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The use of soil classification in journal papers between 1975 and 2014

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ABSTRACT

We classify soils to group our knowledge, increase our understanding, and communicate results. I have analyzed how soil classification and factor and soil property naming have been used in journal papers between 1975 and 2014. There is an exponential increase in the use of *Taxonomy* and *WRB* but the increase in the number of soil science papers is much faster than the use of *Soil Taxonomy* and *WRB*. The percentage of papers with soil classification information was highest in *Geoderma* (34%). The soil biology journals had soil classification in only 6% of their papers. *Soil Taxonomy* seems to be more frequently included particularly in journals from the USA, whereas *FAO-Unesco* and *WRB* are more frequently used in European journals. Soils in dry areas (Aridisols, Calcisols, Gypsisols) seem to be under-researched, whereas Spodosols (Podzols), Vertisols, Anthrosols, Chernozems, and Luvisols seem over-represented. Soil factor and property naming (e.g. "agricultural soil", "sandy soil") increase faster than the use of *Soil Taxonomy* and *WRB*. Temperate and boreal soil is commonly used in *Soil Biology and Biochemistry* which also tops the number of papers with forest soil, "agricultural soil", "upland soil", "wetland soil", and "valley soil". The more geologically oriented journals use parent material terms like "alluvial soils" and "granite soils". Color soil naming is common in some Chinese (black soil, red soil) and Canadian journals (Brown soil). Problems of soil classification are related to technical issues of soil classification, the adoption of the system, and the lack of instructions in soil science journals. A lack of soil classification in our papers makes transfer of information, data and results difficult.

"The only thing that will redeem mankind is cooperation."
[Bertrand Russell (1954)]

1. Introduction

Many elements of the natural world are named and classified using systems developed in the 18th century. Carl Linnaeus developed taxonomic classifications of plants and animals and almost all living organisms. Rock classification followed pioneering work of James Hutton and Charles Lyell in the 18th and early 19th centuries. Systematic classification of soils started in the mid-1800s — initially focussing on geologic concepts and parent materials (e.g. Morton, 1843; Senft, 1857; Ramann, 1893) and then with an emphasis on climate and vegetation (Dokuchaev, 1883; Sibirtsev, 1900). Since that time, a bewildering number of classification systems have been developed. Systems have focused on, for example, chromatic aspects, soil age and development (Kubiëna, 1950), textural differentiation (Chamberlin, 1882; Whitney, 1909), maturatal — based on age (Wolfanger, 1930; van Wambeke, 1962) or zonal and azonal groupings (Marbut, 1927). There has been wide discussion on whether systems should be genetic or morphometric (Cline, 1949; Beckmann, 1984; Bockheim et al., 2005). As Leeper (1952) summarized it: we are slowly coming to agree to classify soils-as-they-are, and not to classify them according to guesses about their origin.

Soil classification leaped in the early 1950s (Eswaran, 1999) but the 1960 World Congress of Soil Science in Madison, USA, was pivotal. At the congress, the "7th Approximation" of the USDA was presented there (Soil Survey Staff, 1960). This system was presented as a conceptual change to the factorial-genetic concepts that dominated USA soil classification during the 1920s to 1950s (Bockheim et al., 2014). The "7th Approximation" was modified and published in 1975 as *Soil Taxonomy: a Basic System of Soil Classification for Making and Interpreting Soil Surveys* (Soil Survey Staff, 1975). *Soil Taxonomy* has undergone two editions (1975, 1990) and 12 classification keys of which the most recent was published in 2014 (Soil Survey Staff, 2014). Secondly, at the World Congress in 1960 a decision was made to prepare a World Soil Map (Hartemink et al., 2013). The World Soil Map's legend was turned into the *FAO-Unesco* soil classification, that in 1998 was published as the *World Reference Base for Soil Resources* (*WRB*), with the latest edition published in 2014 (IUSS Working Group WRB, 2014). In addition to these two soil classification systems, there are many national soil classification systems of which an overview was given by Krasilnikov et al. (2009).

There are other ways that soils have been classified including folk classification systems (Barrera-Bassols and Zinck, 2003), numerical approaches (e.g. Bautista et al., 2005; Hughes et al., 2014), capability classification systems (e.g. Helms, 1997; Sanchez et al., 2003), or diagnostic

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horizon classifications (FitzPatrick, 1980). Both *Soil Taxonomy* and *WRB* have been endorsed by the *International Union of Soil Sciences* (IUSS) as the internationally accepted soil classification systems. The *WRB* was endorsed at the World Congress of Soil Science in 1998 and *Soil Taxonomy* at the World Congress of soil Science in 2014.

There are many reasons why soils are classified and these have been fairly well defined by *Soil Taxonomy* and *WRB* (Soil Survey Staff, 1999; IUSS Working Group WRB, 2014). Firstly, the importance of soil classification stems from the need to bring systematics to the study of soil, as without classification the knowledge would be factual chaos that is difficult to retain and impossible to understand (Hallberg, 1984). Classification enables us to see relationships among and between soils and their environment, to formulate principles of prediction value, to establish groups at various levels, for the proper use of experience, and to extend the results of research (Soil Survey Staff, 1951; Beinroth et al., 1980; Beckmann, 1984).

It has been more than 40 years since the two international soil classification systems have been established, so it can be assumed that soil classification is grounded in the soil science community and other disciplines. Here, I analyze how soil classification is used in scientific journal papers in the past 40 years. As a punter of soil scientific publications (for research and as editor and reviewer), I have noticed that in many papers soil classification was absent or vague terms like "sandy soil" or "agricultural soil" were used. This prompted me to try to quantify the current use of soil classification and investigate possible trends over time. The analysis was restricted to the two international used soil classification systems: *Soil Taxonomy* and *World Reference Base for Soil Resources* as well as its predecessor *FAO-Unesco*. Data were extracted from the Scopus database (Elsevier) which metrics are slightly higher than that of the Web of Science (Minasny et al., 2013).

2. *Soil Taxonomy*

The number of papers in Scopus that contain *Soil Taxonomy* soil order information (e.g. Alfisols, Ultisols) is presented in Table 1. The numbers represent the papers with soil order information so that suborder (e.g. Ustults) or great groups (e.g. Haplusterts) information was not included in the analysis. Over the period 1975–2014, there were over 6000 papers containing information on the order Oxisols. The number of papers with Alfisols, Ultisols and Vertisols was around 4000 whereas the rest of the orders were mentioned in less than 2000 papers. Aridisols was mentioned in less than 200 papers, and there were less than 40 papers on Gelisols, which is not surprising given that this order was only established in 1999. Overall, there was a sharp increase in the number of papers containing *Soil Taxonomy* soil order information from less than 200 in the decade 1975–1984 to over 18,000 papers in the 2005–2014 decade. The number of papers mentioning specific soil orders has tripled in the past two decades.

Fig. 1 presents a count of papers in *Geoderma* and *Soil Survey Horizons* that included *Soil Taxonomy* orders as well as suborder or great group levels. For *Geoderma*, this is based on 2079 papers published between 1967 and 2001 (Hartemink et al., 2001). In the 1980s, most attention was given to Alfisols and Inceptisols, but in the late 1990s there was a steady rise in research conducted on Spodosols, Entisols and Mollisols. Alfisols and Inceptisols accounted for almost 20% of all papers in *Geoderma*, and Spodosols were the subject of about 7% of all papers. Oxisols and Ultisols have been researched in less than 7% of the papers; Histosols have received minimal attention.

