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Comparing soil taxonomy and WRB systems to classify soils with clay-enriched horizons (A case study: arid and semi-arid regions of Iran)

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Abstract

Comparing the ability of ST and WRB systems to describe soils with clay-enriched horizons was the aim of the present research. In arid and semi-arid regions of Iran, two study sites were considered. Three pedons at each study site were selected, described and sampled. Soils were classified based on ST (2014) and WRB (2015) systems. The micro-morphological investigations were done to confirm the illuvial clay accumulation in Bt horizons. Results showed that the required characteristics of an argillic horizon were not met in any of the Bt horizons. The poor correlation between ST and WRB systems was related to the different definition and criteria of clay-enriched horizons in the systems. Using “Differentic” and “Cutanic” qualifiers, the WRB system could describe properties of an argic horizon more efficiently than the ST system. Although the evidence of clay illuviation was observed as lamellae in some argillic horizons in the arid study site, the ST system could not display this characteristic. The WRB system indicates the presence of lamellae using a “Lamellic” qualifier in some cases. These issues are disadvantages for both classification systems in describing the soils with clay-enriched horizons. Defining Natrisalids great group and new subgroups including Calcic Natrisalids, Lamellic Argigypsids and Lamellic Calciargids seems necessary to improve deficiencies of both classification systems. Adding the “Lamellic” qualifier for Calcisols in the WRB system is highly suggested.

Keywords: Clay coating; Illuviation; Lamellae; Luvisols; Soil classification

1. Introduction

Soil Taxonomy (ST; Soil Taxonomy, 2014) and the World Reference Base for Soil Resources (WRB; IUSS Working Group WRB, 2015) were extensively used for soil classification, soil data correlation and scientific publications through the world (Gerasimova, 2010; Huyssteen *et al*., 2014; Brevik *et al*., 2016). Although definitions and nomenclature of the diagnostic horizons in the WRB system are adopted from the ST (Soil Survey Staff, 1975) (FAO, 1988), there are many differences between the criteria of some diagnostic horizons (e.g., argillic or argic, salic and calcic). Brevik *et al*. (2016) noted that the extensive use of only one of the systems is difficult as some objections have not yet been resolved. Several pieces of research (Toomanian *et al*., 2003; Sarshogh, 2010; Esfandiarpour Boroujeni *et al*., 2013; Sarmast *et al*., 2016; Esfandiarpour Boroujeni *et al*., 2018) declared the low compatibility between both soil classification systems.

Illuviation is one of the earliest recognized soil-forming processes and is involved in the genesis of many soil types under different climates (Bockheim *et al*., 2005; Sauzet *et al*., 2016). Soils may become enriched in clay under the influence of different processes such as downward leaching of clay particles in water suspension, in situ formation of new clay

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minerals, destruction of the sand and silt fractions, and the preferential erosion of fine particles from the upper soil horizons downward the illuvial horizon (Quenard *et al*., 2011).

Argillic (or argic in the WRB system), kandic and natric are diagnostic subsurface horizons reflecting the clay enrichment in both ST and WRB systems. In the ST system, the clay-enriched horizons are considered at order (i.e., Alfisols and Ultisols), suborder (i.e., suborders of Aridisols and Mollisols), great group (i.e., great groups of Aridisols, Gelisols, Oxisols, Mollisols, Spodosols, and Vertisols) and subgroup (i.e., subgroups of Andisols, Aridisols, Inceptisols, Mollisols, Oxisols, and Spodosols) levels. Prefixes such as “Alfic”, “Argic”, “Lamellic”, “Natric” and “Ultic” are used at the subgroup level to indicate the presence of clay-enriched horizons. Additionally, RSGs such as Retisols, Acrisols, Lixisols, Alisols and Luvisols and principal qualifiers including Acric, Lixic, Alic and Luvic, indicate the presence of clay-enriched horizons within 100 cm of the soil surface in the WRB system. Bockheim and Hartemink (2013) declared that nearly all classification systems recognize clay-enriched subsoils at a high hierarchical level.

Argillic horizons are distributed in humid through arid regions of the world (Elliott and Drohan, 2009). Although about 85 % of the Iranian's territory is located in the arid and semi-arid belt of the world (NCCO, 2003), but many researchers reported the presence of clay-enriched horizons under different environmental conditions of Iran (Khademi and Mermut, 2003; Khormali *et al*., 2003; Sarmast *et al*., 2016; Bayat *et al*., 2017; Esfandiarpour Boroujeni *et al*., 2018). The presence of clay-enriched horizons in arid and semi-arid regions of Iran is related to more the humid climate of the past (Khormali *et al*., 2003; Bayat *et al*., 2017; Sarmast *et al*., 2017). Argillic and related horizons that increase nutrient status and enhance water retention and many productive soils for food production have clay-enriched horizons (Bockheim and Hartemink, 2013). Thus, identifying and reporting the presence of clay-enriched horizons is important for proper management practices. The objective of this study is to investigate the ability of ST and WRB systems to describe soils with clay-enriched horizons in arid and semi-arid regions of Iran.

