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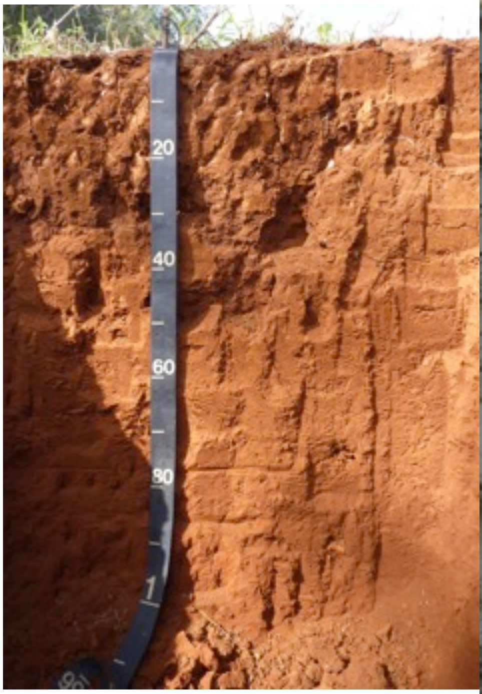

MAGIC NUMBERS

A META-ANALYSIS FOR ENLARGING THE SCOPE OF A UNIVERSAL SOIL CLASSIFICATION SYSTEM

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MAGIC NUMBERS: ENLARGING THE SCOPE OF SOIL CLASSIFICATION SYSTEMS

From the most remote period in the history of the world, organic beings have been found to resemble each other in descending degrees, so that they can be classed into groups under groups. This classification is not arbitrary like the grouping of stars in constellations.
(Darwin, 1859, p. 431; in Medin and Atran, 2004)

Book Index

PREFACE by Richard W. Arnold

Imagine a cosmos that is entirely energy. The energy has many forms most of them extremely active and mobile. On Earth the non-living components are also energy but generally in passive modes, however they respond by absorbing, transmitting, and re-emitting energy that connects with them. They have color, heat, structure, consistency and so forth. Living things, in particular humans, are extremely complex organisms which react to energy stimuli in a seemingly different manner, due to the presence of a brain or similar means that interpret the stimuli. They respond unconsciously to the waves of energy we recognize as senses; sight, sound, touch, smell and taste. In addition humans have a capacity to perceive thoughts, images and other sensory perceptions such that they have both short and long term memories, perceive of other places, times, and thoughts, and develop and use languages.

The English language, for example, only has 47 sound units called phonemes. Crude examples are illustrated as combinations of symbols, primarily letters, to form words that can be heard, or read and translated mentally into millions of perceptions of our environments and our own being. These reactions are primarily unconscious responses. Almost all of our physical responses are unconscious and occur so rapidly we are seldom aware of the connections that have transpired. We may see, feel, and hear changes of energy that are interpreted as fear and our bodies respond to get away or brace for an attack. Such is the fascination of the evolution of our perceptions and responses to constantly changing streams of energy.

Perceptions are interpretations and as such two aspects are of particular interest to this book. One is the discrimination of sensory perceptions into a vast array of groups. When we are born we hear sounds and after some trials and errors we associate a special set with Mother. It is a "prototype" of a unique entity among all others. As our eyes gain exposure we establish many visual prototypes of humans, animals, hard and soft objects, and so on.

Similar events occur with our other senses. We are ready-born classifiers – in fact, the repertoire is indeed vast. Refinement of the prototypes is almost instantaneous as we gain knowledge about our surroundings, and the properties and features relevant to the domains we establish in our brains.

The other aspect is the phenomenon of so-called short term and long term memory. Our beings are bombarded with so much energy which is translated into perceptions that we can only hold a little at any one moment. When sleep or rest occurs, our brains work to sort out those perceptions that are needed for survival, for growth, for understanding, for recall and all the linkages to actions and reactions. It is then that some of the short term memories are converted to long term ones.

Why bother you with these stories? Because we are innate classifiers and are very skilled in the process even if we do not spend much conscious time or effort doing so. Our brains carry on many functions that we still do not understand well, nevertheless we realize we like to be safe, healthy, and satisfied. Many of these needs and desires are associated with how we organize information for efficiency and effectiveness of storage and retrieval.

If you keep these aspects in mind as you browse or read this book, hopefully you will recognize that you have the internal capacity to help develop a universal soil classification. Also you will note the authors have provided some tools and concepts about taxonomies and classifications that give you additional means of evaluating the approximations of structures suitable for such an undertaking.

In addition to the main theme of taxonomic structure, a number of other aspects are pointed out for your consideration. Many will be familiar but a few may be outside your current scope as indicated by the range of offered references.

Do I agree with all the concepts presented? Probably not. For example, my background in pedology suggests that soils as I have known them are scale dependent, and as observed in the field our mental images (whether of individuals or as continua) are organized commonly by degrees of spatial dominance. Thus as map scales become smaller the landscape units become associations of several kinds of soil and are no longer pedotaxa entities. I also believe that parent material complexities have been underutilized, as has the extent of anthropogenic interventions, both in our development of taxonomic structures and as improved models of our traditional paradigm. Consequently better understanding of the details of geomorphic processes and properties for me is essential to obtain consistent extrapolations of field observations. The inconsistencies of my biases as they may affect taxonomic structure suggest that my innate capacities have not yet been fully developed or utilized.

My congratulations to the authors for their willingness to express their thoughts and opinions about developing a universal soil classification system. It was once said that every encounter is an opportunity either to learn or to teach. I am reminded of the story about the three legged stool of teaching. First you must learn how to learn, then you must learn how to teach, and finally you must teach so others may learn. Astronaut Christa McAuliffe, a school teacher who died in the 1986 tragic disaster of the Challenger shuttle takeoff, was once quoted as saying, “I touch the future; I teach”. May we all benefit from the “Magic Numbers”.

Preface

Usually, people consider that building a taxonomy or a dictionary is a simple task. In fact, a fine mathematical structure underlies taxonomies, dictionaries, and international codes of nomenclature. Similarly, the human mind subconsciously works in mathematical terms, in spite of the controversies that differ among experts. For instance, if a dictionary has to be compiled, the work consists in using the smallest possible number of words to convey the same amount of information. This is why over the last years mathematicians, experimental psychologists, philosophers and experts in cognitive sciences, among others, have been detecting astonishing mathematical similarities between different taxonomies and dictionaries.

In the era of the Internet, “the network of the networks”, scientists debate whether networks are more efficient than hierarchical systems to transmit information. However hierarchies are actually just a special kind of network with their own characteristics or laws of organization.

From many points of view, science is a social construct. Accepted and defended ideas within society permeate into the scientific practice, inducing biases and fads. If Internet and social networks did not exist, probably the science of networks would not have emerged as a hot topic today. This is not the first time that science and society have been linked by underlying bonds that are not visible to most humans. For example, the Newtonian mechanics produced a vision of the world where a number of aspects of everyday life were represented as parts of an engine. In all periods of history, people have devised the world with relatively distinct perspectives.

Cognitive experts, anthropologists, and experimental psychologists agree that the language determines our thinking. Without a sophisticated language our reasoning would be very primitive. This is why different cultures have different ways to perceive the surrounding world. Our reasoning requires fragmenting the world continuum into discernible hard classes. This is the purpose of any classification. All individuals and cultures use, consciously or unconsciously, hierarchies in all aspects of every day's life.

Classification is basic for all languages. Experts of a given science communicate using a common language. The more universal the language, the fewer the impediments to suitable communication between the members of a global scientific community. Universal classifications are vital tools as a language of communication in a given scientific community. A major question is whether soil taxonomies are similar to biological taxonomies that have sophisticated universal classifications.

However, both our cognitive structures and the laws of physics determine that mental structures are necessary in order to operate an efficient language or information system to transmit information. This language must conform with the needs of our cognitive processing systems, whether implicit and explicit, eliminating all biases as much as possible, but taking into account the shortcomings of our cognitive apparatus. A classification built without explicit rules will need to be adjusted by trial and error tests.

The fact that the structure of all taxonomic systems, although established independently, is mathematically similar seems to show that there is a natural tendency to get an efficient language or information system. The fact that, for example, the USDA Soil Taxonomy and bio taxonomies have similar structure corroborates partly this hypothesis.

Likewise the authors address many other different aspects related to the building of taxonomies other than structural ones. Each of them could be considered as part of a whole or as independent pieces. For example we expose the pros and cons of developing taxonomies as closed or open systems in which the purposes of the designers (architects) of a universal classification soil classification make their own decisions with as much information as possible.

The purpose of this manuscript is to describe and analyze the state-of-the-art in taxonomic structures as a basis to address the issue of building a universal soil classification system.

This document is not a finalized doctrinal corpus, but a discussion paper to initiate an orderly discussion on the world of taxonomies.

A draft of this document was previously submitted to some colleagues for critical assessment. Some considered it as a defense of classical versus mathematical classifications. Others inferred that the manuscript is a defense of the USDA-Soil Taxonomy against the WRB (2006-2007) (FAO, 2006). Although hierarchical taxonomies are considered a good choice on which to build a Universal Soil Classification, the diagnostic criteria used by the USDA Soil Taxonomy are neither advocated nor questioned. The same is true with respect to the qualifiers of the WRB as well as the potential products of a given numerical soil taxonomy. Research shows that hierarchical classifications are innate to the human mind (Mosterín, 1984, Sattler, 1986). It is possible that the USDA-Soil Taxonomy, WRB (2006-2007) and numerical approaches will provide interesting and complementary features and a rationale to move ahead to a truly new Universal Soil Classification System.

1. A meta-analysis of a universal soil classification: the purpose of this document

The term meta-analysis, as defined by Glass (1976), has a strong statistical bias. In the next pages meta-analysis will be considered as the study that combines the results of different scientific disciplines and perspectives to obtain a broad view of taxonomies from qualitative and quantitative points of view (see also Ibáñez et al., 2009). This approach involves branches of the human, social and experimental sciences. In many aspects, the approach follows the Actor-Network-Theory proposed by Bruno Latour (1999) in which humans (experts and non-experts) and technologies interact in a scientific activity. Human and non-human agents must be considered as parts of a single system, therefore, this perspective implies a systemic approach to the object of study.

This study addresses the analysis of soil taxonomy, although the procedure is applicable to the development of other taxonomies.

We believe there is the need for a deep analysis of all the system elements involved before addressing the analysis of the mental and social constructs that generally require expert working groups and subgroups to perform necessary tasks to move ahead an objective, such as a Universal Soil Classification. The meta-analysis from this point of view should be prior to studies, in order to provide a common doctrinal corpus and scientifically coherent guidelines.

2. Introduction to taxonomies

A classification is the act, process, or result, of placing objects into different classes. The terms classification and taxonomy are not synonymous, as taxonomy concerns the logical scheme (theory) of a given classification.

Classification will be referred to as the systematic grouping of objects (e.g. organisms, soil types, or pedotaxa) into categories and classes on certain bases, whereas taxonomy will refer to the relationships among objects on the basis of structure, resemblance, evolution or other kinds of relationships. Originally, the word taxonomy was used in science only to classify living organisms, but later it was applied in a wider sense referring either to a classification of things or the principles underlying the classification (e.g. Mosterín, 1984).

Classifying is a human procedure and, as such, the activities involve uncertainty and subjectivity (Lévi-Strauss, 1978). Different analyses of everyday scientific work indicate classification to be a physical and temporal, socially distributed activity that does not eliminate uncertainty and inconsistency, but tends to minimize contradiction (Roth, 2005).

There are different ways to classify objects (e.g. nominal and tabular as the *Mendeleev periodic table*). New approaches to classify are being developed taking advantage of increasing computational capabilities. Some of these new alternatives are not usual to the human mind, which is thought to process information through discreteness or "reification" (Mosterín, 1984). Reification, or hard class partitioning, consists in breaking up so-called continua into discrete classes in order to get the best communication possible among humans (Houdé et al., 1998).

A taxonomic classification is the act of placing objects or concepts into a set of categories based on the definitions of taxa and using properties of the objects as indicators of the words of the definition. All people classify objects or concepts according to a given ontology; that is, universal knowledge of being. Examples of taxonomic classification include library classification, scientific classification of organisms, classification of finite simple groups, medical classification, subject classification, security classification, folksonomies, and so forth. Most taxonomies are hierarchical. In mathematical terms, this means breaking a given continuum or domain of interest (e.g., pedosphere) in an iterative way into discrete units, such as soil types or pedotaxa (Figure 1). In logical terms, nested classifications are based on an increasing degree of detail or refinement (Mosterín, 1984). In topological terms, hierarchies imply tree structures. A tree is a way of representing a hierarchical structure in a graphical form that simulates an inverted aboveground tree. In graph theory, a tree is a connected acyclic graph; every finite tree structure has a member that has no superior called the root node. The lines connecting elements are called branches; the elements themselves are called nodes, and a node without other branching nodes is an 'end-node'. It is usual to distinguish between hierarchy and network, but a hierarchy is in fact a special type of network conforming to certain well specified rules.

The term hierarchy is an old one (in Greek: Ιεραρχία, derived from *ιερός*-hieros, sacred, and *άρχω*-arkho, rule), usually associated with the ecclesiastical hierarchy. It appeared in the Oxford dictionary (English language) the first time in 1380. The social world around us is full of hierarchies (e.g. military, castes, and so on). It seems to be an integral part of our society and our minds.

Figure. 1 shows a simple and symmetrical interactive fragmentation model: The Standard Cantor Bar, as described by Tang et al. (2008).

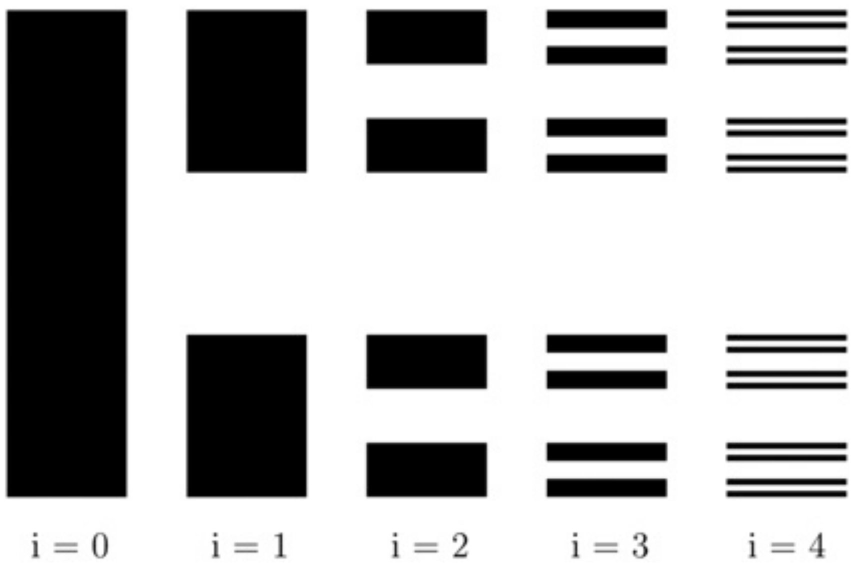


Figure 1. Breaking the continua: taxonomies as nested classifications of fineness (detail) increasing from the top levels to the lower ones figure show a Cantor Bar, when the continua is break step by step (iteration) in two nested ones (after Tang et al 2008, with permission). The Cantor Bar could be considered as the most elementary symmetrical nested classification. Legend: i = 0 (root node), i = 2 (first hierarchical level), I = 2 (second hierarchical level), (…) I = 4 fourth (hierarchical level or in this image the end node).

Most traditional soil classifications are hierarchical. They use the structure proposed by the Swedish botanist Carolus Linnaeus (1707-1778) who used comparative anatomy to group taxa according to shared morphological characteristics. Thus, it is possible to consider that current classifications are hierarchical by tradition; however, hierarchical organization also appears to be inherent to human thought.