We also classified all 1080 contributions published in *Soil Survey Horizons* (now named *Soil Horizons*) between 1960 and 2009. Since 1975, references to all soil orders increased and peaked for most orders in the mid and late 1990s. This includes reference to suborder or great group levels. Almost half of all contributions in *Soil Survey Horizons* included a reference to a soil order. Alfisols, Entisols, Inceptisols and Mollisols were most represented in contributions to *Soil Survey Horizons* (Hartemink et al., 2012). From the 1980s onwards, the majority of the contributions were from midwestern USA and about 17% of the soils discussed were Mollisols. The number of papers on Gelisols (introduced in 1999) was lowest along with Oxisols. Whereas Gelisols account for 8.7% of the soils in the USA, Oxisols comprise only 0.02% (Soil Survey Staff, 1999).

Table 1
Papers with one or more *Soil Taxonomy* order in any text field over the period 1975–2014. Soil orders in bold were already in the first edition of *Soil Taxonomy* (Soil Survey Staff, 1975); Gelisols and Andisols were added in 1999 (Soil Survey Staff, 1999). Data extracted from Scopus.

Soil order	Number of papers			
	1975–1984	1985–1994	1995–2004	2005–2014
Alfisol	50	243	1057	2508
Andisols	0	0	266	1108
Aridisols	3	12	59	117
Entisols	12	30	181	538
Gelisols	0	0	14	22
Histosols	4	18	134	388
Inceptisols	11	35	177	924
Mollisols	9	52	361	1127
Oxisols	30	188	1377	4624
Spodosols	11	115	877	1088
Ultisols	20	144	940	2857
Vertisols	27	170	1167	2964
Total	178	1034	6610	18,265

Comparing the distribution of *Soil Taxonomy* soil orders as found in Scopus, *Geoderma* and *Soil Survey Horizons* to the global extent of each order there seem to be some striking differences. It appears that the number of papers on Aridisols is much lower than their relative global extent (Fig. 1). The same applies to Gelisols. The Scopus database shows a large relative volume of paper on Oxisols compared to their global extent, whereas Spodosols are overrepresented in and Entisols underrepresented. There are a relatively large number of papers on Vertisols in Scopus and *Soil Survey Horizons* compared to its global extent.

3. *FAO-Unesco* and *WRB*

The number of papers containing *FAO-Unesco* or *WRB* soil groups in the past 40 years is presented in Table 2. As opposed to the soil order information of Table 1, this is probably a more accurate account as the names do not change at lower levels of classification. The legend to the 1:5 million World Soil Map was introduced in 1974 and Major Soil Groupings (also called soil units, reference soil groups, soil groups) have been added and discarded between 1974 (FAO-Unesco, 1974) and the *WRB* report of 2006 (IUSS Working Group WRB, 2006). Some soil groups have had a steady flow of papers like Cambisols, Chernozems, Ferralsols, Luvisols, Podzols and Vertisols. Other soil groups saw less increase over time. It seems that no paper has yet been published on Durisols. Overall, there were 19,440 papers that contained *FAO-Unesco* or *WRB* soil group information between 1975 and 2014, which is twice the amount of papers containing soil classification in the previous decade.

The total number of papers with soil-group information between 1975 and 2014 is presented in Fig. 2 that also shows the percentage of global land area for each group based on the 2006 version of *WRB* (IUSS Working Group WRB, 2006). Some soil groups have received less attention than their relative extent would warrant (underrepresentation) whereas other soil groups have received more attention that their relative extent (overrepresentation). Soils that are seemingly underrepresented are Acrisols, Arenosols, Calcisols, Cryosols, Ferralsols, Gleysols, Gypsisols, Kastanozems, and Leptosols, whereas soils that are overrepresented include Anthrosols, Chernozems, Luvisols, Podzols and Vertisols.

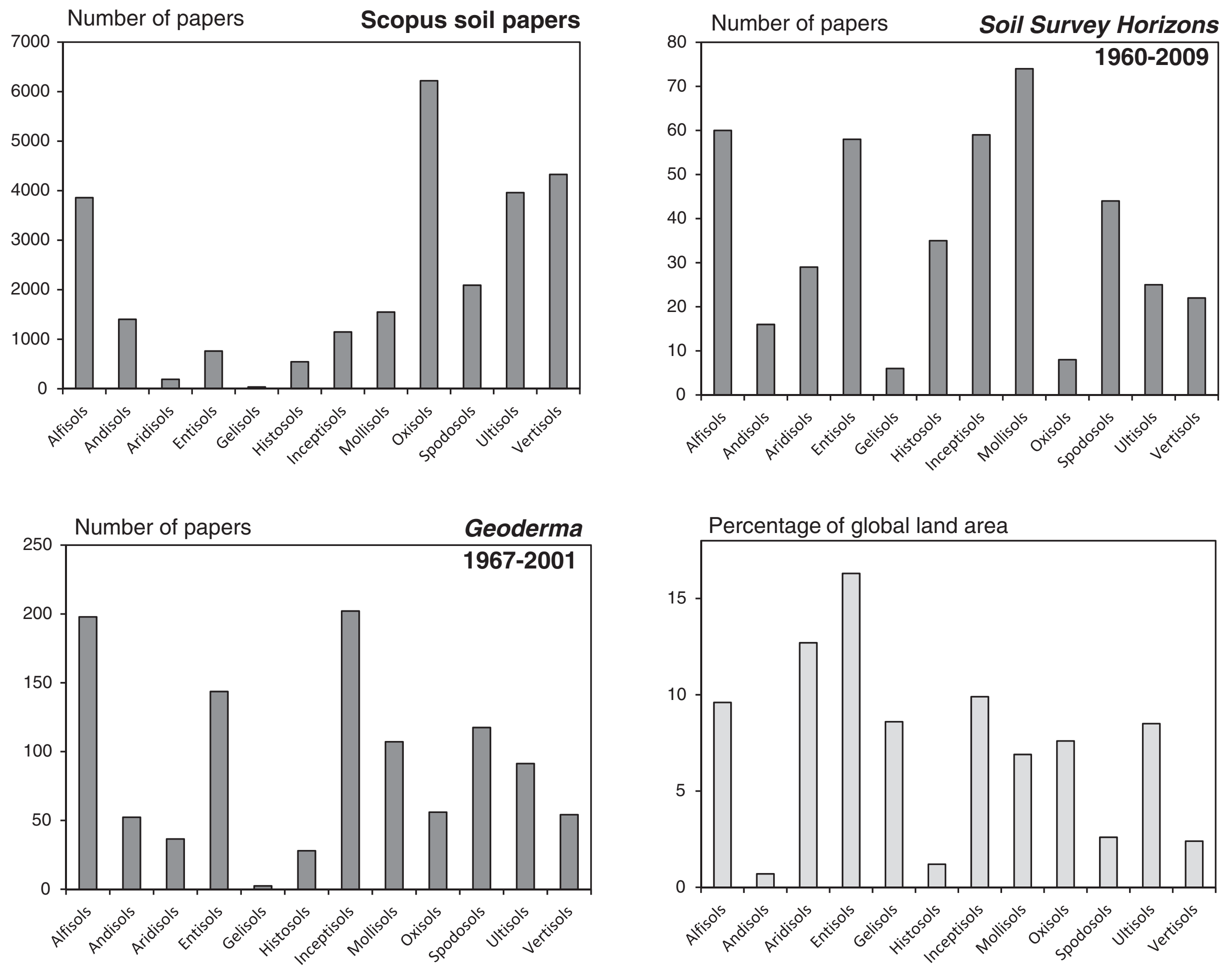

Fig. 1. Use of *Soil Taxonomy* between 1975 and 2014 in soils papers (data from Scopus), in papers of *Soil Survey Horizons* (modified from Hartemink et al., 2013), papers in *Geoderma* (calculated from Hartemink et al., 2001), and the distribution of soil orders over the global land area (USDA NRCS data).