2. Materials and Methods

2.1. Study sites

The study was conducted in Chaharmahal-va-Bakhtiari (site 1) and Kerman (site 2) Provinces located in semi-arid and arid regions of Iran (Fig. 1), respectively. The coordinate of pedons, mean annual precipitation and temperature, soil moisture and temperature regime of the study sites are shown in Table 1.

2.2. Field and laboratory works

Based on the previous studies and field checks, three pedons were selected at each study site. Soil description was done based on the guidelines for soil describing and sampling (Schoeneberger *et al*., 2012). The air-dried samples were carefully crushed (by hand, to avoid destruction of the weathered rock fragments, if present) and sieved to less than 2 mm. Then, the volume percent of rock fragments was determined. The particle-size analysis was done by hydrometer method (Gee and Bauder, 1986). Calcium carbonate equivalent was determined by treating the sample with 3N HCl (Nelson, 1982). The gypsum percentage was quantified by precipitation in acetone (US Salinity Laboratory Staff, 1954). The content of organic carbon was determined by wet digestion (Walkley and Black, 1934). Cation exchange capacity with ammonium acetate (Sumner and Miller, 1996) and sodium adsorption ratio (Lanyon and Heald, 1982) were measured. The pH in saturated paste and electrical conductivity in saturated extract were performed in the fine earth fraction (<2 mm diameter).

Undisturbed soil samples were collected from Bt horizons for micro-morphological investigations. Soil clods were air dried and impregnated under vacuum with a polyester resin. After polymerization, the blocks of hardened soils were mounted on 75 ×100 mm microscope slides, cut to about 500 μm thickness and polished to about 20 to 30 μm thickness (Lee and Kemp, 1992). Thin sections were studied under Plane Polarized Light (PPL) and Cross-Polarized Light (XPL) using an HP petrographic microscope and described according to Stoops (2003) guideline. Then, classification of soils was done based on the ST (Soil Taxonomy, 2014) and WRB (IUSS Working Group WRB, 2015) systems.

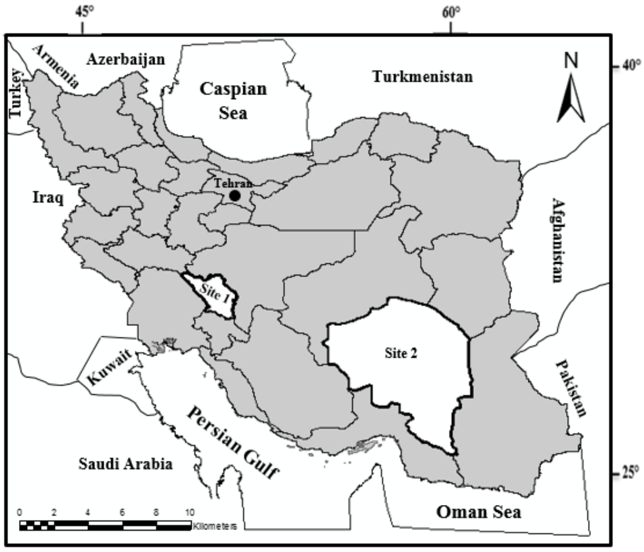

Fig. 1. Location of Chaharmahal-va-Bakhtiari and Kerman Provinces in Iran

Table 1. Environmental characteristics of different study sites.

Study site	Province	Pedon no.	Coordinate (UTM[a]) X	Coordinate (UTM[a]) y	MAP[b] (mm)	MAT[c] (°C)	SMR[d]	STR[e]	Land use
Site 1	Chaharmahal-va-Bakhtiari	1	484755	3575633	320	12.5	Xeric	Mesic	Range land
		2	526156	3537936	255	10.7	Xeric	Mesic	Agriculture
		3	483833	3568388	320	12.5	Xeric	Mesic	Agriculture
Site 2	Kerman	1	751354	3671593	80.3	18.4	Aridic	Thermic	Range land
		2	337757	3416087	80.3	18.4	Aridic	Thermic	Agriculture
		3	569594	3182670	170	25.8	Aridic	Hyperthermic	Range land

[a] Universal Transverse Mercator
[b] Mean Annual Precipitation
[c] Mean Annual Temperature
[d] Soil Moisture Regime (based on Soil Taxonomy, 2014)
[e] Soil Temperature Regime (based on Soil Taxonomy, 2014)

3. Results and Discussion

The evidence of clay illuviation was observed at all studied pedons except pedon 3 (site 1) during field studies (Table 2). Moreover, clay illuviation was detected as lamellae in pedons 2 and 3 at site 2 (Table 2). The illuvial nature of Bt horizons for all mentioned soils was confirmed by micro-morphological investigations (Fig. 2). The images of thin sections revealed the presence of clay coating, limpid clay coating and lamellae features (Fig. 2). Recognition of clay coating is a very important criterion to define an argillic horizon in several soil classification systems such as Soil Taxonomy (Stoops, 2003). Sauzet *et al.* (2016) reported micro-morphology as a powerful technique to quantify illuviation process in soils. Physical and chemical properties of the studied pedons are shown in Table 3.