Some decades ago, classical hierarchical classifications were questioned by some biotaxonomists who claimed that numerical classifications were more objective (Sneath and Sokal, 1973). In their turn, numerical classifications were questioned (e.g. Steward, 1998, 2002; Ibáñez and Boixadera, 2002; Ibáñez et al., 2005; among others) and they failed to replace the classic approach.

In this book the structure of the USDA Soil Taxonomy is examined from the perspectives of mathematics, thermodynamics, information theory, cognitive sciences, anthropology, ethnobiology and ethnopedology. Based on that information, guidelines for a more ideal soil classification scheme consistent with the human cognitive span can be developed.

3. Taxonomy and the science of the taxonomy: the role of hierarchical schemes

There is evidence that there is an instinctive need to structure phenomena in taxonomic hierarchies (e.g. Kay, 1971, 1975). Universal classifications are vital tools as languages of communication within and between scientific communities (Mayr, 1989; Mosterín, 1984; Sattler, 1986; Krasilnikov, 2002; Ibáñez and Boixadera, 2002; Ibáñez et al., 2005, 2006; Krasilnikov et al., 2009; among others). The main doctrinal corpus has been developed by analytical philosophers, anthropologists, and more recently experts in cognitive sciences (Mosterín, 1984). In fact, most scientific classifications and taxonomies have been built in different disciplines without paying attention to any theoretical structural framework. Most papers dealing with the nature of taxonomies and classifications from a disciplinary point of view address their history, rationale, philosophy, and use. This is also the case in pedology (Krasilnikov, 2002; Buol, 2003; Dudal, 2003; Arnold and Eswaran, 2003; Ahrens et al., 2003; Ibáñez et al., 2005). Currently, classical pedological classifications are being questioned by some pedometricians, using similar arguments as those used previously by numerical taxonomists in biology. Most soil taxonomies are hierarchical (Krasilnikov, 2002; Ibáñez and Boixadera 2002; Shoba and Krasilnikov, 2002; Ibáñez and Saldaña, 2008). Only a few papers are concerned with the mathematical structures and their significance as retrieval information systems in soil science (Guo et al., 2003; Ibáñez and Ruiz-Ramos 2006, Ibáñez et al., 2006: Ibáñez et al., 2009) and a few more in biological taxonomies (e.g. Clayton, 1974; Burlando, 1990, 1993; Minelli et al., 1991). It is of interest that most of these mental constructs follow similar structures and mathematical patterns (Ibáñez and Ruiz-Ramos 2006; Ibáñez et al., 2006).

4. The role of numerical tools in universal classifications

Numerical methods began to be applied in biological classifications with the rise of biometrics in the last decades of the 19th century, and interest for them has increased with the development of computer technology. Numerical taxonomy is based on methods that are objective, explicit, and repeatable (Sokal and Sneath 1963; Sneath and Sokal, 1973). The purpose was to get a “perfect taxonomy” making use of information-rich taxa based on as many features or characters as possible. It was assumed that all characters would have equal weight. Thus, the similarity between two given individuals is a function of the similarity of the characters on which the comparison is based and taxa result from the character correlations in the groups studied. This school is known as phenetics. Similar principles were used to build numerical taxonomies of soil units (Bidwell and Hole, 1964; Webster, 1977).

Numerical classification was criticized by the school of biological systematics (Mayr, 1965, 1969, among others). According to Mayr (1965): "*They are not satisfied with merely providing new methods for quantifying degrees of similarity and converting this information into the grouping of higher taxa. Rather, they insist on a new taxonomy altogether. (...) The choice of the term "numerical taxonomy" for this very special taxonomic theory seems rather unfortunate, when we remember how far back (around 200 years) good taxonomists have insisted on using the "greatest possible number of characters." That only a consideration of the totality of characters can lead to a sound classification was already expressed by Buffon and Adanson in the middle of the 18th (...)*

Ibañéz and Boixadera (2002), Ibáñez et al. (2005) and Ibáñez and Saldaña (2006) used epistemological, philosophical and mathematical arguments to question the arguments of pedometricians. However in both biological and pedological cases, these proposals have not been accepted by the whole of their respective scientific communities (see Sattler 1986 for the case of biological taxonomies). Likewise in biotaxonomy the phenetic approach soon began to be questioned by the cladistic school proposed by Henning (1965, 1979). This controversy does not mean that several tools developed by cladistics and pedometricians can not be very useful for some aspects of the development of novel and improved taxonomies. Currently many taxonomist make use pragmatically of some principles and methods proposed by phenetists, cladist, as well as the most classical biological systematics (A. Bello and M. Arias; nematode taxonomists, personal communication). Many systematists continue to use phenetic methods, particularly in addressing species-level questions, while the ultimate goal of a universal taxonomy is a description of 'tree of life'. All these schools are not incompatible rather they are complementary ones (e.g. Sattler, 1986; Ibáñez et al. 2005).

The number of characters that can be measured or identified in soils to obtain "a complete space of characters" is very large. Gathering these characters is expensive and time-consuming. In practice, the number of soil characters that are measured depends both on theoretical principles and economic interests (utilitarian bias). Furthermore, most biologists work with a restricted range of related taxa, whereas pedologists work with a variety of taxa in nature: "the whole of the soil patterned continuum" (Ibáñez and Boixadera, 2002). In this case pedometric tools seem not to be a user friendly option. Pedologists, like biologists, agree that distinct pedotaxa-biotaxa demand different characters and features to be measured. This also occurs with the characterization of distinct genetic soil horizons.

Numerical tools are useful when large soil databases are available to build a more formalised classification that solves some specific problems in a given taxon. Pedometrics and fuzzy logic (e.g. Kosko, 1993; MacBratney and Odeh, 1997) are also useful for "ad hoc" purpose-oriented soil classifications at detailed scales in homogeneous landscapes (e.g. for precision farming). Fuzzy sets can be used to identify intergrade soils. Although children can be trained to deal with fuzzy logic we do not believe it is as easy or normal to learn compared to hard classes. Fuzzy classes and algorithms are useful for many computer activities. International Codes of Biological Nomenclatures use consensual methods, instead of fuzzy sets, to discern and recognize different hybrid taxa. A similar procedure could be implemented in soil taxonomy (Ibáñez et al., 2005).

Pedometric tools could be very useful to support decisions if objective, explicit, and repeatable numerical protocols are used. The same numerical procedures should be mandatory for all taxonomic problems of the same guise (e.g. the election of precise similarity and/or distance algorithms). In practice there are a plethora of them, producing very different clusters of related taxa.

It is interesting to note the examples shown by Kachanoski (1988) as well as, Ibáñez and Saldaña (2008) concerning so called random variability of soil properties and a deterministic sequence of soil horizons assemblage. In some homogeneous landscapes, when the samples are taken to standard depths it is possible to detect that the variability of soil properties could conform to a nugget model, whereas the assemblage of soil horizons is deterministic. Possibly in some cases numerical taxonomies and the classical ones generate very contradictory and irreconcilable results.

A dilemma appears if a Universal Soil Classification were to be based on: (i) the most complete (as possible) number of soil characters, (ii) works with a priori set of diagnostic horizons, features and properties proposed by expert judgment, and (iii) a given mix of both approaches. The resulting products of each of these three alternatives may be very different. It should be remembered that the first option does not permit identification of pedotaxa in the field, and requires prior soil sampling, analysis and application of numerical procedures in the laboratory to assign a given soil profile to a given taxon.

Biological taxonomies often break higher categories into the same number of subcategories (subtaxa per taxa). However, from a logical point of view this procedure is not necessary (Kay, 1971, 1975). Gregg showed that a family that contains a single genus, that in turn contains a single species, violates mathematical-logical premises because the same taxon may be assigned to multiple levels in the Linnean hierarchy. Biotaxonomists by tradition do not follow the arguments forwarded by Gregg. However in "some instances" it could be interesting to fragment the soil patterned continua in branches with different ramifications. For example, if a new soil classification wants to incorporate some unusual natural bodies such as oceanic soils or Mars soil-regolith, it is possible and probably desirable to separate them into only a few classes, at least in the first editions. Indeed, it takes time to make the necessary scientific studies, explorations and findings to distinguish clear-cut classes and their relationships. With time these hierarchical branches will grow when scientific knowledge permits the formulation of more scientific sound classes (Figure 2).

Classifications in general are symmetrical and do not permit the existence of non-homogenous ramifications like those in natural structures such as drainage basins, roots, branches in threes and shrubs. Thus it is possible to conjecture that this trend could be a cognitive bias that disturbs the information processing by our cognitive apparatus, as we explain in sections 5, 9 and 10.

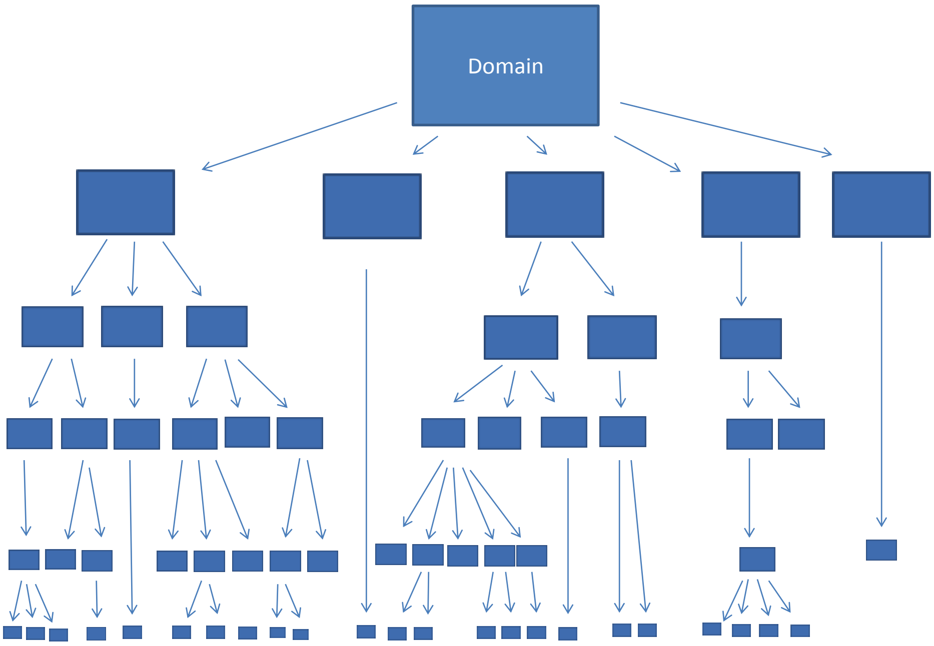


Figure 2. The Gregg Paradox: Asymmetrical Hierarchical Taxonomies

5. Ontological categories: the dilemma of the higher hierarchical levels

As we will analyse in the sections 13.3, 13.4, 13.5 and 13.11 according to the Miller Rule and the MaxEnt Principle, seven plus or minus two hierarchical levels is an optimum to build an efficient classificatory system. Furthermore, this number also appears to break other natural, social or technological phenomena as shown in Table 1.

However, many soil classification schemes, as for instance the USDA Soil Taxonomy, have many subtaxa per taxa at the highest level of the hierarchy (Orders). The same is true for the WRB (1998, 2006-2007), with 30-32 "Reference Soil Groups" (Table 2). These numbers are excessive according to the working hypotheses shown in sections 13.4, 13.5, 13.7 and 15. To solve this drawback, it is recommended to include one or two additional hierarchical levels, as the WRB frame actually does when grouping the Reference Soil Groups into ten generalized higher level classes.

GENETIC DIVERSITY	TAXONOMIC DIVERSITY	ECOLOGICAL DIVERSITY
Megagenome (global)	Kingdom (Division)	Biosphere
↓	↓	↓
Community	Phylum	Biome
↓	↓	↓
Population	Class	Landscape
↓	↓	↓
Organism	Order	Ecosystem
↓	↓	↓
Cell	Family	Ecosystem
↓	↓	↓
Organules	Genus	Patches
↓	↓	↓
Chromosomes	Species	Habitat-Niche

Table 1. "The Magic Number Seven" is common in hierarchical patterns and scales of diversity among many others phenomena (after di Castri and Younès 1996).

1st WRB Level	2nd WRB Level	1st WRB Level	2nd WRB Level
Histosols	14	Chernozems	9
Cryosols	19	Kastanozems	9
Anthrosols	12	Phaeozems	20
Leptosols	16	Gypsisols	17
Vertisols	16	Durisols	13
Fluvisols	21	Calcisols	15
Solonchaks	21	Albeluvisols	14
Gleysols	25	Alisols	19
Andosols	25	Nitisols	12
Podzols	15	Acrisols	23
Plinthosols	17	Luvisols	19
Ferralsols	22	Lixisols	20
Solonetz	15	Umbrisols	11
Planosols	27	Cambisols	26
Chernozems	9	Arenosols	20
Kastanozems	9	Regosols	19
Phaeozems	20	Total	531

Table 2. Structure of the WRB 1998. A Structure very far from the Magic Number 7

Likewise at the second level, the WRB (1998) has an excessive number of subtaxa per taxa (Table 2), and this suggests that an additional level would be useful. In most of the cases, the number of subtaxa (second level) per taxa (first level) exceeds the Miller rule, although the branching system is rather uniform and does not follow the Willis Curve (see section 13.1). Thus, the WRB (1998) is a fine system according to the Mayr criteria (see section 13.4) and the MaxEnt Principle, but not the Miller rule. In addition the new WRB version (2006-2007), the flat structure does not enable us to know the number of subtaxa per taxa, and thus the global pedodiversity as occur in biological taxonomies.

Another similarity between folk biology (see sections 13.9, 13.12, 13.14) and modern biological taxonomies is that the most general rank such as plants or animals (vertebrates and invertebrates or into the former ones animals reptiles, amphibians, birds, mammals), usually are not explicitly named. The highest hierarchical levels correspond to the notion of "ontological category", as used in philosophy and psychology. Medin and Atran (2004) argue that ontological categories may be learned relatively early in childhood (see also Hatano and Inagaki, 1999). Ontological categories have three advantages: (i) they give conceptual consistency to the taxonomic schemes; (ii) they are readily perceived (didactic) for beginners; and (iii) they allow dividing the current higher hierarchical level in a number of subtaxa that easily comply with the Miller rule (see section 13.11). Because ontological categories are not used in the denomination of lower hierarchical levels in biological systems they do not generally disturb the rationale of the latter. According to Medin and Atran (2004): *"(…) the next rank down in folk taxonomy is that of life form. Most life form taxa are named by cultural and locality specific terms (primary lexemes), (…) psychologically, members of a life form share a small number of perceptual diagnostics (…) (Brown, 1984)".* Pedological classifications do not include this type of ontological levels in their branching systems.

6. Ad hoc hierarchical levels into the hard hierarchical levels: a common practice in biotaxonomies

Pedology, as well as plant and animal sciences, requires a precise and simple system of nomenclature worldwide (see sections 8 and 14.1) that deals with the terms which denote the ranks of the taxonomic groups or units, and also with the scientific names applied to the individual taxonomic groups. Codes aim to provide a stable method of naming taxonomic groups, avoiding and rejecting the use of names which may cause error, ambiguity or confusion. Next in importance is the avoidance of the useless creation of names. Maybe pedologists, in contrast to biotaxonomists, do not feel the need of an "International Code of Pedological nomenclature". Such a code would allow easier correlation between future national soil classifications and link them to a universal one. The WRB was done with this purpose, but the final product is a soil classification. If a universal classification is considered as a universal language, an international code would be its lexicon.