4. Use in journal papers

The use of *Soil Taxonomy*, *FAO-Unesco* or *WRB* was investigated for 15 soil science journals over the period 1975–2014 (Table 3). Those 15 journals published over 43,000 papers containing *Soil Taxonomy*, *FAO-Unesco* or *WRB* in any text field. Papers that mostly have such information were published in *Catena*, *Geoderma*, *Soil and Tillage Research* and the *Soil Science Society of America Journal*. The percentage of papers with soil classification information was highest in *Geoderma* (34%) followed by *Catena*, *Soil Use and Management* and the *European Journal of Soil Science*. The soil biology journals (*Applied Soil Ecology*, *Biology and Fertility of Soils*, *European Journal of Soil Biology*, *Soil Biology and Biochemistry*) had soil classification in 6% of their papers, or less. Overall, *Soil Taxonomy* seems to be more frequently included, although *FAO-Unesco* and *WRB* are more frequently used in the *European Journal of Soil Science* and *Soil Use and Management*. The USA based journals *Soil Science* and *Soil Science Society of America Journal* mostly use *Soil Taxonomy*.

The number of papers containing *Soil Taxonomy*, *FAO-Unesco* or *WRB* in any text field over the 1975-2014 period has been indexed as was the total number of soil papers in Scopus (Fig. 3). There is an exponential growth in soil science papers, and the growth in papers containing *Soil Taxonomy* is larger than the growth in papers of the other systems. The use of *FAO-Unesco* is on the decline whereas there is considerable increase in the use of *WRB* in the past two decades. Overall, it seems that the use of *FAO-Unesco* and *WRB* soil groups exceeds *Soil Taxonomy* soil orders but this only includes soil order names (e.g. Ultisols) and not lower levels of classification (e.g. Usterts).

5. Soils named after a forming factor or soil property

Browsing through the soil science literature, it appears that soils have been characterized or named (so not classified) as products one of the five soil forming factors: in the climatic context (tropical soils); as a product of rock weathering (parent material: basalt soils); land use (e.g. forest soils); topographic position (e.g. valley soils) or age (young soils, highly weathered soils). They have also been named based on their color, texture, and drainage regime. Table 4 lists the number of papers for each of these terms over the period 1975–2014 grouped and summed by decade. The terms "tropical soil", "forest soil", and "agricultural soil" are widely used as are "sandy soil" and "clay soil". Of the soil color connotation, the "red soil" is most commonly used to characterize the soil. The use of all these terms more than doubled in the past two decades.

The number of papers per year between 1996 and 2014 for the most widely used soil naming terms is given in Fig. 4. It shows the trend in these terms (indexed) compared to the increase in soil papers over the same period. All these terms outstrip the growth of soil science papers, and terms such as "agricultural soil" and "urban soil" show fast growth in the scientific literature.

Table 5 lists the journals in which these terms where mostly used. The terms "temperate soil" and "boreal soil" are commonly used in

Table 2
Number of papers with one or more *FAO-Unesco* or *WRB* soil group in any text field over the period 1975–2014 (number per decade). Soil groups in bold are from FAO-Unesco (1974); others are additions from *WRB* (IUSS Working Group WRB, 2006). Groups with an asterisk were discontinued in 2006. Data extracted from Scopus.

Soil group	Number of papers			
	1975–1984	1985–1994	1995–2004	2005–2014
Acrisols	1	7	100	815
Albeluvisols	0	0	1	68
Alisols	0	1	12	42
Andosols	14	32	241	858
Anthrosols	0	1	23	466
Arenosols	0	9	39	152
Calcisols	0	0	31	97
Cambisols	4	65	406	1865
Chernozems	71	106	1461	2751
Cryosols	0	2	10	24
Durisols	0	0	0	0
Ferralsols	1	10	144	1247
Fluvisols	3	14	79	340
Gleysols	3	33	208	617
Greyzems	0	1	8	7
Gypsisols	0	0	3	3
Histosols	4	18	134	338
Kastanozems	0	0	13	39
Lithosols*	1	7	63	84
Leptosols	0	0	29	149
Lixisols	0	1	28	85
Luvisols	7	79	546	1806
Nitisols	0	2	35	170
Nitosols*	0	4	26	150
Phaeozems	1	5	66	366
Planosols	7	12	62	135
Plinthosols	0	0	5	34
Podzols	150	341	1708	2495
Podzoluvisols*	0	2	31	41
Rankers*	2	24	62	96
Regosols	9	11	130	362
Rendzinas*	19	59	242	292
Solonchaks	4	11	90	160
Solonetz	15	23	127	198
Technosols	0	0	0	74
Umbrisols	0	0	3	23
Vertisols	27	170	1167	2964
Xerosols*	0	0	10	9
Yermosols*	0	4	18	18
Total	343	1054	7361	19,440

Soil Biology and Biochemistry which also tops the number of papers with "forest soil", "agricultural soil", "upland soil", "wetland soil", and "valley soil". The more geologically oriented journals use parent material terms like "alluvial soil" and "granite soil". Color soil naming is common in some Chinese (black soil, red soil) and Canadian journals (Brown soil). *Geoderma* has the most papers with a soil textural naming (sandy soil, clay soil). The term "aquic soil" is commonly used in papers and journals from China.

6. Discussion

In the previous sections I presented an analysis on the use of soil classification by counting papers containing *Soil Taxonomy*, *FAO-Unesco* and *WRB* information, as well as factor or soil property naming. Considerable differences were found over time which reflects the use of these classifications as well as the changes in the soil science discipline. Here, I shall discuss the trends followed by possible explanations for what was found. Before discussing trends, there are some limitations in the data:

(i) Only soil orders were searched so that suborder or great group levels were not included. This likely underestimates the number of papers that contain *Soil Taxonomy* classification.
(ii) The counts of *FAO-Unesco* and *WRB* are probably more accurate than the *Soil Taxonomy* counts as there is no change in names at lower levels of classification.
(iii) Histosols and Vertisols occur in both *Soil Taxonomy* and *FAO-Unesco*/*WRB* so that there is some double counting.
(iv) Some papers may have more than one soil order or soil group, which overestimates the number of papers containing soil classification.
(v) Many more papers may contain soil classification in one of the many (national) systems (e.g. French, Australian, Russian). This underestimates the number of papers containing soil classification.
(vi) Some papers may include a capability classification, folk classification, or numerical classification — such classification systems were, however, not part of the current analysis.

6.1. Trends

There is an exponential growth in soil science papers which is accompanied by an increase in soil classification either by *Soil Taxonomy* or *WRB*. The growth in soil science papers is, however, much faster than the growth in use of the two soil classification systems. The increase in soil science papers has been quantified before (Hartemink, 2001; Minasny et al., 2013) and, among others, it is a sign of the vibrance of the soil science discipline, and the publish-or-perish culture of academia and research centers (Hartemink, 1999, 2008). The use of *Soil Taxonomy* seems to be more extensive than *WRB* although the number of papers with *WRB* soil groups is larger than the number of papers containing soil order (*Soil Taxonomy*) use (Fig. 3).