Although the evidence of clay illuviation was observed in Bt horizon of pedon 1 (site 1) during the field study and micro-morphological investigations confirmed clay illuviation, but this horizon was not considered as an argillic horizon and the soil was classified as "Typic Calcixerept" based on the ST system (Table 4). The "t" suffix symbol is defined as "an accumulation of silicate clay as coating on surface of peds or in pores as lamellae or as bridge between mineral grains" (Soil Taxonomy, 2014, page 339). On the other hand, in the ST system, an argillic horizon is a subsurface horizon that shows evidence of clay illuviation, its minimum thickness ranges between 7.5 to 15 cm (depending on the particle-size class or presence of lamellae) and has more clay content than the eluvial horizon within a vertical distance less than 30 cm (Soil Taxonomy, 2014, page 12). Besides, the clay-sized carbonates should also be excluded (Soil Survey Staff, 1999, page 31). Therefore, the required characteristics of an argillic horizon could not be met in some Bt horizons. The use of a suffix symbol is not restricted to those horizons that only meet certain criteria for diagnostic horizons (Soil Taxonomy, 2014, page 337). Bockheim and Hartemink (2013) explained that many Bt horizons may not be qualified as an argillic or related horizon.

Evidence of clay illuviation and thickness requirement (at least 7.5 cm) were found in pedon 1 at site 1, but the illuvial horizon (i.e., Bt horizon) did not show the 1.2 times more clay (32 percent versus 38.4 percent) than the eluvial horizon (i.e., A horizon). In the ST system, if an eluvial horizon remains and there is no lithologic discontinuity between the eluvial and the illuvial horizons and no plow layer directly above the illuvial horizon is present, the illuvial horizon must contain more clay than the eluvial horizon (Soil Taxonomy, 2014, page 12). Under these conditions, if other characteristics of argillic horizon were met, the soil classification may be changed due to a land use change! For example, in the studied pedon, if the land use was changed to the agriculture (Ap instead of A horizon), the soil should be classified as “Calcic Haploxeralf”. Since the plow layer is directly located above the illuvial horizon, increasing clay content is not necessary. This seems to be a limitation for this system and appropriate revision is highly recommended.