A universal soil classification would become the common language between the specialists of a discipline. It may be complemented by an international nomenclature code (INC), as occurs in biological taxonomies. National soil classifications should be related through such an INC, if we do not want to keep on living in a "Tower of Babel". Making a new classification without examining what happens in other disciplines would be a mistake. This could be the role of macro-taxonomists in the future (see sections 12.3 and 12.4). There is much to learn from biological classification, as well as from recent developments in analytical psychology and cognitive sciences in general, with respect to the categorisation process. The human mind has potentialities and limits for memorizing and processing information. We should learn what is known of the human mind in order to process information, inasmuch as a classification, or taxonomy, is a retrieval information system in a fast and user friendly way. Classical conceptions help open our mind to the knowledge and developments of other disciplines which legitimise hard class partitions and hierarchical taxonomies, irrespective of the continuum or patterned continuum dilemma (see sections 7, 12.4 and 13.7) (Ibáñez et al. 2005; Ibáñez and Saldaña, 2008). Furthermore, Ibáñez and Ruiz-Ramos (2006) and Ibáñez et al. (2006) show that biological classifications and the USDA Soil Taxonomy have a similar underlying mathematical structure (Figure 3, 4 and Table 3).

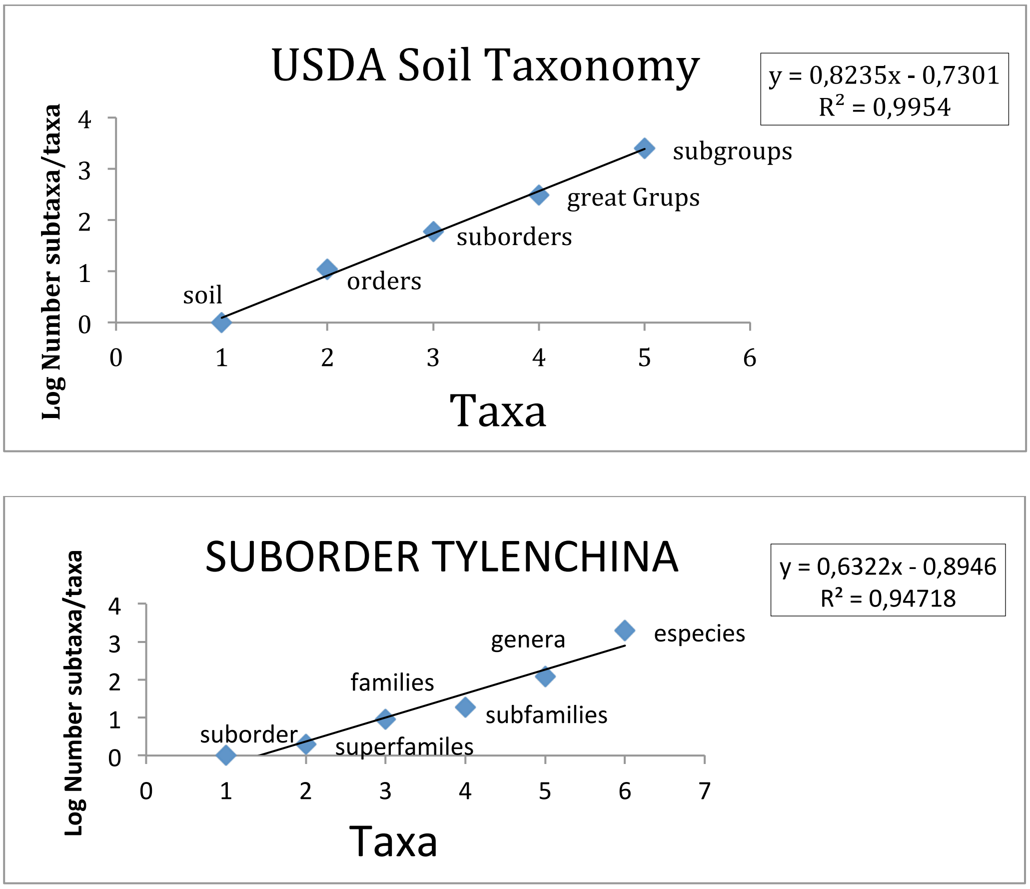
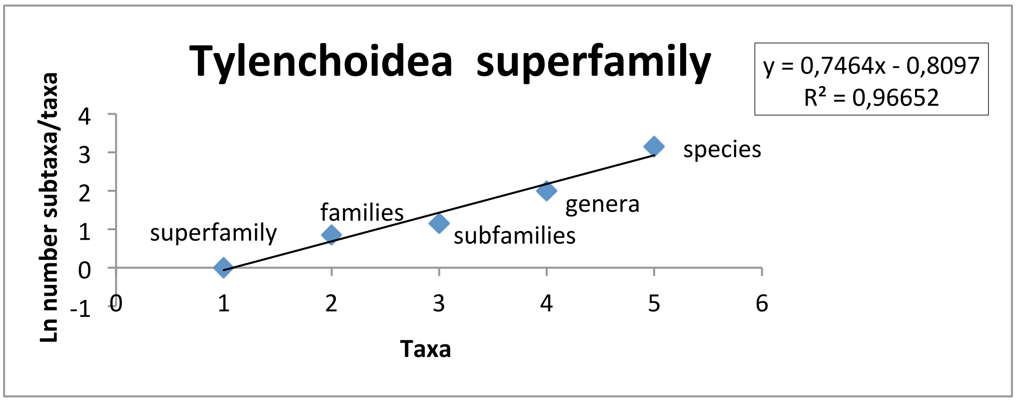
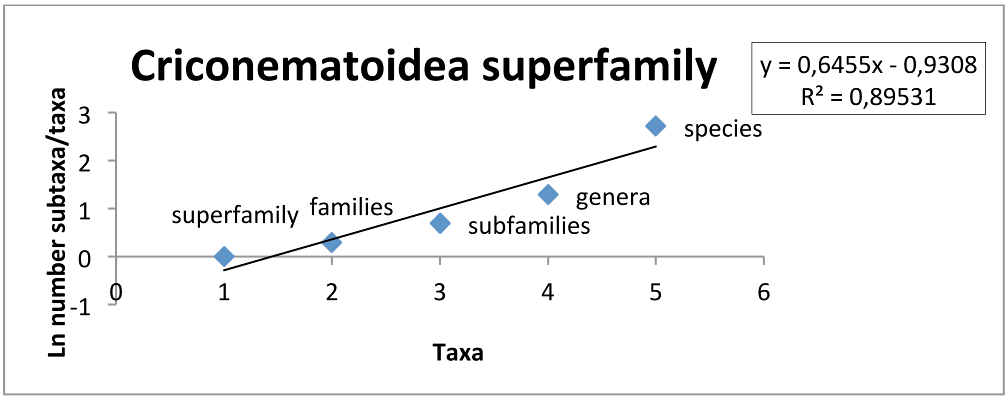
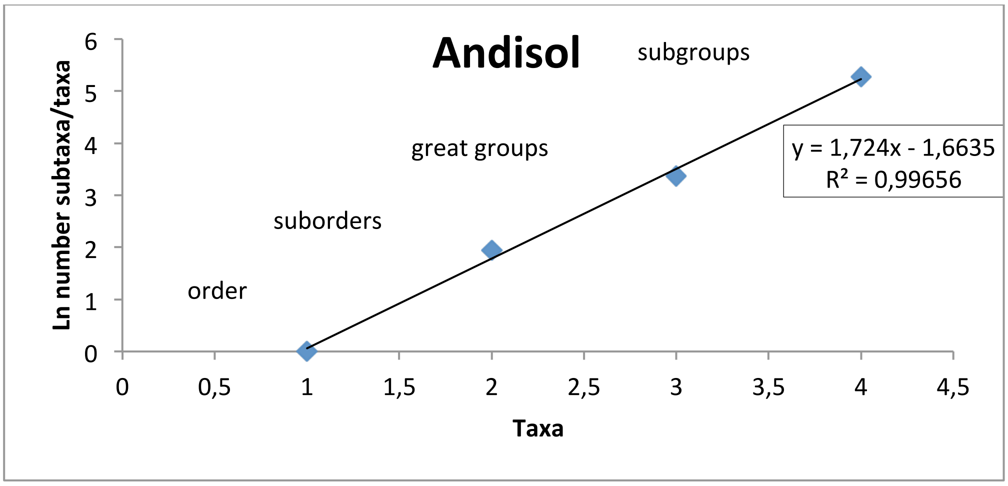


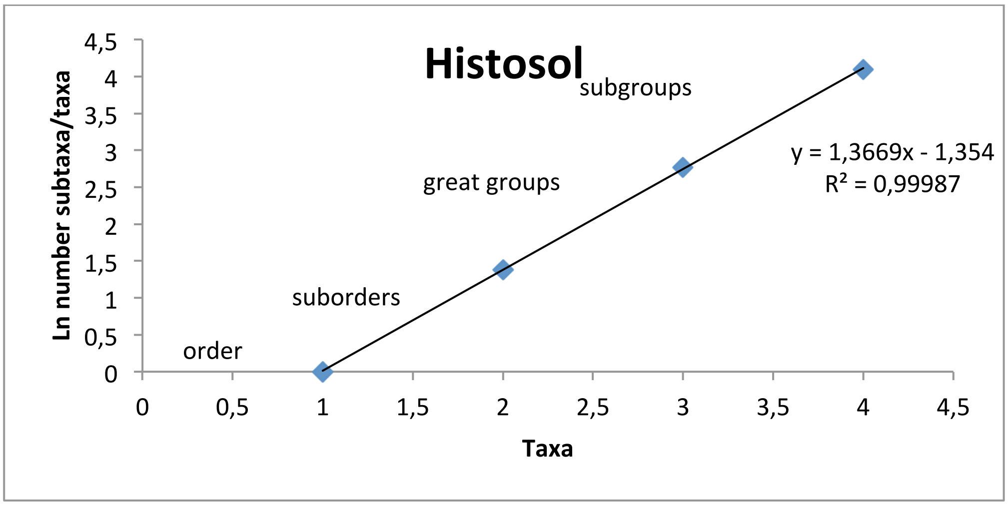
Figure 3. Linear regression of the size of the taxa as a function of the taxonomic category for the (a) whole *Soil Taxonomy* and (b) *Tylenchina* suborder of plant parasitic nematodes.

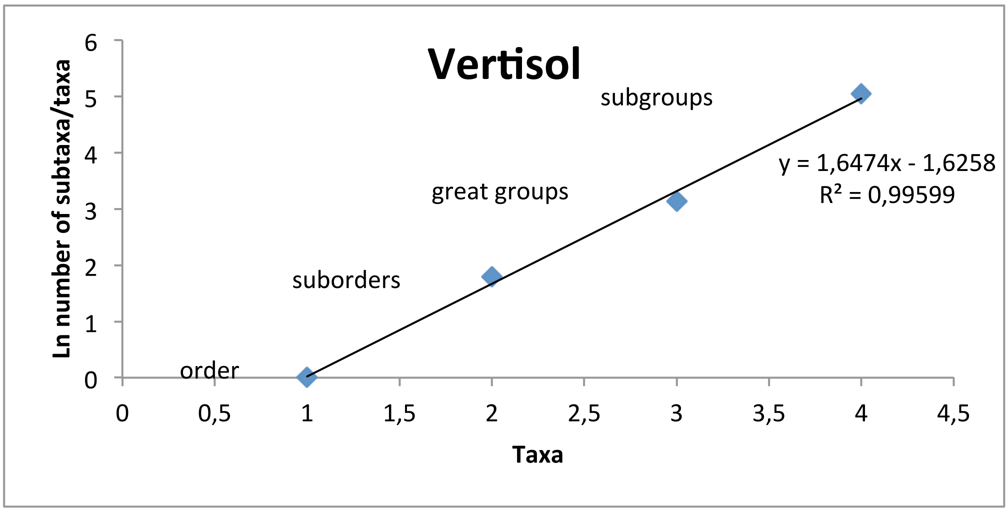
Arguments that a universal soil classifications is not suitable for solving all soil information demands are not epistemologically justified (logically meaningful) (Ibáñez and Boixadera, 2002; Ibáñez et al. 2005). Ad hoc interpretive classifications are required to solve issues of applied research (e.g. ecosystem classification, biocenoses according to biomass production, etc.). Georeferenced soil information systems that allow additional soil data collection and the acquisition of data supplied by the new technologies (satellite imagery, DEMs, sensors of various kinds, etc.), should free universal taxonomies from the applied role to which they were formerly subordinate.

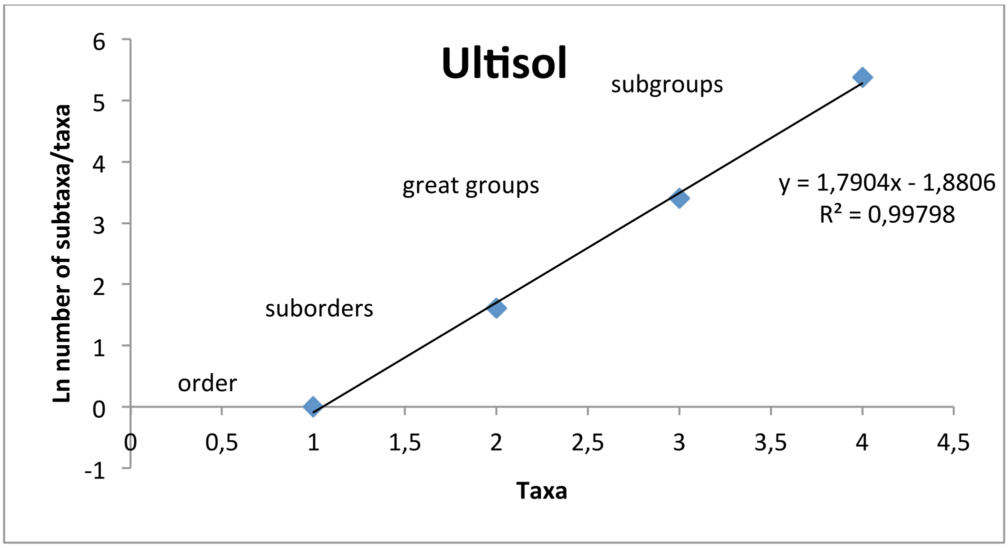

Tylenchoidea superfamily
y = 0,7464x - 0,8097
R² = 0,96652
Ln number subtaxa/taxa
Taxa
superfamily
families
subfamilies
genera
species
4
3
2
1
0
-1
0
1
2
3
4
5
6

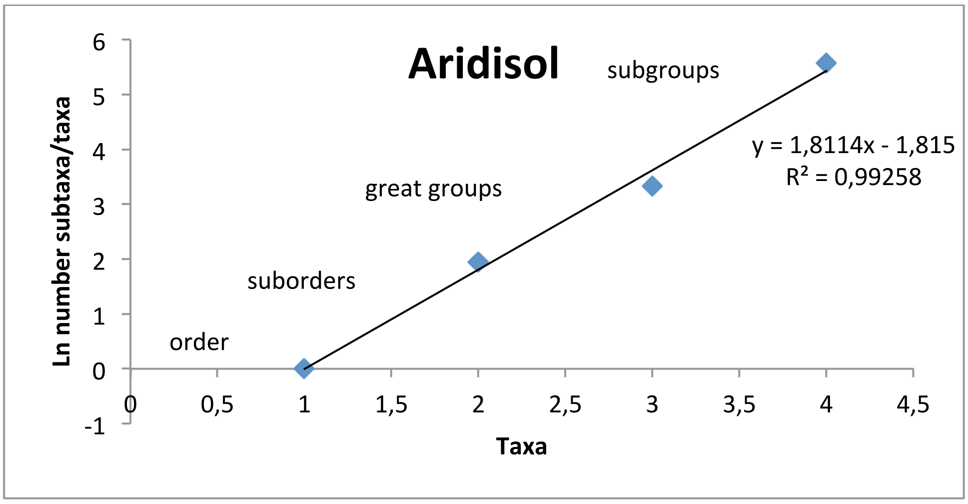

Criconematoidea superfamily
y = 0,6455x - 0,9308
R² = 0,89531
Ln number subtaxa/taxa
Taxa
superfamily
families
subfamilies
genera
species
3
2
1
0
-1
0
1
2
3
4
5
6