The percentage of papers containing soil classification differs largely between soil science journals. In more pedological and global journals like *Geoderma* and *Catena* it is highest; it is lowest in the soil biology journals. It may be that soil classification is somewhat alien to those communities. *Geoderma* has soil classification in about one-third of its papers. An earlier analysis showed that the percentage of papers in *Geoderma* that included soil classification was 30% in the early 1970s, 60% by 1989, and 50% in 2001 (Hartemink et al., 2001). That trend was explained by the increasing number of studies using large numbers of samples having a wide geographic distribution, or the increasing number of desk studies using existing data sets for which no soil classification was available.

This analysis showed that the use in soil factor or soil property naming is much faster than the use of *Soil Taxonomy* or *WRB* classification (Fig. 5). Terms that are popular are "forest soil", "agricultural soil", "sandy soil", "clay soil", "tropical soil" and soil color notations. Soil texture and soil color are most often used in folk soil classification (Barrera-Bassols and Zinck, 2003), and these terms are increasingly being used in scientific journals. The factor and soil property naming may be sensible for characterizing or discussing particular soil features — it was popular in the first half of the twentieth century particularly in relation to land use, and was sometimes called the utilitarian way of classifying soils (Manil, 1959). Terms like "wheat soils" or "coffee soils" were also commonly used, and are still being used in some papers (Watanabe et al., 2007). In 1930, it was already noted that botanic and topographic classes (e.g., grassland soils, upland soils) make little sense: "…the qualifications refer to features identical to the soil. Each of these factors has a profound effect upon its characteristics, but each indicates only indirectly, sometimes incorrectly, its true attributes" (Wolfanger, 1930).

The land-use, topographic, age, parent material and color classification of soils continue to appear in soil science journal papers. Some recent examples are included in Table 7. Soil science evolved beyond all of these simple characterizations a long time ago. The increased use of these terms is perhaps a reflection of particular soil science

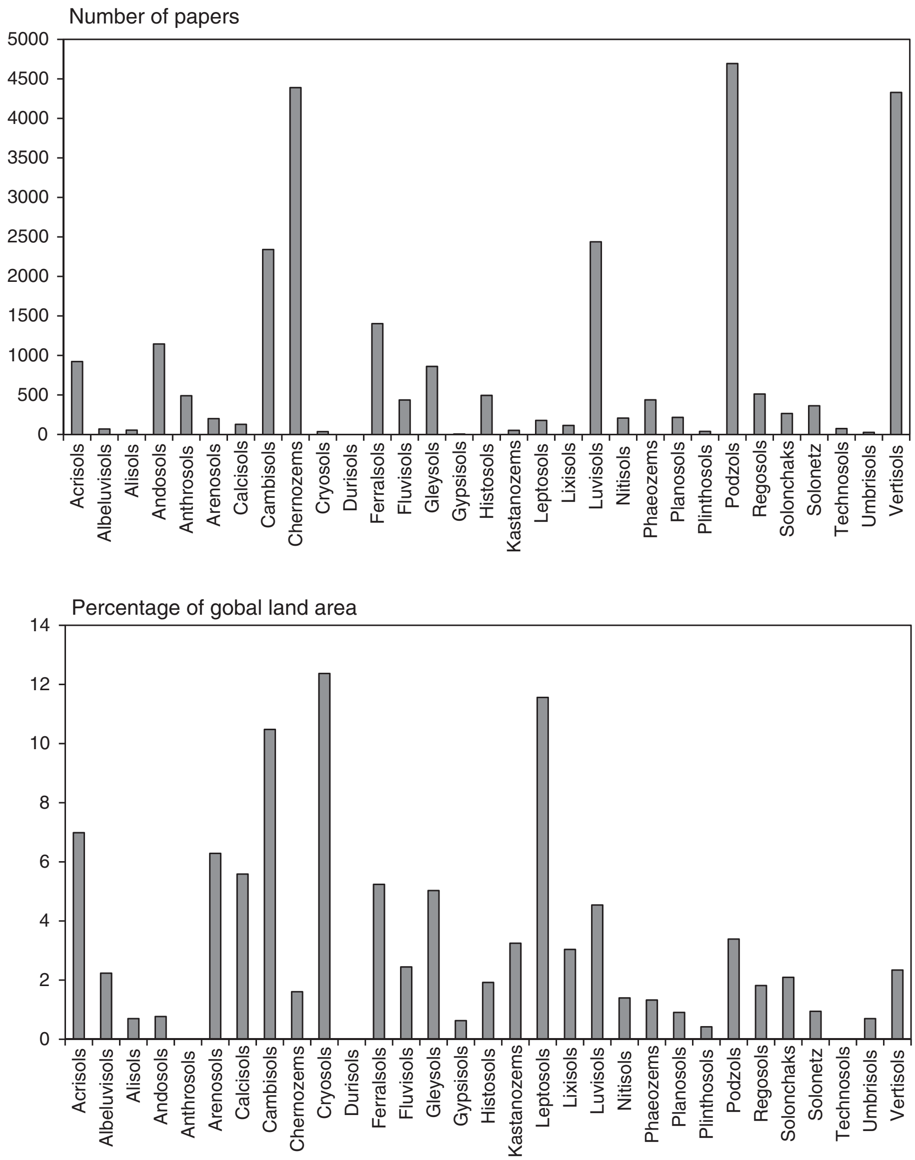

Fig. 2. Use of *FAO-Unesco* and *WRB* between 1975 and 2014 in soil papers (data from Scopus) and the distribution of soil groups over the global land area. From Bridges et al. (1998).

Table 3
Total number of papers for 15 soil science journals over the period 1975–2014, and the number of papers with *Soil Taxonomy*, *FAO-Unesco* or *WRB* [order] or [soil group] in any text field and [soil] in the title, keyword or abstract (in article or review document type only). Data extracted from Scopus.

		Number of papers with			Percentage of papers with		
Journal	Number of papers	*Soil Taxonomy*	*FAO-Unesco*	*WRB*	*Soil Taxonomy*	*FAO-Unesco* or *WRB*	Total
Applied Soil Ecology	2013	79	11	38	4	2	6
Biology and Fertility of Soils	3243	99	15	70	3	3	6
Catena	2576	362	67	197	14	10	24
European Journal of Soil Biology	972	25	5	13	3	2	4
European Journal of Soil Science	1519	126	28	146	8	11	20
Geoderma	4701	995	138	481	21	13	34
Land Degradation and Development	840	59	5	25	7	4	11
Nutrient Cycling in Agroecosystems	1277	86	17	43	7	5	11
Plant and Soil	5430	209	21	141	4	3	7
Soil and Tillage Research	2968	313	55	115	11	6	16
Soil Biology and Biochemistry	8275	261	36	159	3	2	6
Soil Science	1613	210	8	41	13	3	16
Soil Science Society of America Journal	5423	516	7	94	10	2	11
Soil Use and Management	1053	120	19	95	11	11	22
Vadose Zone Journal	1352	54	0	39	4	3	7
Total	43,255	3514	432	1697	8	5	13