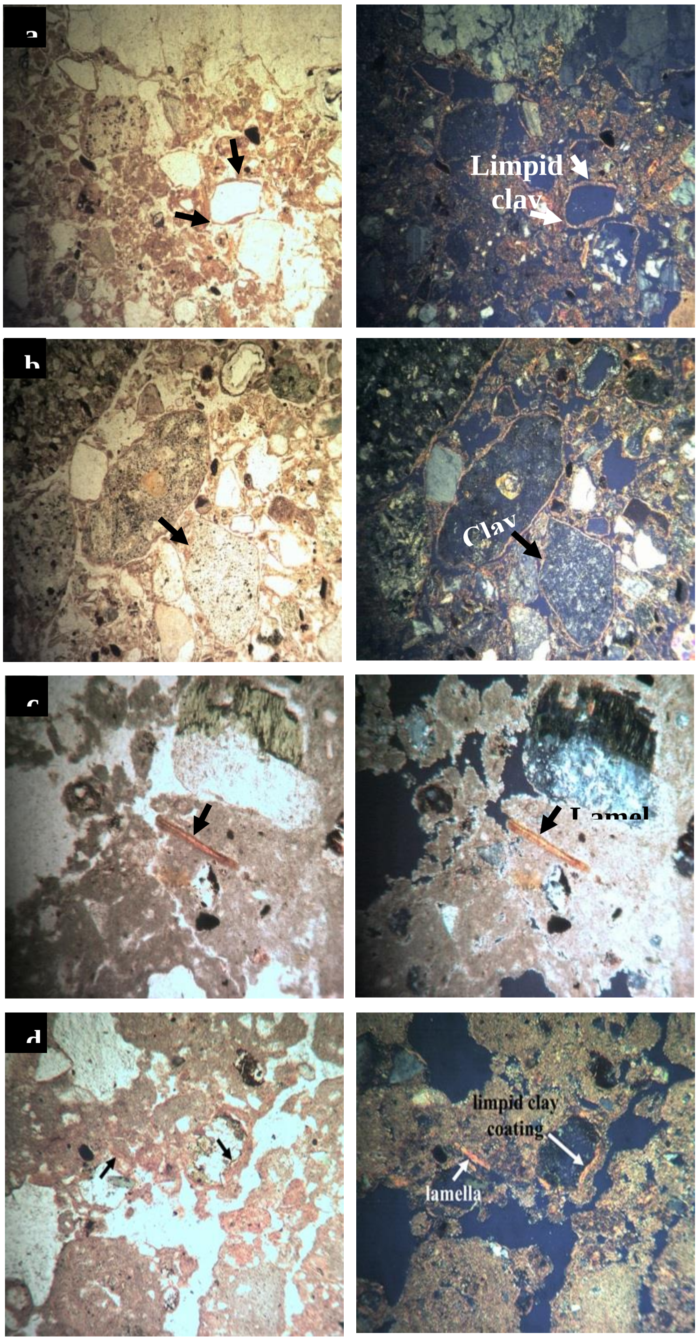

Fig. 2. Clay pedo features in Bt horizons of pedon 1- site 1 (a), pedon 2- site 1 (b), pedon 2- site 2 (c) and pedon 3- site 2 (d). (left: PPL; right: XPL)

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

Study site	Pedon no.	Horizon	Depth (cm)	Color		Structure	Consistency		Cutans and/or concentrations	Special features
				Dry	Moist		Dry	Moist		
Site 1	1	A	0-30	10YR5/3	10YR4/4	1 m gr	so	lo	-	-
		Bt	30-65	7.5YR6/4	7.5YR5/4	2 m abk	h	fi	f, F, CLF on CC	-
		Bk1	65-90	10YR4/6	10YR5/6	3 c abk	sh	fi	m, 2, CAC, MAT	-
		Bk2	90-150	10YR4/5	10YR5/4	2 m abk	sh	fr	c, 2, CAC, MAT	-
	2	Ap	0-20	7.5YR5/4	7.5YR4/4	3 m gr	sh	fi	-	-
		Btk	20-55	7.5YR4/4	7.5YR4/4	2 m sbk	sh	fi	"vf, F, CLF on PF" and "c, 2, CAC, MAT"	-
		Bk	55-135	10YR5/4	10YR4/4	2 m sbk	sh	fi	c, 2, CAC, MAT	-
	3	Ap	0-30	7.5YR6/4	7.5YR4/4	3 f gr	sh	fi	-	-
		Bw1	30-60	7.5YR5/4	7.5YR4/4	3 m sbk	sh	fi	-	-
		Bw2	60-95	10YR4/6	10YR3/4	2 m sbk	sh	fi	-	-
		Bk	95-130	10YR5/5	10YR5/4	2 m sbk	h	fi	m, 2, CAC, MAT	-
Site 2	1	A	0-15	10YR5/4	10YR5/3	1 f gr	so	fr	-	-
		Bk	15-30	10YR4/3	10YR4/4	1 f sbk	sh	fr	m, 2, CAC, MAT	-
		2Bz	30-65	10YR4/4	10YR3/4	2 f sbk	sh	fi	m, 1, SAX, MAT	-
		3Btn	65-110	7.5YR5/4	7.5YR4/4	3 m cpr	h	fi	vf, F, CLF on RF	-
	2	Apz	0-35	10YR5/4	10YR3/4	1 m sbk	sh	fi	f, 2, SAX, MAT	-
		Btz	35-70	7.5YR6/3	7.5YR3/2	2 c sbk	h	fi	f, 2, SAX, MAT	LA
		By	70-110	10YR5/3	7.5YR4/4	2 m sbk	sh	fi	m, 2, GYX, MAT	-
	3	A	0-5	7.5YR4/6	7.5YR4/6	1 m abk	sh	vfr	-	-
		Btk	5-40	5YR5/6	5YR3/2	1 m abk	sh	vfr	c, 2, CAC, MAT	LA
		Cr	40-100	5YR5/6	5YR3/6	-	sh	vfr	-	-
		R	100-150	-	-	-	-	-	-	-

[a] Symbols are used based on Schoeneberger *et al*. (2012) as follows:
Structure grade — 1: weak; 2: moderate; 3: strong.
Structure size — f: fine; m: medium; c: coarse.
Structure type — gr: granular; abk: angular blocky; sbk: subangular blocky; cpr: columnar.
Dry consistency — so: soft; sh: slightly hard; h: hard.
Moist consistency — lo: loose; fi: firm; fr: friable; vfr: very friable.
Cutans — vf: very few; f: few; F: faint distinctness; CLF: clay films (argillans); CC: on concretions; PF: on all faces of peds (vertical and horizontal).
Concentrations — f: few quantities; c: common quantities; m: many quantities; 1: fine size; 2: medium size; CAC: carbonate concretions; GYX: gypsum crystals; SAX: salt crystals; MAT: in the matrix (not associated with peds/pores).
Special features — LA: lamellae.