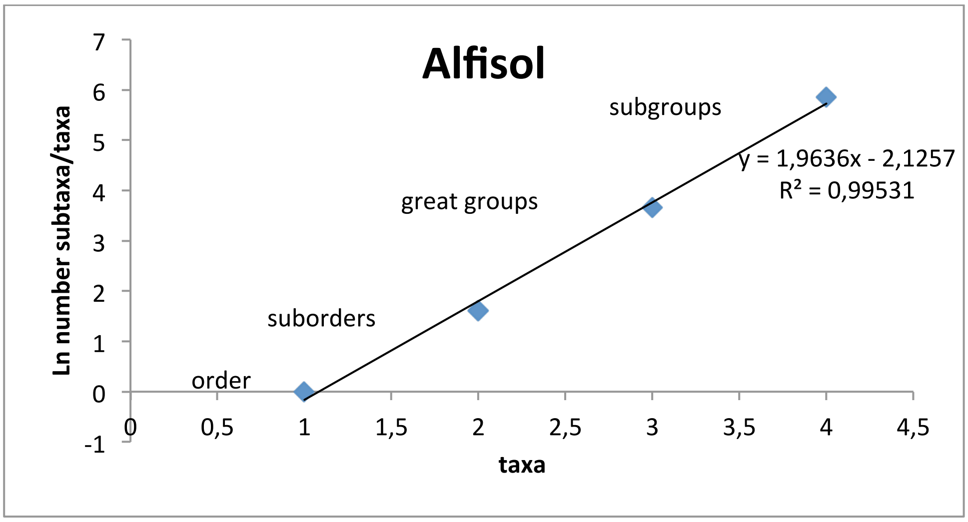

Andisol
y = 1,724x - 1,6635
R² = 0,99656
Ln number subtaxa/taxa
Taxa
order
suborders
great groups
subgroups
6
5
4
3
2
1
0
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5

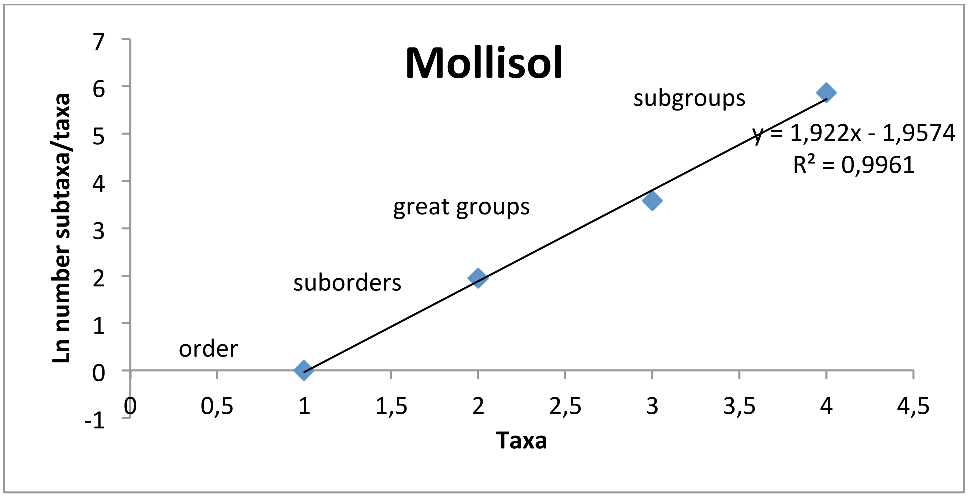

Histosol
Ln number subtaxa/taxa
Taxa
order
suborders
great groups
subgroups
y = 1,3669x - 1,354
R² = 0,99987
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5

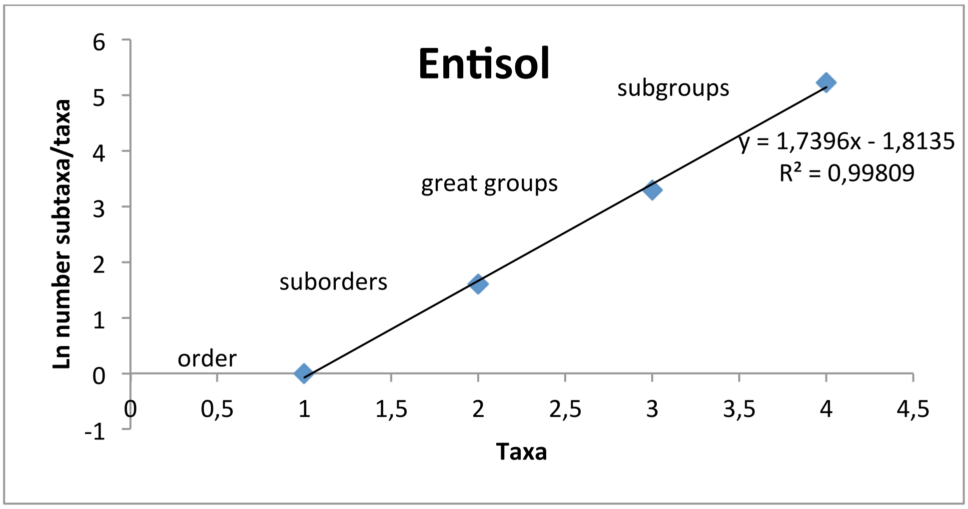

Vertisol
Ln number of subtaxa/taxa
Taxa
order
suborders
great groups
subgroups
y = 1,6474x - 1,6258
R² = 0,99599
0
1
2
3
4
5
6
0,5
1,5
2,5
3,5
4,5

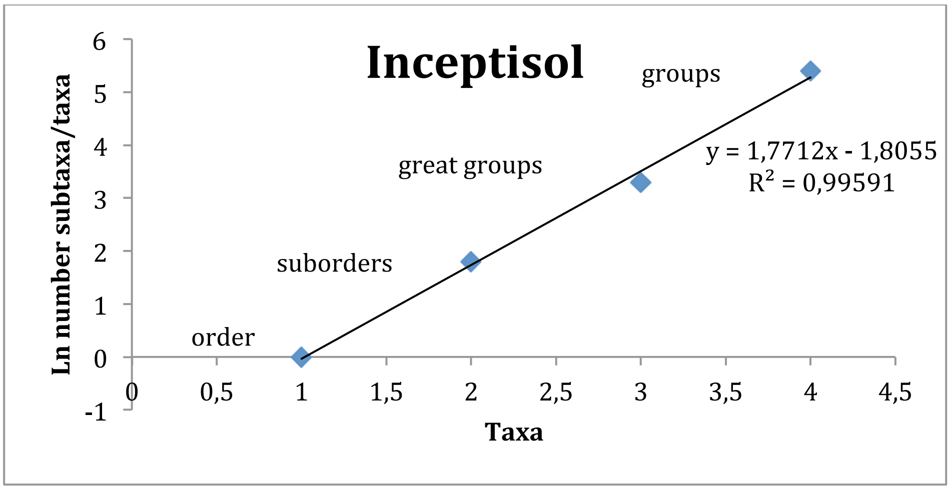

Ultisol
Ln number of subtaxa/taxa
Taxa
order
suborders
great groups
subgroups
y = 1,7904x - 1,8806
R² = 0,99798
-1
0
1
2
3
4
5
6
0,5
1,5
2,5
3,5
4,5

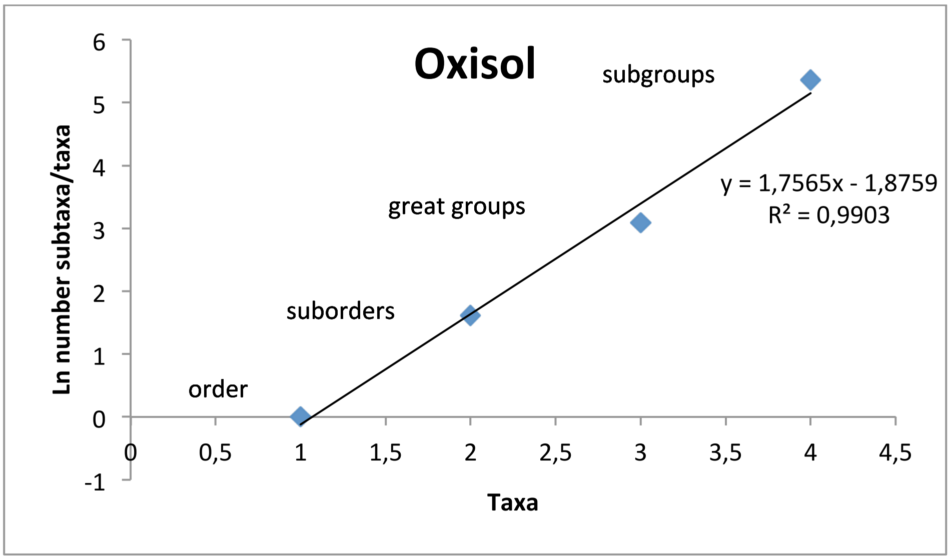

Aridisol
subgroups
great groups
suborders
order
y = 1,8114x - 1,815
R² = 0,99258
Ln number subtaxa/taxa
Taxa
6
5
4
3
2
1
0
-1
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5


Alfisol
subgroups
great groups
suborders
order
y = 1,9636x - 2,1257
R² = 0,99531
Ln number subtaxa/taxa
taxa
7
6
5
4
3
2
1
0
-1
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5


Mollisol
subgroups
great groups
suborders
order
y = 1,922x - 1,9574
R² = 0,9961
Ln number subtaxa/taxa
Taxa
7
6
5
4
3
2
1
0
-1
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5


Entisol
Ln number subtaxa/taxa
Taxa
order
suborders
great groups
subgroups
y = 1,7396x - 1,8135
R² = 0,99809
6
5
4
3
2
1
0
-1
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5


Inceptisol
Ln number subtaxa/taxa
Taxa
order
suborders
great groups
groups
y = 1,7712x - 1,8055
R² = 0,99591
6
5
4
3
2
1
0
-1
0
0,5
1
1,5
2
2,5
3
3,5
4
4,5


Oxisol
Ln number subtaxa/taxa
Taxa
order
suborders
great groups
subgroups
y = 1,7565x - 1,8759
R² = 0,9903
6
5
4
3
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1
0
-1
0
0,5
1
1,5
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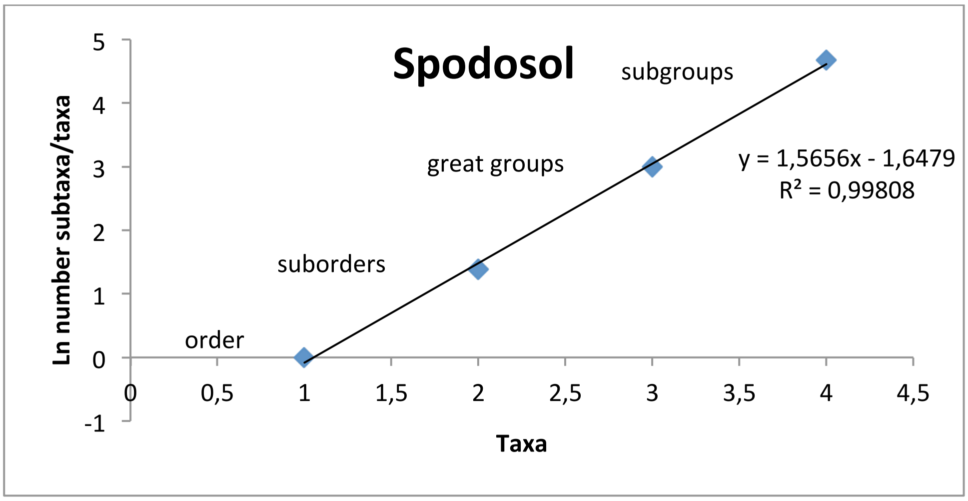
2,5
3
3,5
4
4,5



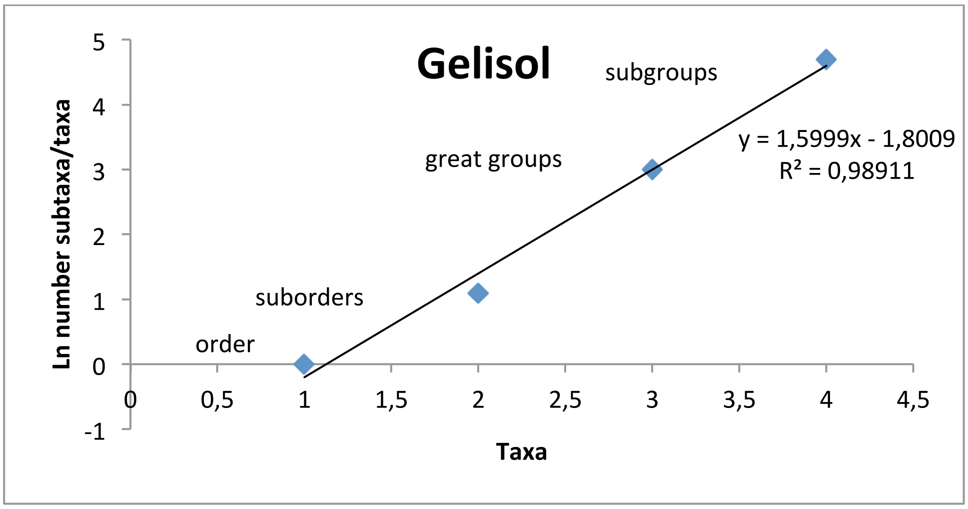


Figure 4. Subtaxa per taxa in logarithmic scale for soil orders of the USDA Soil Taxonomy (1998) and Tylenchena superfamilies. Log-normal plots of the frequency of different taxa in the Soil Taxonomy 1998 and its orders, and in the *Tylenchina* nematode suborder and its superfamilies. Regression line and determination coefficient R^2.

Biological classifications have taxa with conspicuous differences in the number of species included in each one of them. Some biotaxa have many species and others only a few. A rigid number of hierarchical levels could generate problems when, for instance, a genus, a family or an order has too many subtaxa exceeding substantially our short-term memory channel capacity (the Miller Rule).

Biotaxonomies commonly have a certain number of rigid hierarchical levels. When a given taxon has a large number of subtaxa, optional levels can be used to break the taxon into two or more classes (A. Bello and M. Arias personal communication). For example, in nematology, orders, families, genera and species are mandatory levels, whereas superfamilies, subgenera, etc. are flexible levels. Biotaxonomic practice shows that this procedure, which is explicitly mentioned in the International Codes of Nomenclature (see sections 8 and 14.1), is user-friendly and does not violate the rationality of the taxonomies.

Hierarchical Taxonomy	Taxa Number
Soil taxonomy	
Orders	12
Suborders	64
Great Groups	317
Subgroups	2432
***Tylenchina* suborder**	
Families	9
Subfamilies	19
genera	121
Species	1955

Table 3. The Structure of the USDA-ST and the *Tylenchina* Suborder analysed by Ibáñez and co-workers in different Studies (Ibáñez and Ruiz-Ramos, 2006)

Biotaxonomies commonly have a certain number of rigid hierarchical levels. When a given taxon has a large number of subtaxa, optional levels can be used to break the taxon into two or more classes (A. Bello and M. Arias personal communication). For example, in nematology, orders, families, genera and species are mandatory levels, whereas superfamilies, subgenera, etc. are flexible levels. Biotaxonomic practice shows that this procedure, which is explicitly mentioned in the International Codes of Nomenclature (see sections 8 and 14.1), is user-friendly and does not violate the rationality of the taxonomies.

The mandatory hierarchical levels in the "International Code of Botanical Nomenclature (Saint Louis Code), Electronic version" are the following in descending sequence: kingdom (regnum), division or phylum (divisio, phylum), class (classis), order (ordo), family (familia), genus (genus), and species (species) (table 1). Thus, there are seven levels, a figure that is in accordance with "Miller Rule" about the depth of a given taxonomy (see section 13.11).