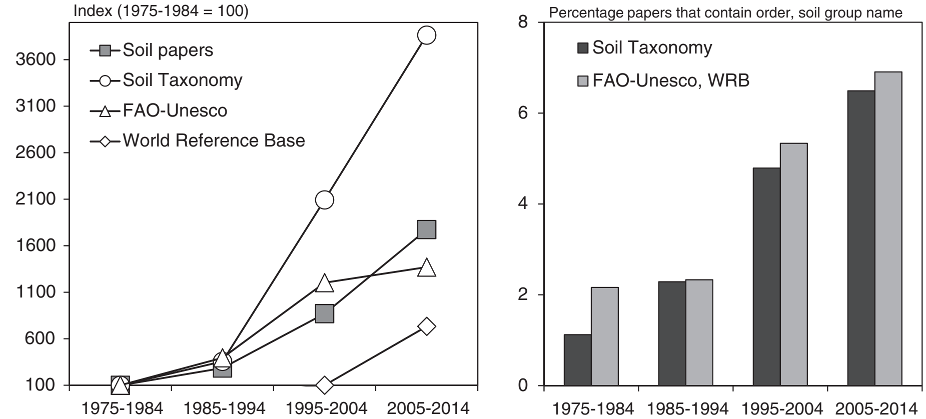

Fig. 3. Trend in number of soil papers between 1975–2014 and the classification in those papers: *Soil Taxonomy*, *FAO-Unesco* or *WRB*. Data are presented by decade and indexed: 1975–1984 = 100 (left diagram). Percentage papers that contain one or more orders or major soil grouping name (right diagram).

subdisciplines ignoring soil classification, and it appears to be common in soil biology journals (Table 5). These terms also tend to be more used by authors from China.

6.2. On the relative extent of orders and groups

This analysis counted the number of papers for each soil order (*Soil Taxonomy*) or soil group (*FAO-Unesco*, *WRB*). The number of papers per soil order or soil group were compared to the relative global extent of each order or group (Figs. 1 and 2). For both soil classification systems, soils in dry areas (Aridisols, Calcisols, Gypsisols) seem to be under-researched, whereas Spodosols (Podzols), Vertisols, Anthrosols, Chernozems, and Luvisols seem over-represented. Soils with distinct pedofeatures (Spodosols and Vertisols) receive more research attention, as do soils with folk names like Podzols and Chernozems (Krasilnikov et al., 2009). Also Vertisols and Podzols are well defined by a combination of soil properties with unique diagnostic horizons so that these soils are nearly immutable (Nachtergaele et al., 2001) and thus relatively easily classified. Papers with Oxisols are largely increasing compared to their global extent, possibly as they are easily perceived (red, acid, highly weathered) but in fact not so easily classified.

Some of these differences are related to research emphasis based on economic and agricultural activities. Although perhaps less than half of all 60,000 soil scientists in the world work in agriculture, the emphasis on soils under agriculture is understandable — agriculture still funds

Table 4
Number of papers using ClORPT or a soil property to characterize and name the soil. The number of papers refers to the papers in Scopus over the period 1975–2014 (number of papers per decade). The search was based on the term (e.g. “old soil”) in all fields (article or review document) and [soil] in the title, keywords or abstract.

Factor	Name	Number of papers			
		1975–1984	1985–1994	1995–2004	2005–2014
Climate	“Tropical soil”	149	503	3506	8503
	“Temperate soil”	4	34	365	1995
	“Boreal soil”	0	0	77	424
Organism	“Forest soil”	400	1686	12,439	29,391
	“Agricultural soil”	172	954	7662	24,821
	“Urban soil”	9	38	591	4007
Relief	“Upland soil”	24	113	828	2301
	“Lowland soil”	6	36	253	514
	“Valley soil”	16	35	248	607
	“Riparian soil”	1	10	157	560
	“Wetland soil”	20	111	951	3661
Parent material	“Basalt soil”	4	4	31	42
	“Granite soil”	5	22	118	243
	“Limestone soil”	6	22	141	280
	“Alluvial soil”	84	190	1041	2306
	“Colluvial soil”	3	13	86	312
Time	“Old soil”	23	32	190	637
	“Young soil”	21	30	108	205
	“Weathered soil”	31	103	595	1892
Color	“Black soil”	27	48	337	1995
	“Red soil”	34	74	707	3568
	“Brown soil”	46	99	552	981
	“Yellow soil”	7	16	101	225
Texture	“Sandy soil”	278	1156	6706	16,396
	“Clay soil”	297	1171	4903	10,452
	“Loamy soil”	25	102	729	1967
Drainage	“Poorly drained soil”	13	65	251	386
	“Well drained soil”	13	58	232	273
	“Gley soil”	19	44	223	341
	“Aquic soil”	0	2	58	420

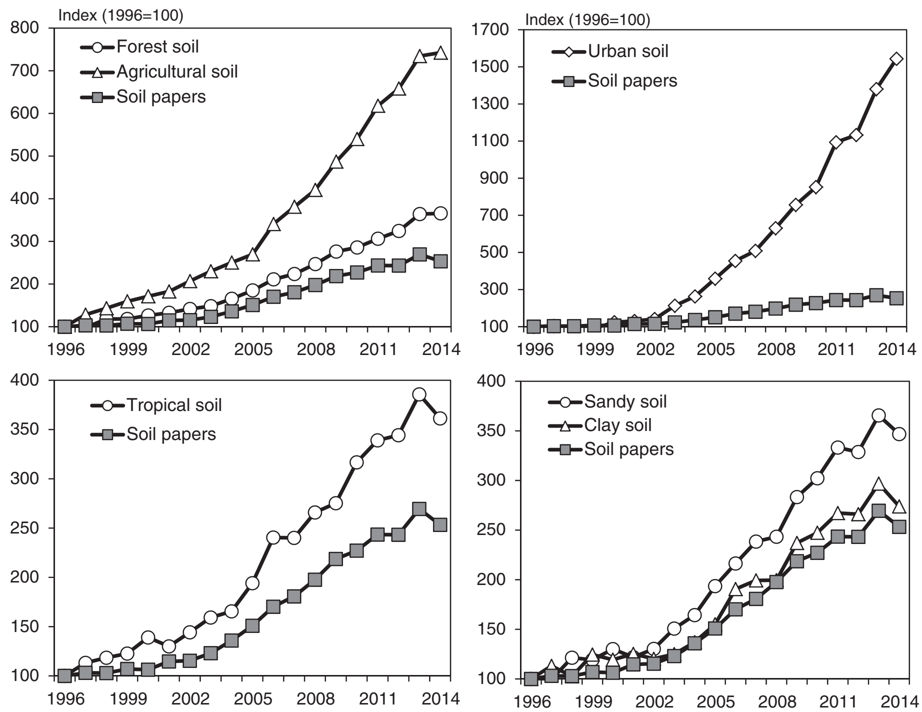

Fig. 4. Trend in soil factor and property naming in relation to total soil papers published between 1996 and 2014. Data are indexed (1996 = 100); note different scales of y-axes.

much research and a considerable portion of the terrestrial earth is used for agriculture. It also explains why research on Aridisols (too dry) and Gelisols (too cold) is smaller than their relative global extent — such soils are not used for agriculture, or very sparsely (e.g. grazing in arid areas).

6.3. Problems with soil classification

The trends suggest that soil classification is problematic and not increasing at the same pace as the number of soil science papers. Moreover, factor and soil property naming is growing much faster than the use of *Soil Taxonomy* or *WRB* (Fig. 5). Some of the problems facing the use of soil classification have been summarized by Langohr (2001): too many classification systems, changing too frequently, too many characteristics, data too difficult to obtain, too complex, too difficult terminology, and classification specialists also disagree. If plant taxonomists would have changed as often their naming and system of classification, few other scientists would bother using Latin names. So soil scientists should perhaps not be surprised that their classification systems are not being widely enough used despite over 40 years of efforts.