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

Study site	Pedon no.	Horizon	Depth (cm)	Clay (%)	Silt (%)	Sand (%)	RF[a] (%)	CCE[b] (%)		Gypsum (%)	O.C.[c] (%)	CEC[d] (cmol$_c$ kg^{-1} clay)	SAR[e] (mmol L^{-1})$^{0.5}$	pH	ECe[f] (dS m^{-1})	Texture[g]
								≤2 mm	≤0.002 mm							
Site 1	1	A	0-30	32	47	21	5.0	15.0	0.0	0.0	0.9	38	0.0	7.8	0.70	CL
		Bt	30-65	35	43	22	5.0	18.0	0.3	0.0	0.7	42	0.0	7.9	0.70	CL
		Bk1	65-90	32	51	17	10.0	29.0	0.4	0.0	0.4	39	0.0	8.1	0.50	SiCL
		Bk2	90-150	34	51	15	12.0	32.0	0.3	0.0	0.1	42	0.0	7.7	0.50	SiCL
	2	Ap	0-20	26	68	6	0.0	25.7	0.0	0.0	0.8	34	0.0	7.8	0.31	SiL
		Btk	20-55	40	55	5	0.0	29.5	3.5	0.0	0.6	31	0.0	7.9	0.35	SiC
		Bk	55-135	34	64	2	0.0	35.0	2.0	0.0	0.3	30	0.0	7.9	0.35	SiCL
	3	Ap	0-30	22	25	53	15.0	40.0	0.0	0.0	0.5	43	0.0	7.5	0.30	SCL
		Bw1	30-60	23	27	50	11.0	44.0	0.2	0.0	0.3	43	0.0	7.7	0.40	SCL
		Bw2	60-95	35	29	38	13.0	43.0	0.4	0.0	0.1	38	0.0	7.8	0.20	CL
		Bk	95-130	30	28	42	10.0	40.0	0.5	0.0	0.1	41	0.0	7.8	0.50	CL
Site 2	1	A	0-15	29	53	18	5.0	22.0	0.4	9.0	0.2	34	5.2	7.8	10.20	SiCL
		Bk	15-30	31	48	21	3.0	30.0	0.7	13.0	0.1	39	5.9	7.8	17.50	CL
		2Bz	30-65	26	14	60	3.0	21.0	0.1	28.0	0.1	32	18.0	7.9	38.70	SCL
		3Btn	65-110	37	36	27	3.0	19.0	0.1	24.0	0.0	42	32.0	7.8	24.00	CL
	2	Apz	0-35	15	38	47	0.0	10.0	0.0	7.3	0.1	33	5.2	7.7	13.10	L
		Btz	35-70	26	41	33	10.0	14.0	0.0	13.8	0.1	36	7.4	8.1	8.10	CL
		By	70-110	12	39	49	10.0	10.0	0.0	24.0	0.1	35	8.1	8.1	8.10	L
	3	A	0-5	15	26	59	20.0	11.0	0.7	0.0	0.2	39	0.8	7.7	0.60	SL
		Btk	5-40	19	22	59	45.0	15.8	0.6	0.0	0.1	40	0.8	7.8	0.30	SL
		Cr	40-100	15	20	65	50.0	5.0	0.1	0.0	0.0	40	1.6	7.7	0.80	SL
		R	100-150	-	-	-	-	-	-	-	-	-	-	-	-	-

[a] Rock fragments
[b] Calcium carbonate equivalent
[c] Organic carbon
[d] Cation exchange capacity
[e] Sodium adsorption ratio
[f] Electrical conductivity of soil saturated paste
[g] CL: clay loam; SiCL: silty clay loam; SiL: silt loam; SiC: silty clay; SCL: sandy clay loam; L: loam; SL: sandy loam.

Table 4. Classification of the pedons in different studied sites based on ST and WRB systems.

Study site	Pedon no.	Classification system: ST (2014)	Classification system: WRB (2015)
Site 1	1	Fine-loamy, Mixed, Superactive, Mesic Typic Calcixerept	Endocalcic Luvisol (Amphicutanic, Hypereutric, Pantoloamic, Ochric)
	2	Fine, Mixed, Superactive, Mesic Calcic Haploxeralf	Luvic Calcisol (Aric, Amphiclayic, Endoloamic, Ochric, Amphicutanic[a])
	3	Fine-silty, Carbonatic, Mesic Typic Calcixerept	Endocalcic Luvisol (Aric, Endodifferentic, Hypereutric, Pantoloamic, Ochric, Amphicambic[a])
Site 2	1	Fine, Mixed, Superactive, Thermic Calcic Haplosalid	Epicalcic Amphisalic Solonetz (Endocutanic, Kantoloamic, Hypernatric, Amphiraptic)
	2	Fine-silty, Mixed, Superactive, Thermic Typic Argigypsid	Hypogypsic Amphilamellic Luvisol (Aric, Amphicutanic, Hypereutric, Pantoloamic)
	3	Loamy-skeletal, Mixed, Superactive, Hyperthermic, Shallow Typic Calciargid	Skeletic Luvic Endoleptic Calcisol (Hypocalcic, Chromic, Katoloamic, Ochric, Yermic, Lamellic[a])