7. Naturalia/artificialia dilemma and the splitters and lumpers controversy

The subjective nature of the traditional species concept (see section 13.7) was recognized by Cowan (1978), Sattler (1986), and Zimmer (2008) among others (see also, Hey, 2001; Ereshefsky, 2001; Hull, 1974, 1997, 1999, etc.). Cowan (1978) defines a species as a group of individuals defined more or less subjectively by criteria chosen by the taxonomists. In a sophisticated way, Sattler (1986) claims that species are peaks in a patterned continuum, as also claim some pedometricians in defence of numerical taxonomies (De Gruijter and McBratney, 1988; McBratney and De Gruijter, 1992). Odeh (1988) says: "*(…) Moreover, unlike species which are characterised by some degree of separateness based on their genetic pattern (Webb, 1954), the soil is a continuum often with no distinct boundaries between individuals. There are no unique soil individuals or pedotaxa as used by Ibáñez et al. (…)"*. However the concept of species and biological taxonomies have some of the same problems as the concept of pedotaxa and soil classifications (Ibáñez and Boixadera, 2002; Ibáñez et al., 2005; Ibáñez and Saldaña, 2008).

The intrinsic degree of artificiality of all taxonomies is exemplified by the splitters and lumpers controversy. Lumper taxonomists tend to emphasize the similarities between taxa trends, thereby recognizing relatively few ones, whereas splitters highlight differences with the belief that the clarity inherent to small groups is paramount. The latter propose many new species, whereas the former try to group these species in less taxa. Obviously, the "*publish or perish*" strategy in biotaxonomies is more productive for splitters than for lumpers (O' Donnell et al., 1995; Hey, 2001). The horizontal gene transfer flux has been recognised recently as a common process in the most diverse taxa (O' Donnell et al., 1995; Hey, 2001), putting in doubt traditional individualistic concepts. There is a similarity between the propositions in biology (Van Valen, 1976) and pedology (Wilding et al., 2002) about taxa without species or complex taxa. Therefore, the naturalia/artificialia dilemma is scientifically unsolvable (Ibáñez and Boixadera, 2002; Ibáñez et al., 2005), as is the splitters/lumpers dilemma.

8. How International Codes of Nomenclature in botany and zoology dodge the hybrid taxa problem in hard classifications

It is a common, but not a recommended practice that each discipline has its own idiosyncrasy as a psychological fact to reaffirm its own identity. This procedure is not recommended because in multidisciplinary "projects" (in the broadest sense of the term) it is difficult to change ideas, opinions, information, etc. Because, some pedons (soil profiles) have problems to be identified and classified it is possible to make use of biological experience. Hybrids are usual in plants. Biotaxonomists do not use fuzzy logic procedures as a user friendly tool (see sections 14.1 and 15.2). When a soil surveyor works in a given region or landscape, he can detect pedotaxa of the most disparate origin. He commonly uses a field key related to the local soil universe. Biotaxonomy is a very specialized discipline, thus when a team of biotaxonomists do a given inventory, they work with a very restricted group of taxa. Consequently a soil surveyor and soil taxonomist may differ in their approach to taxonomy.

The International Code of Botanical Nomenclature has very clear rules to specify hybrid taxa (and extinct taxa), including hybrids between two or more taxa belonging to different hierarchical levels, including hybrids among living and extinct biotaxa.

The articles H.1.1 and H.2.1 of the "*International Code of Botanical Nomenclature" (Saint Louis Code), Electronic version*: *Appendix I, Names of hybrids* state that: H.1.1. Hybridity is indicated by the use of the multiplication sign × or by the addition of the prefix "notho-" to the term denoting the rank of the taxon, and H.2.1. A hybrid between named taxa may be indicated by placing the multiplication sign between the names of the taxa; the whole expression is then called a hybrid formula. The procedures and rules of the above mentioned code are very detailed and clear to the reader.

Furthermore, relative to the classification of some paleosols the "*International Code of Botanical Nomenclature (Saint Louis Code), Electronic version*", chapter 1 states that: "*1.2. Fossil taxa may be treated as morphotaxa. A morphotaxon is defined as a fossil taxon which, for nomenclatural purposes, comprises only the parts, life-history stages, or preservational states represented by the corresponding nomenclatural type*". Is it not possible to do the same with buried pedotaxa that have difficulties of be classified with the modern soil taxonomies? Furthermore, this code also takes into account rules for hybrid morphotaxa nomenclature (see sections 8, 14.1, 14.2, and 15.2).

9. Taxonomic bias

Utilitarian, historic and geographic biases have been recognized to affect biological taxonomies (Walters, 1986; Sattler, 1986; Cronk, 1989; Hey, 2001; Ereshefsky, 2001).

In the case of the FAO (1998) Major Soil Groups, the correlation between surface area and number of soil types is moderate, indicating that the surface covered by a given taxon is usually correlated with its global extent (unpublished data).

There is a strong correlation between the surface area and the number of soil families and soil series in the USDA Soil Taxonomy. (Figure 5 a,b). This geographic bias decreases from the lower to the higher hierarchical levels of the system. At the top of the hierarchy, there is no correlation between the number of suborders per order and their respective surface area. It is remarkable that Oxisols depart from this rule (Ibáñez et al., 2009), however Oxisols are very limited in the U.S. (national geographic bias).

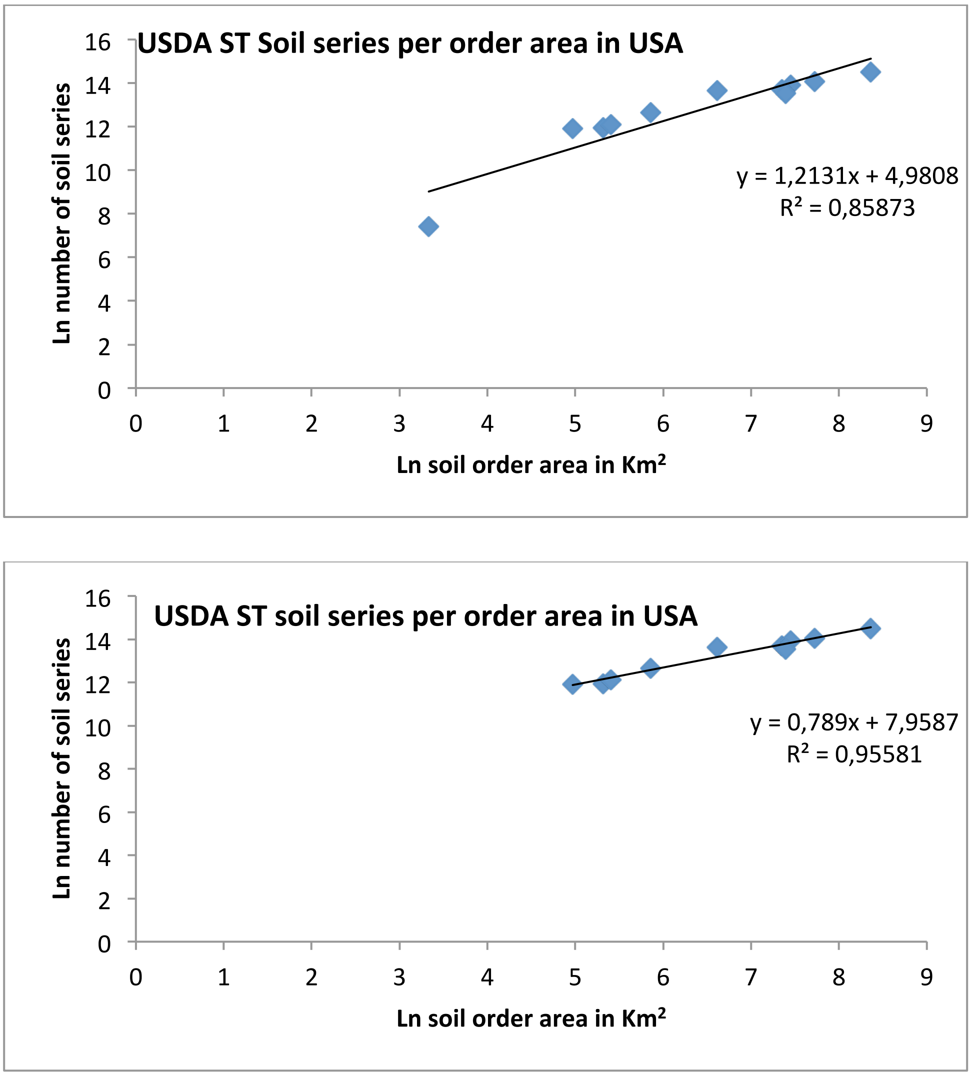


Figure 5. Dependency of the number of soil series in soil orders on the areas occupied by the is o Orders in the United States with (a) or excluding Oxisols (b), Data from Guo et al., (2003)

10. The risk of future taxonomic bias

New technologies often enable tasks that previously required much more time to perform. However, any classification to serve as a universal language should limit the use of technological artifacts. Excessive technologic dependence prevents pedologists worldwide to use a common system of soil classification and communicate with each other because of different degrees of availability of technological development and information. The massive use of new technologies could open up a gap between experts from countries with different degrees of technological development, generating unnecessary discrimination. The use of new technologies for identification and classification of soils (both software and hardware) are helpful but should not be necessary to perform such tasks by others. No biological taxonomist, or geomorphologist or expert in lithology makes use of these instrumentations in field. However this strategy will raise the question of whether soils from Mars should likely be included, in view that the technology required is very sophisticated and as a consequence it is not possible to have numerous field descriptions of profiles. In this vein the solution could be propose at the highest hierarchical level ontological categories for the new "soil-like bodies" that permit classify them in keeping with the advantages of the Gregg Paradox, but separate of the core a Universal Soil Classification that is concerned mainly with the ontological category "soils". These special ontological categories should be conceived and treated separately from the other ones in such a way that their rationality does not interfere with the remaining system. Such strategy could be recommended in these very specific and idiosyncratic cases (see in section 5, 16.3).

In contrast, soil classifications traditionally have paid attention to the potential use of soils for agricultural production and, more recently, for environmental services. These utilitarian constraints influence the construction of taxonomies on purely scientific criteria (see sections 12.3, 13.5, 13.8, 13.9 and, 14.2). In the past soil scientists had to reconcile basic scientific criteria with other purely utilitarian ones (land use) when developing taxonomies and producing soil maps. Nowadays, digital soil databases according to standardized and consensual criteria, with the use of remote sensing tools, geographical information systems, and soil monitoring programs, support multipurpose soil information systems which are used to generate ad hoc practical interpretations to satisfy the large variety of societal demands. This complementarity allows separating soil taxonomy from the utilitarian use of soil information such as the old land capability classes.

The use of utilitarian criteria affects the quality of soil classifications, such as making use of transient soil proprieties in higher levels of a classification thereby mixing (when not relegating) with the more permanent ones with a strong genetic meaning (see also sections, 12.3, 13.8, 14.2). This strategy likely causes confusion about the rationality of a scientific genetic soil classification as a basic tool. Likewise the use of prefix and suffix qualifiers in the WRB (2006-2007) seems oriented more towards implementing soil databases than as a true taxonomic mechanism. The question is whether the WRB should be understood and reorganized as an international code of nomenclature or as a soil classification.

There are also cultural and geopolitical considerations to be taken into account. Developed and developing countries have different soil information demands and address environmental issues such as soil degradation with different tools and strategies. Often, developed countries are seen as imposing their criteria on developing ones. A scientifically sound taxonomy needs to have a hierarchical structure of kinds of soil or pedotaxa grounded on stable criteria, avoiding geopolitical, societal and economic biases. A universal soil classification should be technologically independent so that the mental construct can be applied in all circumstances and by all the scientific community regardless of their economic and technologic potentials.

At the higher levels of the hierarchy, soil features, properties and variables should be as simple as possible, while more complex or technologically dependent features should be introduced at the lower levels of the classification.

11. Taxonomy and culturally transmitted information: The memes

According to Dawkins (1989) "*We need a name for the new replicator, a noun that conveys the idea of a unit of cultural transmission, or a unit of imitation. 'Mimeme' comes from a suitable Greek root, but I want a monosyllable that sounds a bit like 'gene'. I hope my classicist friends will forgive me, if I abbreviate mimeme to meme*". Meme is a cognitive concept or pattern that can be culturally transmitted from some individuals to others (Cavalli-Sforza and Feldman, 1981; Atran, 2001). If a meme acts as a unit for carrying cultural ideas in a discrete way, a pedo-meme could be understood as a carrier of discrete scientific constructs among experts regardless of the fact that the object involved varies in continua or patterned continua. Therefore, a pedotaxo-meme expresses with a short name many properties considered relevant for describing a given kind of soil or pedotaxon in a process of "compression" of information. For the community of pedologists, a pedotaxon could be considered as a meme or a pedo-taxomeme. Likewise taxonomy, as a universal language among experts of a given discipline, could be understood as a structured organization (clusters) of taxo-memes, or taxo-memeplexes (also known as meme complexes or memecomplexes) (Blackmore, 1989).

Memes are lamarckian (selection) culturally transmitted information bits (Cavalli-Sforza and Feldman, 1981) which have evolved over time. Similarly, a pedo-taxomeme is a user-friendly way to compress and transmit the information on soil properties that appears spontaneously among humans of a given culture (in our case, pedologists). So does our cognitive system (Cavalli-Sforza and Feldman, 1981). Therefore, a soil taxonomy is a cluster of pedo-taxo-memes or pedo-taxomemeplexes. The artificial names of the upper categories of the US ST are an example of taxo-memes.

The pedo-taxo-memes of different classifications could be understood as pedo-taxo-allelememes or homologous memes (Distin, 2005). According to the Dawkins frame, memes are not real entities, but they cannot be understood merely as a metaphor. They become technical realities in a cultural context. For example, kinds of soils or pedotaxa are the cornerstones of conventional soil maps and are considered as real entities from scientific and technical points of view. A good meme or idea can remain valid for a long time, even centuries, whereas bad memes disappear or evolve soon (Dawkins, 1989). From this point of view, it is remarkable that some pedotaxa, without substantial changes, appear in several classifications, whereas others do not. This is the case, for example, of Podzols, Chernozems, Histosols, Vertisols, and Rankers or Rendzinas. These pedo-taxomemes are difficult to eradicate from the minds of taxonomists. Perhaps, they represent more scientifically sound archetypical pedotaxa than others whose content ("essences") may be more fuzzy, confusing or arbitrary. If it is so, a universal soil classification should maintain good pedo-taxomemes and replace the bad ones.

12. The main difference of the social practices between pedological and biological classifications

12.1. Closed versus open systems

The USDA Soil Taxonomy has a structure similar to, although somewhat more regular than that of some biotaxonomies, and has taxa sizes with smaller ranges. The opposite is true for the nematode *Tylenchina* suborder where a large number of very small taxa were found (number of subtaxa per taxon between 1 and 2). Ibáñez et al. (2005) explain this discrepancy associated with the idiosyncratic social practice of the tested taxonomies. In other words, while soil classifications are the result of the consensus in a given expert group with periodical revisions (closed systems), most biological systems are open and grow continuously over time with the input of the whole scientific community involved in describing and distinguishing new taxa, and publishing these in scientific journals. In order to carry out a universal soil classification pedologists must decide if a closed or open system is required. Both possibilities have their pros and cons (Ibáñez and Boixadera, 2002).

In general soil pedological classifications are closed systems. These have constraints and slow the incorporation of discovering new soil types. Many pedologists are frustrated when they can not include soil taxa in the described closed systems of a given soil taxonomy (Mabel Susana Pazos, *pers. com*). In fact the USDA Soil Taxonomy was been criticised many times for this reason. The WRB (2006-2007) could be considered much more satisfactory in this respect. It is clear that a closed system slows down the inventory of global soil diversity.