Overall, problems and criticisms of soil classification schemes can be divided into three groups: (i) technical issues related to the classification of soil — that is the system of soil classification and the inherent problems related to establishing criteria and boundaries; (ii) the adoption of the system by the soil science and wider scientific community; and (iii) the lack of instructions in soil science journals and issues related to training and education. These are discussed below and may help to better explain the observed trends.

6.3.1. Inherent problems

Soil classification more or less started in the early 1950s (Eswaran, 1999). There have been two opposite approaches in classifying soils: genetic and morphological of which the morphological approach became dominant. Since that time, soil classification has not been short of criticism (Thorp, 1948; Leeper, 1952; Pierre, 1958; Manil, 1959; Webster, 1960). Some have advocated that soil classification using the "soil profile approach" with its planar characteristics is fundamentally flawed (Jones, 1959). According to Jones (1959) soil classification is essentially soil profile classification and he defined the soil profile as "a soil lamina with empirical width and depth aligned radially towards the center of the earth" or, essentially, a two-dimensional entity.

Two international soil classification systems emerged in the 1970s: *Soil Taxonomy* Soil Survey Staff (1975) and FAO-Unesco (1974) that developed into WRB in 1998. They have not been free of criticism although it should be noted that there seems to be more criticism on *Soil Taxonomy* than on *FAO-Unesco* or *WRB*. The possible reasons are beyond the scope of this paper. The main criticism on *Soil Taxonomy* was summarized by Cline (1980) and by Hallberg (1984). Early on, the issue on the definition the soil individual, pedon and polypedon has haunted *Soil Taxonomy* (Holmgren, 1988). One of the key criticisms of *Soil Taxonomy* has been the naming and nomenclature (1984). From the beginning, it was already considered bizarre, incomprehensible, barbarous in formation, and conspicuously lacking in euphony (Heller, 1963), although the rationale for the nomenclature has been explained in detail (Smith, 1986). A second major criticism has been on the use of soil temperature and soil moisture regimes at the highest (order) level (Eswaran, 1999). From a geomorphological point of view, *Soil Taxonomy* has an overemphasis on the surface horizon whereas the horizons beneath the A horizon are commonly more important (Birkeland, 1999). Other have found that *Soil Taxonomy* has too few descriptors that can be used for extragrades, that it relies too much on laboratory data that can take months to acquire, or is not genetic enough (Schaetzl and Anderson, 2005). There have been problems with buried and cumulic soils (Hallberg, 1984), soil order change following erosion (Mokma et al., 1996), the lack of a geographic focus (Campbell and Edmonds, 1984) and soils not fitting the hierarchy (Cline, 1980; Swanson, 1999).

The same soil may be classified differently — also by experts. Kauffman (1987) showed the same soil was classified as and Oxisol, Ultisol, Alfisol or Mollisol independently by a group of 14 international soil classification experts. The results using the *FAO-Unesco* soil classification system were equally diverse. Differences were attributed to incomplete data, problems with the assessment of diagnostic horizons and criteria, and inconsistencies in the keying procedure (Kauffman, 1987). Other have also found that there is a need for improvements in

Table 5
Number of papers with factor or soil property naming over the period 2005–2014, and the top-5 of journals in which these papers were published.

Factor, property	Name	Journal	Number of papers
Climate	"Tropical soil"	*Geoderma*	328
		Soil Biology and Biochemistry	304
		Revista Brasileira de Ciência do Solo	229
		Plant and Soil	195
		Communications in Soil Science and Plant Analysis	178
	"Temperate soil"	*Soil Biology and Biochemistry*	175
		Geoderma	97
		Plant and Soil	71
		Soil Science Society of America Journal	60
		European Journal of Soil Science	57
	"Boreal soil"	*Soil Biology and Biochemistry*	29
		Global Change Biology	27
		Biogeosciences	20
		Journal of Geophysical Research	15
		Canadian Journal of Forest Research	14
Organism	"Forest soil"	*Soil Biology and Biochemistry*	1524
		Geoderma	867
		Forest Ecology and Management	806
		Plant and Soil	768
		Soil Science Society of America Journal	538
	"Agricultural soil"	*Soil Biology and Biochemistry*	931
		Geoderma	588
		Science of the Total Environment	523
		Soil Science Society of America Journal	498
		Chemosphere	480
	"Urban soil"	*Environmental pollution*	176
		Science of the Total Environment	158
		Environmental Monitoring and Assessment	130
		Chemosphere	126
		Journal of Hazardous Materials	94
Relief	"Upland soil"	*Soil Biology and Biochemistry*	101
		Geoderma	74
		Soil Science and Plant Nutrition	60
		Soil Science Society of America Journal	53
		Communications in Soil Science and Plant Analysis	51
	"Wetland soil"	*Soil Biology and Biochemistry*	122
		Ecological Engineering	121
		Soil Science Society of America Journal	116
		Geoderma	111
		Wetlands	100
	"Valley soil"	*Soil Biology and Biochemistry*	23
		Soil Science Society of America Journal	22
		Polar biology	16
		Geoderma	15
		Antarctic Science	15
Parent material	"Alluvial soil"	*Geoderma*	73
		Communications in Soil Science and Plant Analysis	68
		Eurasian Soil Science	59
		Soil and Tillage Research	47
		Soil Science Society of America Journal	41
	"Colluvial soil"	*Geomorphology*	19
		Geoderma	16
		Erath Surface Processes and landforms	15
		Engineering Geology	11
		Water Resources Research	11
	"Granite soil"	*Journal of Geotechnical and Geoenvironmental Engineering*	17
		Soils and Foundations	14
		Yantu Lixue Rocks and Soil Mechanics	11
		Canadian Geotechnical Journal	9
		Engineering Geology	8
Time	"Old soil"	*Soil Biology and Biochemistry*	65
		Global Change and Biology	48
		Geoderma	39
		Biogeochemistry	33
		Biogeosciences	25
	"Weathered soil"	*Geoderma*	93
		Revista Brasileira de Ciência do Solo	66
		Plant and Soil	51
		Soil Biology and Biochemistry	49
		Soil Science Society of America Journal	43
Color	"Black soil"	*Chinese Journal of Applied Ecology*	172
		Transactions of the Chinese Society of Agric Eng	102
		Acta Ecologica Sinica	92
		Geoderma	64
		Pedosphere	54

Table 5 (*continued*)

Factor, property	Name	Journal	Number of papers
	"Red soil"	*Chinese Journal of Applied Ecology*	306
		Acta Ecologica Sinica	282
		Pedosphere	121
		Geoderma	116
		Journal of Soils and Sediments	77
	"Brown soil"	*Chinese Journal of Applied Ecology*	60
		Acta Ecologica Sinica	33
		Geoderma	30
		Canadian Journal of Plant Science	30
		Canadian Journal of Soil Science	28
Texture	"Sandy soil"	*Geoderma*	382
		Soil Science Society of America Journal	321
		Plant and Soil	290
		Journal of Environmental Quality	276
		Communications in Soil Science and Plant Analysis	260
	"Clay soil"	*Geoderma*	300
		Soil and Tillage Research	280
		Soil Science Society of America Journal	254
		Journal of Geotechnical and Geoenvironmental Engineering	225
		Electronic Journal of Geotechnical Engineering	164
Drainage	"Poorly drained soil"	*Journal of Environmental Quality*	20
		Geoderma	16
		Soil Science Society of America Journal	13
		Soil and Tillage Research	12
		Canadian Journal of Soil Science	11
	"Aquic soil"	*Chinese Journal of Applied Ecology*	34
		Acta Ecologica Sinica	30
		Pedosphere	24
		Huanjing Kexue Environmental Science	15
		Transactions of the Chinese Society of Agric. Engineering	15

the definitions of the diagnostic requirements for horizons, properties and taxa, and that most soil scientists proceed too fast when classifiying soils (Langohr, 2001).