[a] According to the WRB system's rules, if qualifiers apply but are not in the list for the particular RSG, they should be added last as supplementary qualifiers (IUSS Working Group WRB, 2015, page 13). Although, these suggestions should be officially accepted by the WRB Working Group

On the other hand, the WRB system clearly shows the existence of an argic horizon using "Luvisol" at the RSG level. The mismatch could be related to the various definitions of clay-enriched horizons in the two classification systems. Non-similarities in definition of diagnostic horizons or properties between ST and WRB systems were noted by several researchers (Esfandiarpour Boroujeni *et al*., 2013, Sarmast *et al*., 2016; Esfandiarpour Boroujeni *et al*. 2018). Although a calcic horizon was started ≤ 100 cm from the soil surface and Calcisols has priority compared to Luvisols, but an argic horizon (Bt horizon) overlies the calcic horizon in this pedon. This is the reason why the soil was not classified as "Calcisol". The presence of the calcic horizon was indicated using "Calcic" qualifier. Moreover, the "Endo-" specifier shows a calcic horizon starts ≥ 50 cm from the soil surface and no such horizon occurs < 50 cm of the mineral soil surface (IUSS Working Group WRB, 2015, page 18). The "Cutanic" is another qualifier considered by the WRB system. This supplementary qualifier indicates that an argic horizon has evidence of clay illuviation. The addition of the "Panto-" specifier to "Loamic" qualifier shows that the horizon starts at the mineral soil surface and has its lower limit ≥ 100 cm from the soil surface (IUSS Working Group WRB, 2015, page 18) (Table 4).

The existence of an argillic subsurface horizon in pedon 2 at site 1 is directly considered by the ST system (Calcic Haploxeralf). The simultaneous presence of argic and calcic horizons (i.e., Btk horizon) above the calcic horizon within 100 cm from the soil surface and priority of "Calcisols" to "Luvisols" in the WRB system proves that the presence of argic horizon is not accounted at the RSG level of this system. The presence of an argic horizon with a CEC ≥ 24 $cmol_c$ kg^{-1} clay and BS ≥ 50 % starting ≤ 100 cm from the soil surface was considered using the "Luvic" qualifier (IUSS Working Group WRB, 2015, page 128).

Moreover, the presence of a calcic horizon was considered in the subgroup level (Calcic Haploxeralf) of the ST system. Application of the "Amphi-" specifier with the "Clayic" qualifier indicates that the horizon with a silty clay textural class starts within 50 cm of the mineral soil surface and has its lower limit between 50 and 100 cm of the mineral soil surface. Meanwhile, the "Endo-" specifier combined with "Loamic" qualifier is a proof that the layer ≥ 30 cm thick with a silty clay loam textural class starts ≥ 50 and ≤ 100 cm from the soil surface (IUSS Working Group WRB, 2015, page 128).

The "Aric" and "Ochric" qualifiers in the WRB name of pedon 2 at site 1 show that surface layer was ploughed to a depth of ≥ 20 cm and has ≥ 0.2 % organic carbon. The "Cutanic" qualifier was considered in the WRB name as supplementary qualifier (Table 4). If qualifiers apply but are not in the list for the particular RSG, they should be added last as supplementary qualifiers (IUSS Working Group WRB, 2015, page 13).

The different definition of clay-enriched horizons in ST and WRB systems caused the Bw2 horizon of pedon 3 at site 1 as different diagnostic horizons (cambic horizon in ST and argic horizon in WRB). An argic horizon must have either more clay content than the coarser textured horizon or evidence of clay illuviation in the WRB system, but both criteria are mandatory in the ST system. The soil was classified as "Typic Calcixerept" and "Luvisol" in the ST and WRB systems, respectively. This is another example of poor correlation between both classification systems for describing clay-enriched soils. Although no evidence of clay illuviation was observed, the WRB system described the presence of an argic horizon well within 100 cm of the soil surface at the RSG level. If the soil shows a lithic discontinuity directly over the argic horizon, or if the surface horizon has been removed by erosion, or if a plough layer directly overlies the argic horizon, then the illuvial nature in the WRB system must be clearly established by an evidence of clay illuviation (IUSS Working Group WRB, 2015, page 25). The Bw2 horizon and the overlying coarser textured horizon (i.e., Bw1 horizon) were not separated by a lithic discontinuity in pedon 3 at site 1, the Bw1 is not part of a plough layer, and the ratio of clay in the Bw2 horizon to that of the Bw1 horizon is 1.5 (i.e., ≥ 1.4). Such a horizon (i.e., Bw2 horizon) can be considered as an argic horizon according to the WRB system.