Open systems allow for greater community participation in the construction of taxonomies step by step, but not without problems. One major shortcoming in biological taxonomies consists in the proliferation of synonyms. "*Botanists had long believed the accepted number of flowering plant species to be an overestimate, but few are likely to have guessed the scale of the miscalculation. New research suggests that at least 600,000 flowering plant names - more than half - are synonyms, or duplicate names*" (Nature News Blog, 2010).

Current open official databases in Internet allow detecting and correcting issues of taxa synonymy.

A universal soil classification should consider the pros and cons of both ways to make taxonomies prior to performing other activities. It is not recommended to forget the satisfaction of users when they can implement a taxonomy. In this respect, the WRB (2006-2007) has been welcome to many experts (Mabel Susana Pazos, *pers. com*).

12.2. Universal soil classification: closed or open systems?

If closed systems exclude the participation of many experts, they also allow a consensus more easily. In contrast open systems are more participative and capture many points of view. In any case it is interesting to keep in mind that the most complete classifications (the biological ones) not only make use of open systems, but also of Universal Codes of Nomenclature which are agreed on by experts including both macro-and micro-taxonomist experts (Ibáñez and Boixadera, 2002).

12.3. Macrotaxonomists versus microtaxonomists

Ibáñez and Boixadera (2002) called attention to the absence of theoretical pedologists fully trained in the foundations of taxonomies and their architectures in general. Biotaxonomies are open systems for all taxonomists. They try discovering new species and if possible even novel higher hierarchical taxa, often forced by the terrifying slogan of *"publish or perish*". Biotaxonomists commonly have a tacit division between macro-taxonomists and micro-taxonomists. The former are in charge of the architecture and rationale at the higher classification levels, whereas the latter are field taxonomists. Furthermore, various taxa have different numbers of experts depending on the taxa of economic interest (utilitarian bias), leading to the multiplication of new taxa, in contrast to what happens with other taxa. Similarly more complex taxa (e.g. vertebrates) and/or species with larger body sizes have been studied more, whereas microscopic and simple taxa get less attention (e.g. May, 1992, 1994; Wilson, 1985; Usher, 2005). This bias has been called vertebrate chauvinism (May, 1988).

-In general, only the most reputable biotaxonomists present proposals for the reorganization of the highest hierarchical levels; it is usual that at these levels the number of subtaxa per taxa have low ratios thereby having much more manageable structures (Ibáñez and Ruiz-Ramos, 2006). It is remarkable that many subtaxa per taxa at the higher hierarchical levels fall near the magic number seven plus or minus two (see sections 13.1 and 14.2). It is thought to be a consequence of the partition of the scientific tasks in biological classifications between macro-taxonomists and micro-taxonomists.

12.4. Taxonomies: The role of macro-taxonomists versus micro-taxonomists

A micro-taxonomist needs good fieldwork experience but does not need to be an expert in theoretical constructs. In contrast, a macro-taxonomist does not need as much experience of field description and classification but more training in the scientific domains that concern the efficient transmission of information and other theoretical aspects related with taxonomic constructs.

A universal classification usually requires the participation of macro-taxonomists and micro-taxonomists. The former are in charge of designing the architecture of the taxonomic system and establishing the rules for the partition of the patterned continua into categories. The latter, following the advice of the macro-taxonomists, work mainly at the lower hierarchical levels of the system. Each higher classical hierarchical level of a taxonomy would commonly be divided by micro-taxonomists in each of the different subtaxa following the basic scheme set forth by macro-taxonomists.

13. Selected criteria to assess (compare) the efficiency of classifications

13.1 Willis curve

An early analysis of the mathematical structure of biological classifications was carried out by Willis and Yule (1922). These authors showed that the branching of biological classifications from the top to the bottom of their hierarchical trees reflects a hollow curve or Willis curve that is characterized by a very large number of taxa (e.g. genera) containing only one or very few subtaxa (e.g. species) and by a small number of taxa containing many subtaxa (Figure 6). The USDA Soil Taxonomy also conforms to this type of curve (Figure 6) (Ibáñez and Ruiz-Ramos, 2006) as does field biodiversity and soil inventory data (Figure 7) (Walters, 1986; Dial and Marzluff, 1989; Burlando, 1993; Ibáñez et al. 2005). Further mathematical analysis shows that Willis curves often fit power (Willis and Yule, 1922; Corbet, 1942), logarithmic, geometric, lognormal (Williams, 1964) and/or broken stick distributions (e.g. Ibáñez and Ruiz-Ramos, 2006).

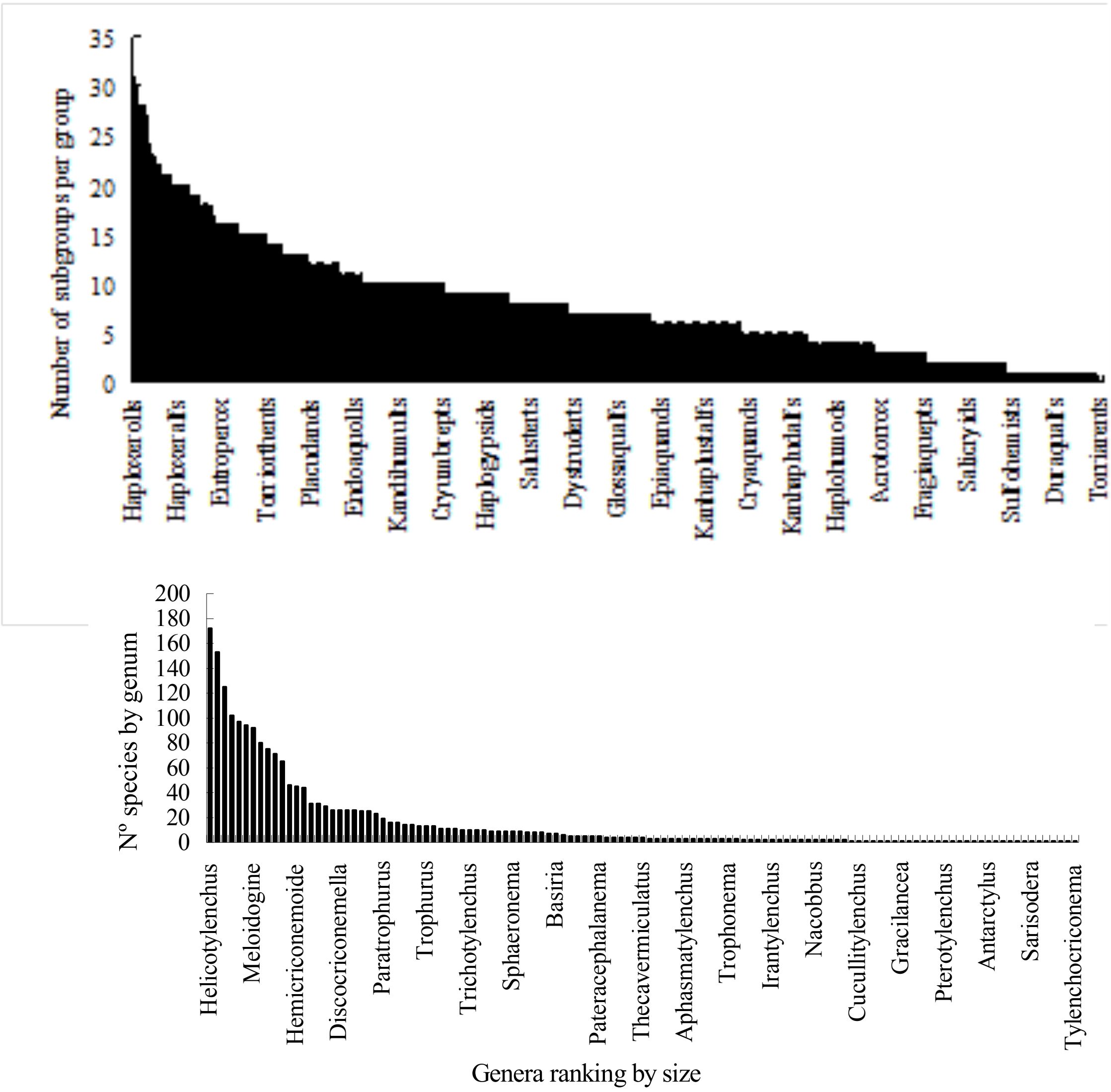


Figure 6. (a) Hollow curve of size-frequency distribution for Soil Taxonomy great groups obtained when plotting the number of subgroups per group; (b) Hollow curve of size-frequency distribution for nematode *Tylenchina* genera obtained when plotting the number of species by genus (after Ibáñez and Ruiz-Ramos (2006). Only some great groups or genera are shown on the X axis as plots of all of them produce illegible diagrams.

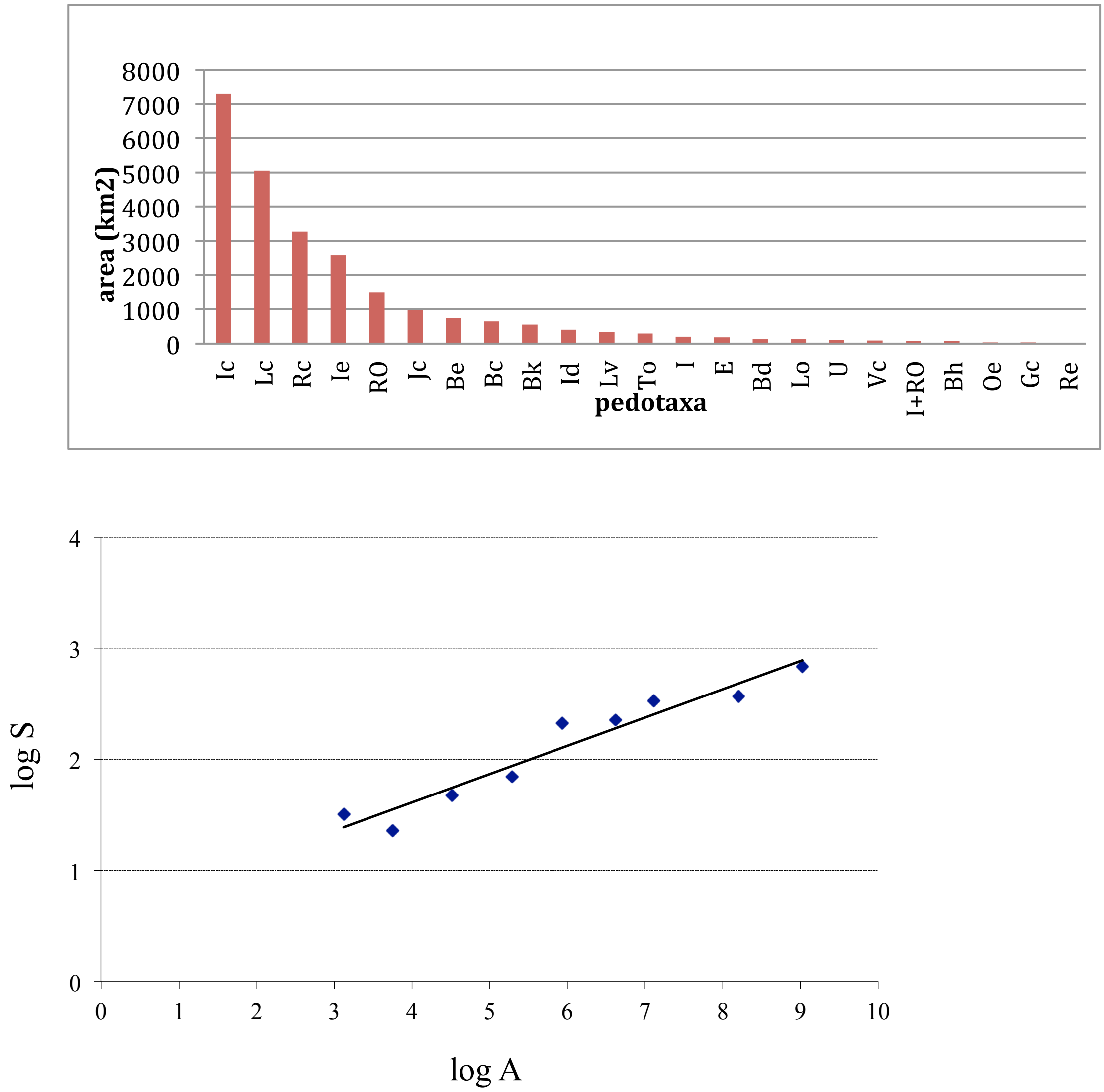


Figure 7. (a) Hollow Curves in Soil Inventories: Rank-abundance for pedotaxa (FAO, 1988) in the Aegean Islands; (b) Power law Fit of the Hollow Curve showed in (a). Regression line plot for the power model of *log S* (pedotaxa richness) versus *log A* (area). The regression line equation is log S = 0.255 log A + 0.594 and the coefficient of determination is 0.932. Modified of Ibáñez et al. (2003).

13.2 Taxa-size distributions

Clayton (1974) showed that a 'taxa-size' distribution in a given biological taxonomy, that is, the number of subtaxa in a taxon, fits well to a power law formalized as:

$$N = \mathrm{k}S^{-\mathrm{D}} \qquad [1]$$

Where N = frequency of genera, S = the number of species per genus (genus size), k = a group-inherent constant, and D = the exponent (fractal dimension) corresponding to the slope of the regression line in a log-log plot. Taxa-size frequencies also fit other distributions types with similar degrees of confidence. In general, power laws fit well to most data sets, both in pedological and biological taxonomies. Biological and pedological classifications seem to have the same structure from the point of view of statistical distribution models (Ibáñez and Ruiz-Ramos, 2006). The small differences detected are a matter of degree and do not reveal much concerning the mathematical structures of either classification. They may relate to underlying fractal and multifractal structures in both kinds of classifications (Ibáñez et al., 2006).

13.3 Branching systems and bifurcation ratios

When the size of each taxon, corresponding to the logarithm of the number of individuals, is plotted as a function of taxonomic category, similar results for a pedological and a biological classification were obtained (Ibáñez and Ruiz-Ramos, 2006) (Figures 3). In addition to whole taxonomic sets, several distributions of subtaxa in taxa at higher levels (suborders/orders) were considered to test if the same statistical pattern could be detected at different levels of the taxonomies (Figure 4). The USDA Soil Taxonomy shows a more regular structure than the biological classification of the *Tylenchina* suborder of nematodes (Figure 6), although the results demonstrate similar branching systems based on subtaxa taxon relationships (Ibáñez and Ruiz-Ramos, 2006). Comparable results were obtained by Burlando (1990, 1993) and Minelli et al. (1991; pp 195-197) for the numerous biological classifications they tested.

Bifurcation ratios, as proposed by Horton and modified by Strahler (1957) for drainage basin hierarchies, were calculated to compare the branching systems (Ibáñez and Ruiz-Ramos, 2006). Bifurcation ratios (BR) measure the number of branches (subtaxa) or growth from a given taxa node. BR for both classifications, the USDA Soil Taxonomy and the *Tylenchina* suborder of nematodes, have a wide variance in hierarchical tree structures as is common in natural systems (e.g. drainage basins, and pedological and biological inventories) (Table 4). The branching of the soil families and series in the USDA Soil Taxonomy were not tested because there is no worldwide inventory of these hierarchical levels, which means that they are, for the time being, incomplete components of a universal classification.