Currently, few – if anyone at all – work full time on developing and fine-tuning existing soil classification systems. There are global efforts and the *International Union of Soil Sciences* (IUSS) has a Commission on Soil Classification and Working Groups on *WRB* and the *Universal Soil Classification System*. Much of the work done is done by 10 to 20 soil scientists from across the world. Such work is important to advance the development of standardization in observation, measurement, naming and interpretation. There are several new observation methods and potentially a large amount of new soil data that may provide insight in the way we understand and categorize soils (Hartemink and Minasny, 2014). It should be borne in mind, that the inherent problems with global soil classification is not unique to soil science; there are no universally accepted systems to classify landscapes, geomorphology, or physiography; for land cover there are two systems (LCCS, IGBP) and there are several systems for ecological classifications (Nachtergaele et al., 2001). There are great hopes and strides that newly developed Universal Soil Classification System (Hempel et al., 2013) may move soil classification in the 21st century following rapid advances in soil mapping (McBratney et al., 2003).

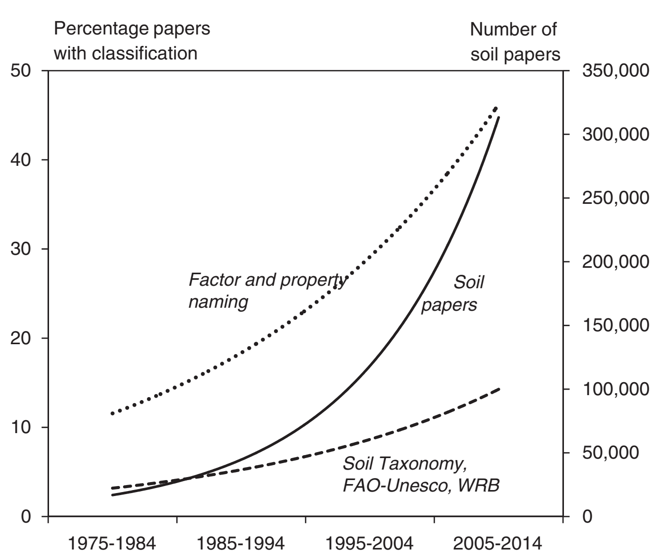

Fig. 5. Trends in the percentage of soil papers that have factor and property naming, or classification by *Soil Taxonomy*, *FAO-Unesco* and *WRB* (left y-axis), and number of papers published per decade over the period 1975–2014 (right y-axis).
Data from Scopus.

6.3.2. Adaptation of soil classification

The second issue is related to the adaptation of the system. Like any other botanical or zoological classification system, soil classification uses complex terms, nomenclature and jargon. *Soil Taxonomy* is probably thoroughly understood and actively used by a small circle of pedologists, and few soil scientists would dare to classify a soil themselves (Swanson, 1999). At lower level of classification, the definitions and criteria become exceedingly complicated and data requiring. There is no short cut to learn these terms. For *Soil Taxonomy* the nomenclature was developed so that each class had a name that was mnemonic that connote some properties of the soils (Heller, 1963). The name also places a class in the system and the system of nomenclature was developed primarily by classical linguists, and class names were coined from Greek and Latin roots. Classifying soils not only requires knowledge about the system but also data on the soil properties in addition to climatic data (*Soil Taxonomy*). Another problem related with the adaptation of soil classification system is that systems change (orders and

Table 6
Instructions for authors on soil classification for major soil science journals. Information from guidelines and instruction for authors from the journal's websites.

Journal	Guidelines and instructions for authors
Applied Soil Ecology	Identify soils by Great Group name at least, and preferably by soil series name and. This should either be the FAO World Reference Base (*WRB*) for Soil Resources or the UDSDA soil classification systems.
Biology and Fertility of Soils	No instructions
Catena	No instructions
European Journal of Soil Biology	No instructions
European Journal of Soil Science	No instructions
Geoderma	No instructions
Geoderma Regional	Provide World Reference Base (FAO) and *Soil Taxonomy* soil classifications in the keywords. Please indicate the soil classes of your study area in *Soil Taxonomy* or *WRB* (or both), using only the soil class and not the description.
Land Degradation and Development	No instructions
Nutrient Cycling in Agroecosystems	No instructions
Plant and Soil	No instructions
Soil and Tillage Research	No instructions
Soil Biology and Biochemistry	No instructions
Soil Science	No instructions
Soil Science Society of America Journal	All soils discussed in the manuscript should be identified according to the U.S. soil taxonomic system at first mention; reference to the NRCS soil series, and SSSA glossary (SSSA, 1997).
Soil Use and Management	No instructions
Vadose Zone Journal	Use of *Soil Taxonomy*, official soil series, reference to the SSSA glossary (SSSA, 1997) and to *Soil Taxonomy* (Soil Survey Staff, 1975).

soil groups are added, soil groups disappear) which has discouraged users.

Soil classification has a bad reputation and for that reason has become absent from some teaching programs (Langohr, 2001) or is being taught questionably and with outdated versions of *Soil Taxonomy* (Brevik, 2002). Attempts have been made to illustrate and simplify *Soil Taxonomy* in order to encourage its use among students and soil professionals (Soil Survey Staff, 2015); no such efforts exist for *WRB* except perhaps for its soil atlas (Bridges et al., 1998). Handbooks on soil classification are not user-friendly and are often in need of a glossary and an index (Langohr, 2001) and there is a need to correct some of the existing textbooks on physical geology (Brevik, 2002).

6.3.3. The soil science journals

The last problem with the use of soil classification is the limited instruction in soil science journals. Table 6 lists the guidelines and instructions for authors on the use of soil classification in 15 soil science

Table 7
Recent examples of factor or soil property naming in the title of soil science papers.