Besides, description of argic horizon properties is another considerable point for the WRB system. The application of the "Differentic" qualifier in the WRB name precisely emphasizes that the soil has an argic horizon that meets diagnostic criterion 2a for the respective horizon and argic horizon does not necessarily show the evidence of clay illuviation (IUSS Working Group WRB, 2015, pages 23 and 24). The "Endo-" specifier also indicates that the horizon starts between 50 and 100 cm from the soil surface. Furthermore, the "Panto-" specifier for the "Loamic" qualifier shows that the layers have a textural class of sandy clay loam and clay loam starting at the mineral soil surface and have their lower limit ≥ 100 cm from the soil surface. Adding the “Cambic” qualifier as soils having a cambic horizon not consisting of albic material and starting ≤ 50 cm from the soil surface in the list of supplementary qualifiers for “Luvisols” is highly recommended. Since the “Neocambic” qualifier was considered for “Luvisols”, it is suggested that the “Cambic” qualifier be separated from “Neocambic” by a slash (/). Moreover, application of the “Amphi-” specifier with the “Cambic” qualifier indicates that the cambic horizon starts within 50 cm of the mineral soil surface and has its lower limit between 50 and 100 cm of the mineral soil surface (Table 4).

Comparing ST and WRB systems for describing the pedon 1 at site 2 declared that the WRB system indicates a natric horizon starting ≤ 100 cm from the soil surface using “Solonetz” at the RSG level. Meanwhile, the presence of this horizon is totally neglected by the ST system (Table 4). Although “Argids” subgroup (Aridisols that have an argillic or natric horizon and do not have a petrocalcic horizon within 100 cm of the soil surface, Soil Taxonomy, 2014, page 107) was defined in the ST system, the presence of a natric horizon is not accounted at the subgroup level. More emphasis has been placed on the salic horizon than clay-enriched horizons in the ST system. However, “Solonetzs” have more preference than “Solonchacks” in the RSG level. Soils with a high content of exchangeable Na have special management requirements since sodic conditions impede plant growth and increase erodibility (Gray *et al.*, 2011). Therefore, it seems a limitation for the ST system and defining the “Natrisalids” great group (Salids that have a natric horizon within 100 cm of the soil surface) and consequently “Calcic Natrisalids” subgroup is highly recommended. Esfandiarpour Boroujeni *et al*. (2013) also suggested adding “Natrisalids” great group and “Calcic Natrisalids” subgroup for the Salids suborder in the ST system.

Moreover, evidence of clay illuviation and an exchangeable Na percentage (ESP) of ≥ 15 throughout the entire natric horizon are two important characteristics that could be shown by “Endocutanic” and “Hypernatric” qualifiers in the WRB system. Although two soil classification systems showed the presence of calcic and salic horizons, the WRB system, with the application of “Epi-” and “Amphi-” specifiers seems more informative in comparison to the ST system. The “Raptic” qualifier in the WRB name of pedon 1 at site 2 clearly shows the presence of lithic discontinuities between Bk-Bz and Bz-Btn horizons. Whereas, horizon designations (i.e., A, Bk, 2Bz, 3Btn) denote the existence of lithic discontinuities, ST system couldn’t consider this property in the soil name (Tables 2 and 3). Therefore, it is suggested to define “Raptic” great groups as other soils that have a lithologic discontinuity within 100 cm of the soil surface to better describe soil properties. Moreover, using the “Amphi-” specifier for “Raptic” qualifier shows the characteristic is present two or more times, once or more times somewhere ≤ 50 cm from the mineral soil surface and once or more times somewhere > 50 and ≤ 100 cm from the soil surface (IUSS Working Group WRB, 2015). Furthermore, using the “Kato” specifier in the WRB name for the “Loamic” qualifier indicates the horizon or layer starts within 50 cm of the mineral soil surface, and has its lower limit ≥ 100 cm of the soil surface; and no such horizon or layer occurs < 1 cm of the soil surface (IUSS Working Group WRB, 2015).

The existence of an argillic horizon (or argic horizon in the WRB system) in pedon 2 at site 2 was identified by ST (Typic Argigypsid) and WRB (Luvisol) systems. Although the evidence of clay illuviation was observed as lamellae, the ST system could not display this characteristic (Tables 2 and 4). The WRB system indicates the presence of lamellae using “Lamellic” qualifier. In many regions of Iran, there were increasing clay with depth as lamella was reported by different researchers such as Sarmast *et al*. (2017) and Yaghmaeian Mahabadi and Givi (2017). Lamellae play an important role in the flux and retention of water and nutrients and affects plant growth (Hannah and Zahner, 1970; Bockheim and Hartemink, 2013; Ober *et al*., 2017). Therefore, defining the “Lamellic Argigypsids” subgroup as Argigypsids have evidence of clay illuviation as lamellae is necessary. Moreover, “Amphi” specifier for “Lamellic” qualifier indicates the layer with this characteristic starts within 50 cm of the mineral soil surface and has its lower limit between 50 and 100 cm of the soil surface (IUSS Working Group WRB, 2015).

On the other hand, the ST system only shows the existence of a gypsic horizon within 100 cm of the soil surface. Whereas the WRB system shows the amount of gypsum using “Hypogypsic” qualifier (gypsum content in the fine earth fraction is < 25 % by mass). This difference was confirmed by Toomanian *et al*. (2003) and Sarmast *et al*. (2016).