Bifurcation Ratios	Categories	N1/N2	N2/N3	N3/N4	N4/N5	N5/N6
Suborder	*Tylenchina*	16.16	6.37	2.11	4.5	2
Superfamily	*Tylenchoidea*	14.07	7.21	2	7	
Superfamily	*Criconematoidea*	26.7	4	2.5	2	

Bifurcation Ratios	N1/N2†	N2/N3†	N3/N4†	N4/N5†
Whole taxonomy	7.67	4.95	5.33	12
Andisols	6.7	4.14	7	
Hitosols	3.75	4	4	
Oxisols	9.68	4.4	5	
Vertisols	6.74	3.83	6	
Ultisols	7.17	6	5	
Aridisols	9.43	4	7	
Spodosols	5.4	5	4	
Alfisols	9	7.8	5	
Mollisols	9.75	5.14	7	
Entisols	6.96	5.4	5	
Inceptisols	8.22	4.5	6	
Gelisols	5.5	6.67	3	

Table 4. (a) Bifurcation Ratios subtaxa/taxa for the *Tylenchina* Suborder of nematodes (After Ibáñez and Ruiz-Ramos, 2006). Legend: Formula: BR=Ni/Ni+1; N1: species; N2: genus; N3: subfamily; N4: family; N5: superfamily; N6: Suborder. (b) Bifurcation ratios (BR) for the Soil Taxonomy $BR=N_i/N_i+1$; N1: subgroups; N2: great groups; N3: suborders; N4 orders; N5: the whole Soil Taxonomy.

13.4. Entropy of information systems

Mayr (1969) encouraged biological taxonomists to create equal sized taxonomic units, because excessively large taxa as well as an excessive number of small size taxa reduce the usefulness of these constructs as information retrieval systems. Currently, biological classifications have a wide range of taxa sizes, conforming to the Willis curve type (as estimated from the biodiversity literature by Ibáñez et al., 1995, 1998, and 2005). According to Mayr's criteria, this is not compatible with an optimal efficiency in transmission of information by the human mind which prefers equal size groups (see section 13.4, 13.10 and 18.1).

In a more formal way, the Principle of Maximum Entropy (MaxEnt Principle) in the fields of statistical thermodynamics, complexity sciences and fractal physics states that the least biased and most likely probability assignment is that which maximizes the total entropy subject to the constraints imposed on the system (Jaynes, 1957). The MaxEnt Principle allows a novel statistical characterization of taxonomic constructs irrespective of whether or not they are fractal objects (e.g. Pastor Satorras and Wagensberg, 1998). An evenness index (E), as estimated from the biodiversity literature (see Ibáñez et al., 1995, 1998, and references therein), is obtained by dividing the total entropy, H', by the maximum entropy, $Hmax$, of a given dataset with values between 0 (the less equitable possible distribution) and 1 (the most equitable distribution where all taxa have the same number of subtaxa). The evenness index can be used as a surrogate measure of the Mayr criteria and the MaxEnt Principle. In a similar way, the *Hmax* values that describe the situations where all classes have the same number of objects can be applied as an indicator of the number of subtaxa included in a given taxon and their respective sizes. In addition, the estimated total entropy H' is used in ecology as an index of diversity (Shannon and Weaver, 1949). In appendix 18.3, a more detailed description is given with reference to relationships between evenness, fractals and multifractals.

The evenness values indicate that the USDA Soil Taxonomy has a more regular branching system than the *Tylenchina* suborder, suggesting that taxa sizes are more regularly spread (symmetry) in the former than in the latter. The most noticeable outcome is that evenness values of both taxonomies are very high, close to one, indicating a high level of efficiency. Similar evenness values appear in the Chinese Soil Taxonomy (Zhang and Zhang, 2008). Thus, in entropic terms selected biotaxonomies and pedotaxonomies appear to be good information systems (Mayr, 1969).

13.5. Fractals and multifractals

Fractal trees with arborescent or dendriform structures imply hierarchies and are an excellent way to maximize the economy of the flow of matter and energy (Pastor-Satorras and Wagensberg, 1998) according to the MaxEnt Principle. A working model suggests that the human mind may have or could adopt this principle to maximize the economy of information flow.

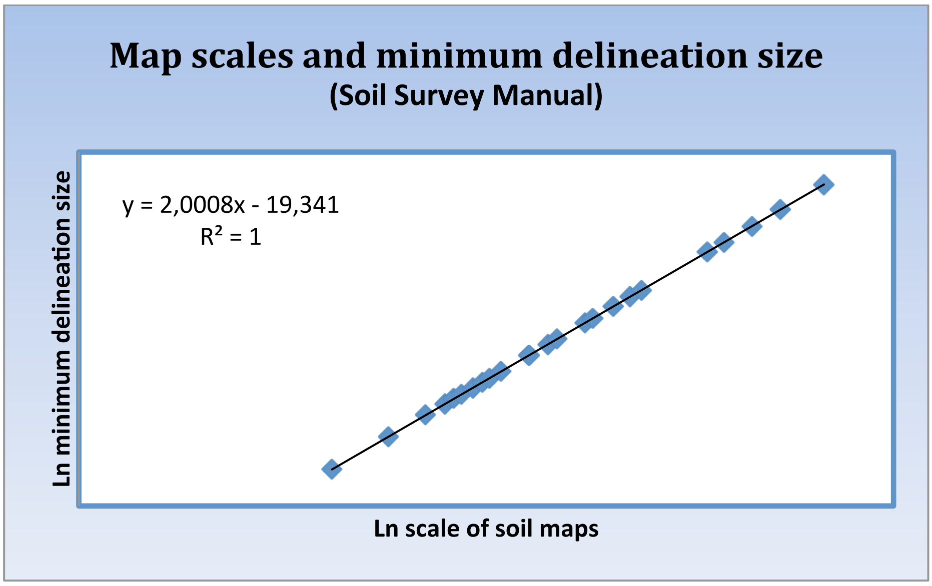
Burlando (1990, 1993), Minelli et al. (1991), and Minelli (1993) examined taxonomies of several target biotaxa and concluded that biological classifications and phylogeny have power law and/or lognormal distributions. Although fractal structures conform to power laws, lognormal distributions do not show scale-invariant properties. When a statistical fit to power law over three or more orders of magnitude is made, some marked deviations generally appear in biological and soil taxonomies (Ibáñez and Ruiz-Ramos, 2006). For this reason, a multifractal analysis is likely to provide additional interesting information.

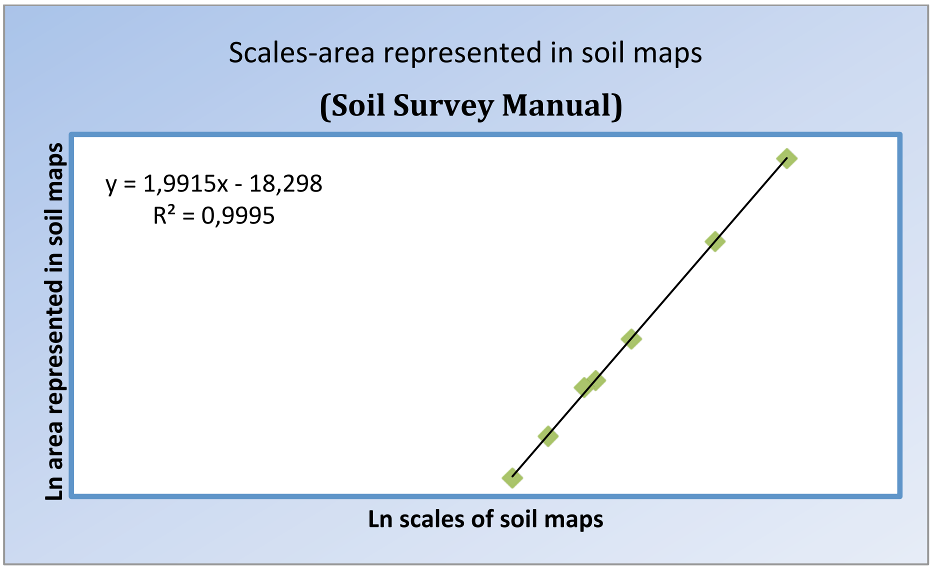
Guo et al. (2003) conjecture that the USDA Soil Taxonomy structure could be fitted to a lognormal distribution. However, Ibáñez and Ruiz-Ramos (2006), using the same tools and criteria as Burlando and Minelli, show that the 1998 version of the USDA Soil Taxonomy and the *Tylenchina* suborder of nematodes fit better to a power than a lognormal distribution. Both classifications have similar structures from different mathematical perspectives. Furthermore, all biological classifications tested by Burlando (1990, 1993), Minelli et al. (1991), and Minelli (1993) show similar mathematical structures.

Multifractals are fractal types, but they contrast with pure fractals or monofractals in that multifractals contain multiple scaling rules (Mandelbrot, 1974; Grassberger, 1985; Chhabra and Jensen 1989). A multifractal analysis of the same data show that both classifications, the USDA Soil Taxonomy and the *Tylenchina* suborder, fit well to multifractal distributions when the largest taxa-sizes are not considered. It is remarkable that the largest taxa-sizes in the *Tylenchina* suborder correspond to species of major economic interest as, for instance, plant parasitic nematodes that, in general, produce the most harmful pests to crop production, or are the most cosmopolitan ones. In a similar way, the largest taxa sizes in the USDA Soil Taxonomy are some of the Haplo great groups, mainly those of high interest for crop production (Ibáñez et al., 2006). This shows a utilitarian bias of the USDA Soil Taxonomy (see sections 12.3, 13.8, 14.2 and 15.2).

13.6. The Fractal mind of soil scientists

The fractal-multifractal nature of the USDA Soil Taxonomy is strongly linked with conventional soil survey practices (Ibáñez et al., 2009). Most surveys are packed with power law distributions, such as for instance the relationship of the categoric level and minimum polygon size with the map scale. Beckett and Bie (1978) were the first to call attention to the frequency of power laws in soil survey standards (Figure 8). This is also the case in many other natural resources sciences (Ibáñez et al., 2009).





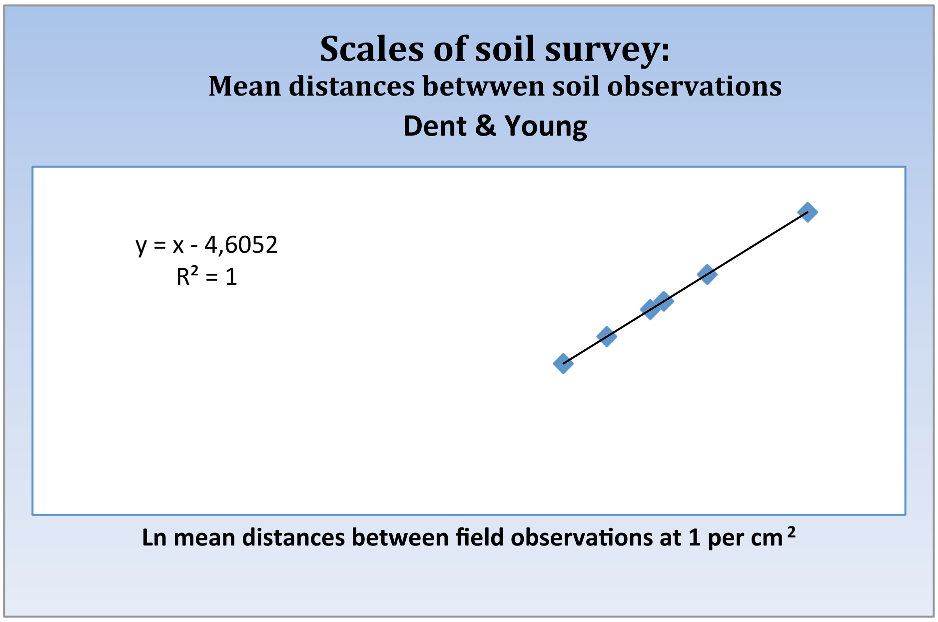
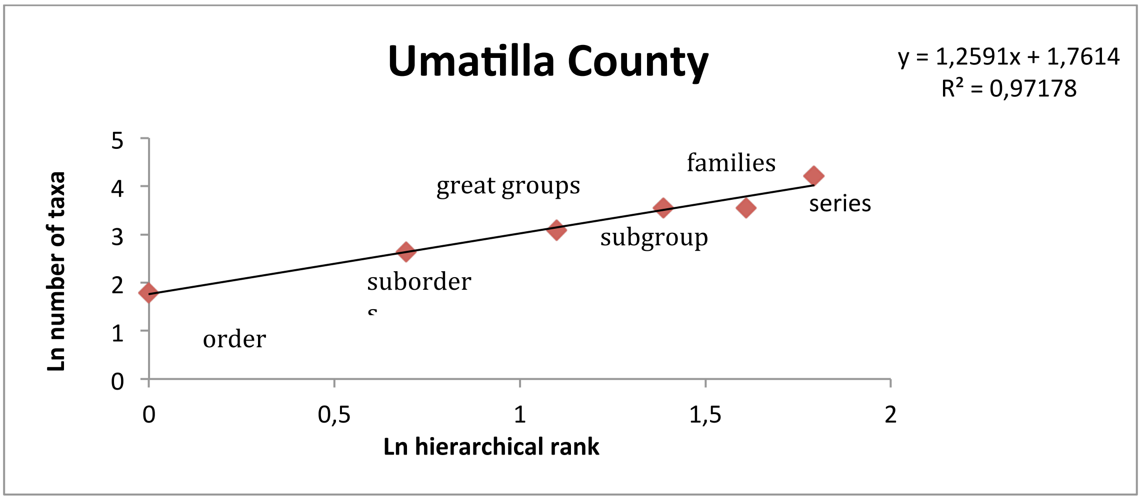
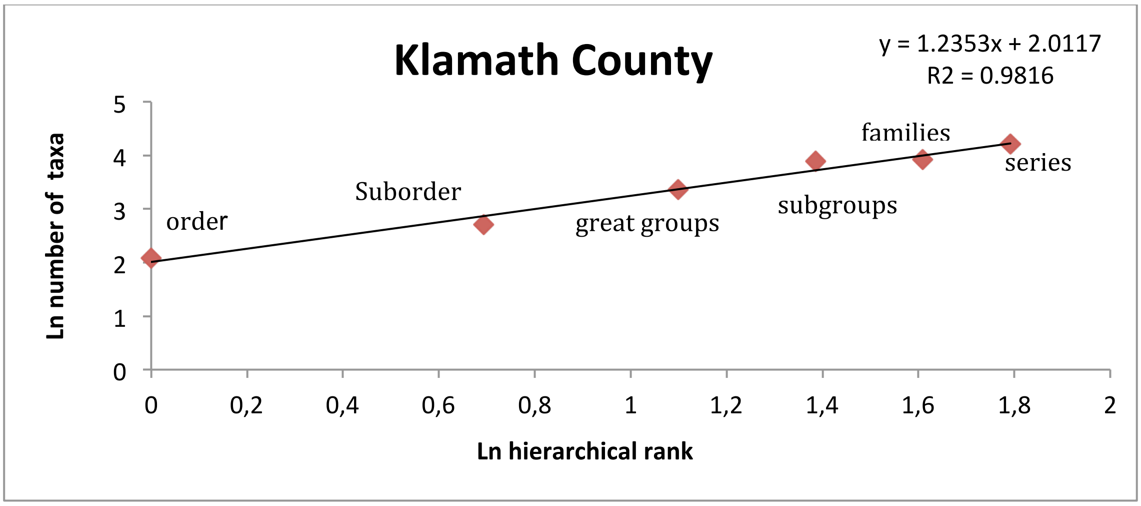
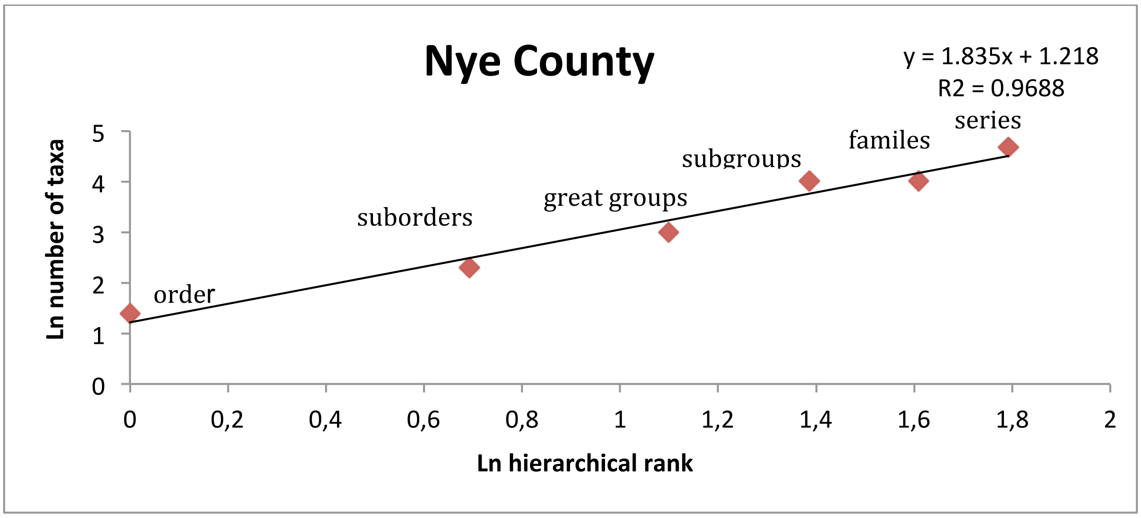


