family level.

Table 4. Classification of the selected representative pedons based on ST and WRB systems in two study sites.

Classification system		
WRB (2015)	**ST (2014)**	**Study Site and Pedon No.**
Calcaric Regosol	Loamy, Carbonatic, Mesic, Shallow Typic Xerorthent	Site 1, pedon 1
Haplic Calcisol (Chromic)	Fine-silty, Mixed, Active, Thermic Typic Haplocalcid	Site 2, pedon 1
Calcaric Gleysol (Loamic, Zootoxic)	Fine-loamy, Carbonatic, Thermic Typic Epiaquept	Site 2, pedon 2
Calcic Gypsic Gleysol (Salic, Sodic)	Fine-gypseous, Hypergypsic, Thermic Typic Calcigypsid	Site 2, pedon 3

Table 5. Mean of lead and cadmium (mg kg^{-1}) in soil surface samples of Lenjanat region (Mohajer et al. 2012) compared to standard limits.

Element	Mean	Min	Max	Standard limit (FOEFL 2008)
Cd	1.1	0.2	6.3	0.8
Pb	16.9	1.6	168	50

Table 6. Mean of lead and cadmium concentration in different crops (mg kg dry $weight^{-1}$) and livestock organs (mg kg wet $weight^{-1}$) of Lenjanat region (Mohajer et al. 2012).

Element	Muscle of cow	Muscle of sheep	Lettuce	Cabbage	Beetroot	Onion	Turnip
Pb	0.02	4.1	5.8	3.4	5.4	2.7	2.9
Cd	0.02	4.8	0.2	0.2	0.2	0.1	0.1

zonation, how soils form and how they could be classified.

Pedon 3 at site 2 has an *ochric* horizon at the surface which overlies *salic, calcic, gypsic* horizon and *argillic (argic)* horizons with a lithologic discontinuity. It was classified as Typic Calcigypsid in ST and as Gleysol in WRB (Table 4). Therefore, ST is not able to show the existence of the water-table level or the *gleyic* conditions of this soil. Another deficiency of ST is its neglect of the *salic* horizon and also the alkalinity problem. The *salic* horizon should be revised to harmonise ST and WRB. In this case, new great groups such as Natrisalids, Gypsisalids should be added in ST. Neither of the soil classification systems could show the presence of argillic (argic in WRB) at depths lower than 100 cm, i.e., 2Btg. Although lithologic discontinuity could be shown by the horizon designations, neither of the soil classification systems could indicate this property. Therefore, it is recommended to revise the Ruptic qualifier in WRB and to consider this feature at the family level of ST.

Conclusions

Results obtained for the studied soils from Iran indicated that WRB soil classification system could better explain the situation of the soils for management practices addressing issues such as soil pollution, salinity and sodicity. To make it more successful, it is suggested that the surveyor be free to select the appropriate qualifier from the list presented by WRB without limitation. On the other hand, ST could indicate the presence of a root-limiting layer in our soils. Defining new suborders and great groups in Aridisols is highly recommended. The revision of some diagnostic horizons and properties is also necessary to harmonise ST and WRB. Special attention should also be paid to quantify various anthropogenic activities in upcoming editions of both classification systems. It is expected that new tools like proximal sensing could help soil classification through *in-situ* digital morphometrics for all attributes in the near future.

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