Meanwhile, the application of “Cutanic” qualifier is a noticeable point in the WRB system name. Using the “Cutanic” and “Lamellic” qualifiers is not redundant, simultaneously. The “Cutanic” qualifier only shows the evidence of clay illuviation, whereas the “Lamellic” qualifier indicates that illuviation is as two or more lamellae (≥ 0.5 and < 7.5 cm thick) that have higher clay contents than the directly overlying layers, with a combined thickness of ≥ 5 cm, while the uppermost lamella starts within 100 cm of the soil surface (IUSS Working Group WRB, 2015, page 127).

Similarly, two soil classification systems had the potential to consider the presence of a calcic horizon in pedon 3 at site 2. This pedon was classified as “Typic Calciargid” (Soil Survey Staff, 2014) and Calcisol (IUSS Working Group WRB, 2015). The “Hypo” specifier for “Calcic” qualifier in the WRB name indicates that the calcium carbonate equivalent in the fine earth fraction of the calcic horizon is less than 25 %. Therefore, this system provides more information for management practices in comparison with the ST system.

The existence of an argillic horizon (or argic horizon in the WRB system) in this pedon was considered at suborder (Argid) and principal qualifier (Luvic) levels. None of the soil classification systems are able to show evidence of clay accumulation as lamellae (Tables 2 and 4). The “Lamellic” subgroup was only defined for 7 of the 12 orders in the ST system. In the WRB system, the “Lamellic” qualifier was not considered for some of RSGs such as Calcisols. Therefore, defining “Lamellic” subgroups such as “Lamellic Calciargids” at the ST system and “Lamellic” qualifier for Calcisols in the WRB system seems necessary.

Although the “Leptic” qualifier in the WRB system shows existence of continuous rock within 100 cm of the soil surface, this feature is entirely neglected in the ST system. Also, the application of the “Endo” specifier for “Leptic” qualifier shows that this characteristic is present somewhere > 50 and ≤ 100 cm from the mineral soil surface and is absent ≤ 50 cm from the mineral soil surface (IUSS Working Group WRB, 2015, page 17). On the other hand, the “Shallow” soil depth class at the family level shows that the soil is less than 50 cm deep to a root-limiting layer. The concept of lithic contact and root-limiting layers are different in the ST system. A lithic contact is diagnostic at the subgroup level if it is within 125 cm of the mineral soil surface in Oxisols and within 50 cm of the mineral soil surface in all other mineral soils (Soil Taxonomy, 2014, page 28). Meanwhile, the root-limiting layers have a widespread concept and include lithic, paralithic and petroferric contact, densic, manufactured layer, duripan, fragipan, petrocalcic, pertrogypsic and placic horizons (Soil Taxonomy, 2014, page 319). In the WRB system, no qualifier was defined to indicate the presence of the paralithic contact. Therefore, both of the soil classification systems have a weak point in indicating the soil depth limitation. To overcome the above-mentioned problems, the below suggestions were recommended:

1- Revising the definition of Lithic subgroups as soils that have a lithic or paralithic contact within 50 cm of the soil surface; and
2- Defining the “Paralithic” qualifier for all RSGs in the WRB system.

Sarshogh (2010) explained that the ST system (Soil Taxonomy, 2010) can better describe shallow soils of Babaheidar region compared to the WRB system (IUSS Working Group WRB, 2007). Esfandiarpour Boroujeni *et al*. (2018) reported that the WRB system by “Leptic” qualifier shows the presence of continuous rock, but this feature was not considered in the ST system. Furthermore, Esfandiarpour Boroujeni *et al*. (2013) and Sarmast *et al*. (2016) declared that “Paralithic” qualifier should be defined in the WRB system. Another useful point in the pedon 3 at site 2 is the high amount of rock fragments. This feature was accounted by two soil classification systems using the “Skeletal” and “Skeletic” terms. In the ST system at least 35 % rock fragments in the control section for particle-size class causes skeletal term to be used. Whereas ≥ 40 % coarse fragment averaged over a depth of 100 cm from the soil surface or to continuous rock was considered using “Skeletic” in the WRB system. The application of the “Yermic” qualifier to show the arid properties and presence of a desert pavement are among other important points noticeable for the WRB system.

4. Conclusions

1. If the evidence of clay illuviation was observed, distinguishing the Bt horizon as an argillic horizon can be affected by land use.
2. The required characteristics of an argillic or related horizon are not met in all Bt horizons.
3. The application of “Cutanic” and “Lamellic” qualifiers in the WRB system is not redundant, simultaneously.

4. Defining the Natrisalids great group and new subgroups including Calcic Natrisalids, Lamellic Argigypsids and Lamellic Calciargids in the ST system seems necessary to improve its deficiencies.
5. The addition of the "Lamellic" qualifier for Calcisols in the WRB system is highly recommended.

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