Factor	Name	Title	Reference
Climate	“Tropical soil”	Influence of biomineralization on the physico-mechanical profile of a **tropical soil** affected by erosive processes	Valencia et al. (2014)
	“Temperate soil”	Impact of plastic film mulching on increasing greenhouse gas emissions in **temperate upland soil** during maize cultivation	Cuello et al. (2015)
	“Boreal soil”	Logging residue harvest may decrease enzymatic activity of **boreal forest soils**	Adamczyk et al. (2015)
Organism	“Forest soil”	CO2 emissions from a **forest soil** as influenced by amendments of different crop straws: Implications for priming effects	Chen et al. (2015)
	“Agricultural soil”	Role of green waste compost in the production of N2O from **agricultural soils**	Zhu-Barker et al. (2015)
	“Urban soil”	The heterogeneity of **urban soils** in the light of their properties	Greinert (2015)
Relief	“Upland soil”	Resilience of **upland soils** to long term environmental changes	McGovern et al. (2013)
	“Lowland soil”	Nutrient uptake and use efficiency of dry bean in **tropical lowland soil**	Fageria et al. (2013)
	“Riparian soil”	Denitrifier community size, structure and activity along a gradient of pasture to **riparian soils**	Deslippe et al. (2014)
	“Wetland soil”	Linking tree species identity to anaerobic microbial activity in a **forested wetland soil** via leaf litter decomposition and leaf carbon fractions	Yavitt and Williams (2015)
Parent material	“Granite soil”	Application and comparison of shallow landslide susceptibility models in weathered **granite soil** under extreme rainfall events	Pradhan and Kim (2014)
	“Limestone soil”	Speciation and isotopic composition of sulfur in **limestone soil and yellow soil** in Karst areas of Southwest China: Implications of different responses to acid deposition	Zhang et al. (2014)
	“Alluvial soil”	Effects of endogenic earthworms on the soil organic matter dynamics and the soil structure in **urban and alluvial soil materials**	Amossé et al. (2015)
	“Colluvial soil”	Predicting the long-term fate of buried organic carbon in **colluvial soils**	Wang et al. (2015)
Time	“Young soil”	Effect of plant communities on aggregate composition and organic matter stabilisation in **young soils**	Gunina et al. (2015)
	“Weathered soil”	Hierarchical pedotransfer functions to predict bulk density of highly **weathered soils** in central Africa	Botula et al. (2015)
Color	“Black soil”	Tillage and rotation effects on community composition and metabolic footprints of soil nematodes in a **black soil**	Zhang et al. (2015)
	“Red soil”	Effect of soil erosion on dissolved organic carbon redistribution in subtropical red soil under rainfall simulation	Ma et al. (2014)
	“Brown soil”	Different denitrification potential of **aquic brown soil** in Northeast China under inorganic and organic fertilization accompanied by distinct changes of nirS- and nirK-denitrifying bacterial community	Yin et al. (2014)
Texture	“Sandy soil”	Biochar application does not improve the soil hydrological function of a **sandy soil**	Jeffery et al. (2015)
	“Clay soil”	Using TDR and modeling tools to investigate effects of interactive factors on preferential flow and transport in field **sandy clay soil**	Merdun (2014)
	“Loamy soil”	Degree of phosphorus saturation in **agricultural loamy soils** with a near-neutral pH	Renneson et al. (2015)
Drainage	“Poorly drained soil”	Long-term tillage and drainage influences on greenhouse gas fluxes from a **poorly drained soil** of central Ohio	Kumar et al. (2014)
	“Gley soil”	Environmental significance of magnetic properties of **Gley soils** near Rosslau (Germany)	Jordanova et al. (2013)
	“Aquic soil”	Nitrite behavior accounts for the nitrous oxide peaks following fertilization in a **fluvo-aquic soil**	Ma et al. (2015)

journals. It shows that only 4 have such instructions. It is particularly surprising that *Geoderma* and *Catena* have no longer instructions for authors. One of the first editors of *Geoderma*, Roy Simonson, wrote an editorial in 1973 in which he urged that the soil on which data are given in a manuscript should be identified according to: *Soil Taxonomy*, *FAO-Unesco*, or the Canadian, French or Soviet systems. The reasons were twofold: two international systems were available (*Soil Taxonomy* and *FAO-Unesco*) and it was the editorial policy to make a special effort to ensure that the papers appearing will be useful in as many parts of the world as possible. The need for proper information of soil classification in Geoderma manuscripts was repeated in 1978 and in 1983 (Hartemink et al., 2001).

6.4. We should care about soil classification

Soils have names, just like plants and animals. These names are derived from classification and often have Latin or Greek words or national folk names as a root. We classify soils to group our knowledge and increase our understanding. A lack of soil classification makes transfer of information, data and results difficult and affects transfer of technology in all fields where soil scientists are active. The transfer of knowledge (it worked on Typic Haplusterts in Texas, it might work on similar soils in the Sudan) is in the absence of soil classification difficult — if not impossible. Conducting soil research without proper classification would be comparable conducting a field experiment with "green plants" or a laboratory experiment with "some extremely small soil animals". Such is unacceptable to any editor of a soil science journal, yet the use of "agricultural soil" without further details seems quite acceptable. So is the naming of systems by its land use or some soil property (color, texture). Notions like the soil was clay and brown create a great deal of misinformation — that can affect environmental hazards related to agriculture, desertification, degradation and wrong land use decisions (Nachtergaele et al., 2000).

Most soil science journals no longer include instructions on soil classification. There is, however, a responsibility for journal editors and reviewers to point out that authors need to use well-established soil classification terms and that authors should refrain from naming soils based on a forming factor or a soil property. As a first step, such instructions should be introduced or re-introduced in all journals. This is a task for journal editors but could be coordinated by the IUSS Commission 1.4 on Soil Classification, or any of the National Soil Science Societies.

There is much soil information on the web and for most soil scientists there is no need to dig a pit, sample and analyze the soil, and classify it as for most parts of the world the soils have been mapped. There is some demise of pedology and field soil scientists in several parts of the world (Nachtergaele, 1990; Basher, 1997). The situation is particularly problematic in Africa where 25 years of emphasis on soil fertility (and its decline) has resulted in a total neglect of pedology, but it is not that different in several other parts of the world. In some university departments and research centers, there may be no expertise that can help in obtaining information from the internet, soil survey reports or any other source containing soil classification. This may partly explain the increase in soil naming using factor or soil property information.

In addition to the lack of experts, there are issues with soil classification training and education. In 2001, it was noted that specific training on soil classification was diminishing and became optional in many soil science courses (Langohr, 2001). Although the situation is different in different countries, it is advocated here that the use of soil classification should be part of a soil science curriculum. There may be no need for students to classify a soil themselves, but they should be familiar with the terms, appreciate its relevance, and know where the information can be found. Just like they should be able filter any other (soil) information on the web, they should be able to find soil classification information. Much soil science is taught outside agricultural schools and most is related being taught in environmental science, geology and geography (Brevik, 2009) where soil classification is of no less importance.

7. Conclusions

In the past 40 years, much time has been spent in a relatively small part of the soil science community on developing soil classification systems. Although there has been criticism on the products, it has yielded enormous insight on what soils are, and how they could be grouped taxonomically or for environmental or agricultural purposes. From this analysis it was found that there is:

(i) an exponential increase in the use of *Taxonomy* and *WRB*,
(ii) the increase in soil science papers outstrips the use of *Soil Taxonomy* and *WRB*,
(iii) factor and property naming in soil science papers increases much faster than *Taxonomy* and *WRB*.

There is ample soil classification information available on the web but there seems a new generation of soil scientists who do not know how to access it or use it properly. This is accompanied by a decreasing of number of soil scientists and pedologists who know field soil science, soil survey and classification. There is a need for education and instruction in our journals, and teaching curricula.

Renewed interest in pedology following the developments in digital soil mapping and morphometrics, proximal soil sensing, and the Universal Soil Classification System will create appreciation for one of the most demanding task in our discipline: classifying soils. We need to be critical and need to make progress.

Acknowledgments

This paper is dedicated to the late Dr Wim Sombroek – a giant in the field of pedology – who was disturbed that I had used Oxisols in the title of a paper in *Geoderma* ("Here we speak of Ferralsols! Do you understand that!"). He then did not speak to me for six months, after which we became good friends and had fruitful discussions on our common interests, even about soil classification.

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