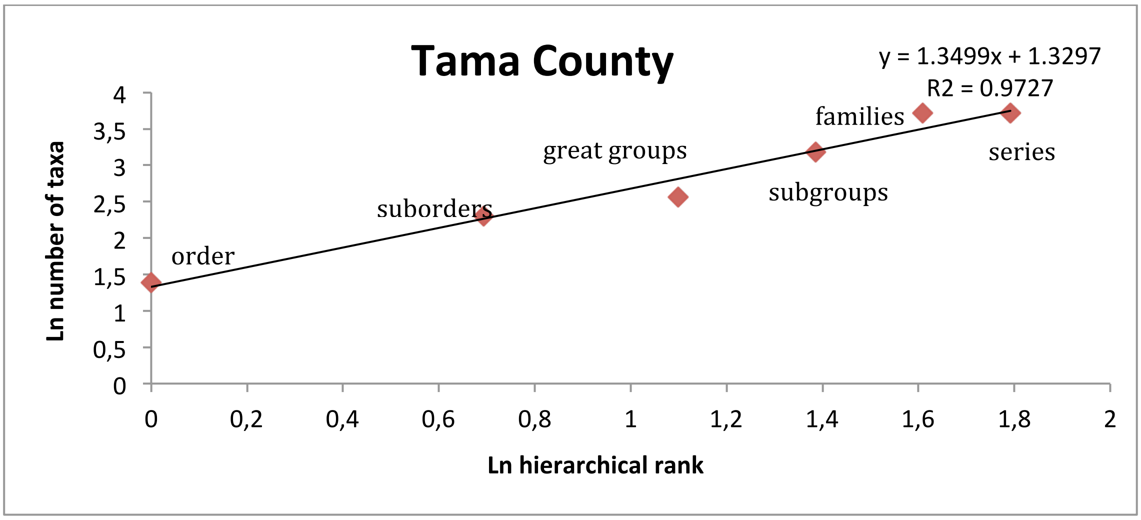
Figure 8. Scales of soil survey and soil maps: Fractals everywhere. (a) Guide to Map Scales and Minimum Delineation size; Data source: Table 2-2 pp. 53 Soil Survey manual. (b) Minimum-size delineations (hectares) according to the map scape. Data source: Table 2-1 Key for Identifying Kinds of Soil Surveys pp. 48-49 from Soil Survey Manual. (c) Survey mean distances between field observations at 1 per cm^2; Data source: Table 6.1 Dent and Young data from Table 6.1 pp. 90 from Dent and Young (1981).

Fractal objects and power laws are scale-invariant mathematical constructs, and the products prepared unconsciously by taxonomists are also fractal in many aspects (Figure 9) (Ibáñez et al., 2006, 2009). It is interesting that maps without legends show high cartographic resemblance and similar information content irrespective of scale. It appears, therefore that the procedures and structures used by soil surveyors and soil taxonomists, and also by scientists of other disciplines such as biotaxonomists and vegetation cartographers, are based on innate information systems (Figure 10). Detecting and recognizing this innate, scale-invariant information processing should help us better understand and improve expert activities and constructs.








Tama County
y = 1.3499x + 1.3297
R2 = 0.9727
Ln number of taxa
Ln hierarchical rank
order
suborders
great groups
subgroups
families
series
0
0,5
1
1,5
2
2,5
3
3,5
4
0
0,2
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1
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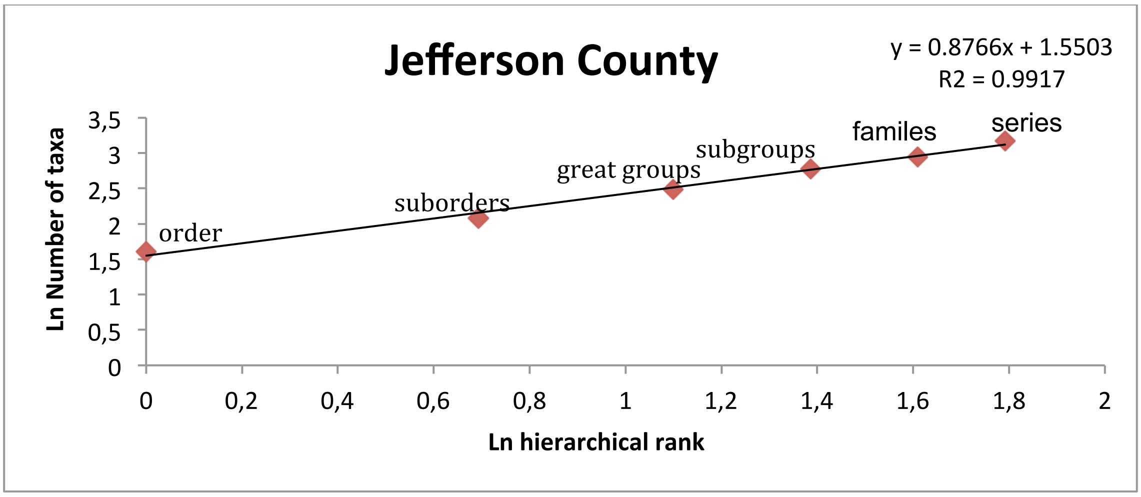
2


Jefferson County
y = 0.8766x + 1.5503
R2 = 0.9917
Ln Number of taxa
Ln hierarchical rank
order
suborders
great groups
subgroups
familes
series
0
0,5
1
1,5
2
2,5
3
3,5
0
0,2
0,4
0,6
0,8
1
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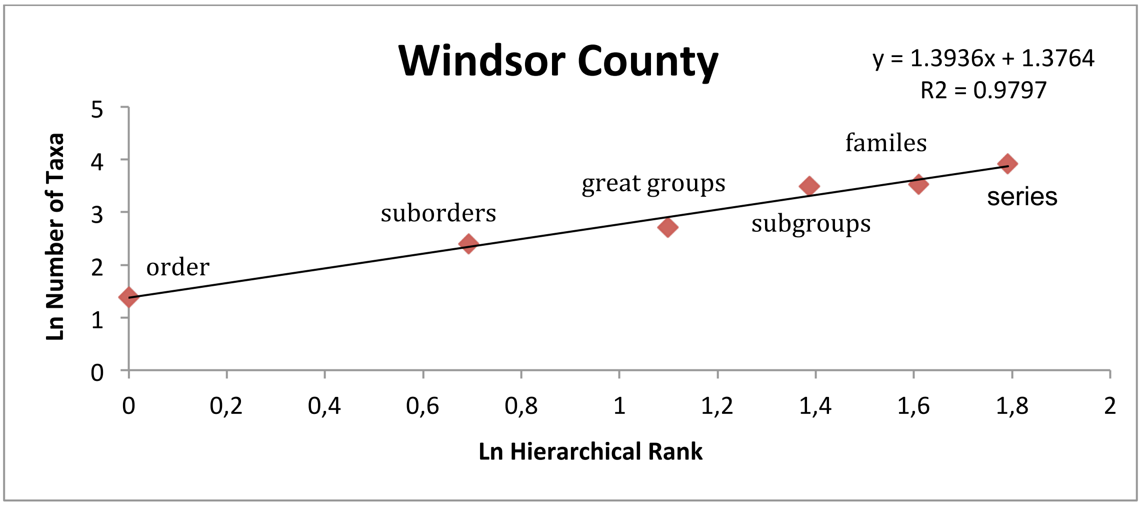
Windsor County
y = 1.3936x + 1.3764
R2 = 0.9797
Ln Number of Taxa
Ln Hierarchical Rank
order
suborders
great groups
subgroups
familes
series
0
1
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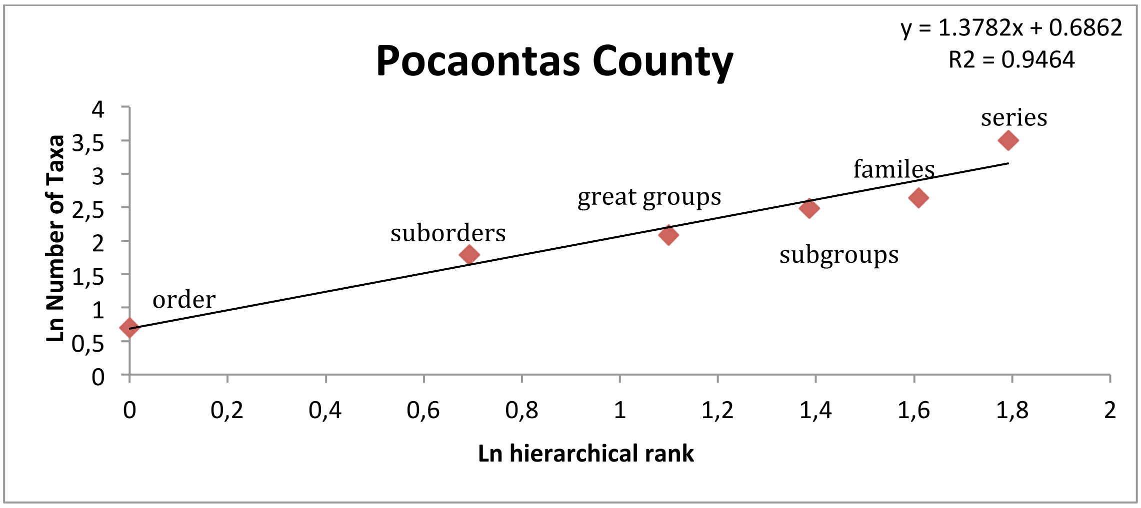
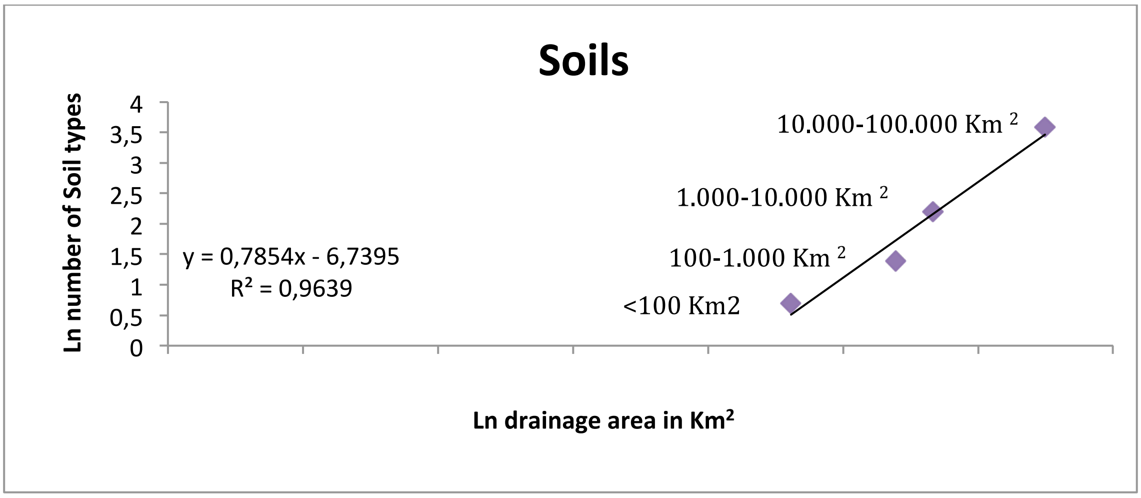


Figure 9. Fractal Mind of Soil Surveyors (After Ibáñez et al.,2009). Dependencies between the number of taxa and their hierarchical rank of the USDA Soil Taxonomy for seven US counties. a—Umatilla County, b—Klamath County, c—Nye County, d—Tama County, e—Jefferson County, f—Windsor County, g—Pocahontas County; From the elf to the right: Order, Suborder, Group, Subgroup, Family, Series.



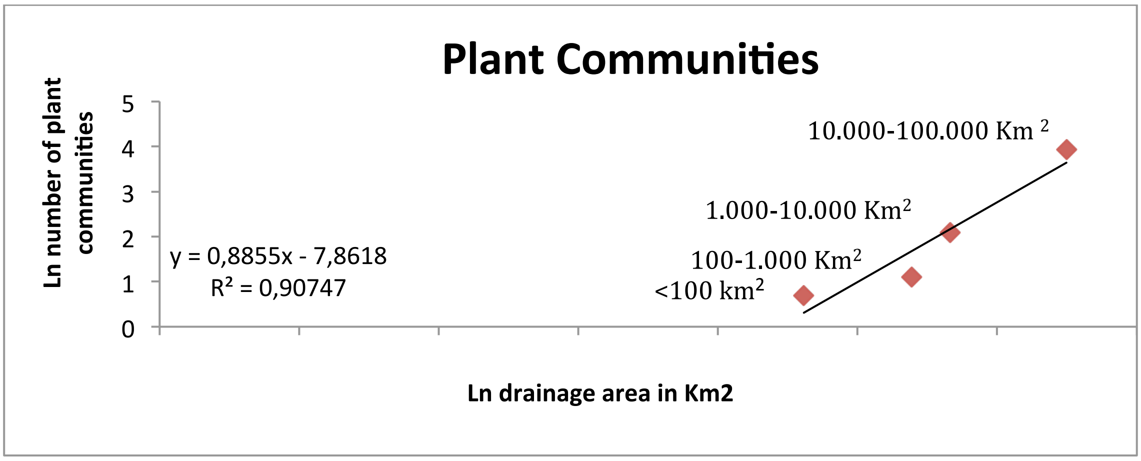


Figure 10. Fractal mind of natural resources surveyors: from a soil map and plant vegetation map of spain. After Ibáñez et al. (2009)

13.7. The Rosch prototype effect (cognitive bias)

Eleanore Rosch (1973, 1975, 1978; Rosch et al., 1976), an outstanding cognitive psychologist of the last century, described the process of categorization and the "prototype effect" (or theory). Her approach is summarized here because of its relevance to the recognition of soils as individuals and as a domain of interest. Domain is suggested here for category to be more consistent with its use in pedology.

- We classify objects at a 'basic level' which is the most abstract (soil vs. non-soil).
- Categorization occurs based on our interaction with the objects.
- At the basic level we can form a mental image of the prototypical domain.
- The meaning is in the interaction between the person and the world.
- Basic-level prototypical domains are the first ones learned by children.
- Domains are created by generalization and specialization at the basic level.
- At the basic level, domains are maximally distinct. Perceived similarity among domain members is maximized, and perceived similarity across contrasting domains is minimized.
- The best way to teach a concept is to show an example of it. The prototype is the best example of a domain.
- The task of a domain system is to provide maximum information with the least cognitive effort.
- Membership of an individual in a domain is determined by the perceived distance of resemblance of the individual to the prototype of that domain.

Rosch and her colleagues found that there is a primary level in hierarchies of naturally occurring objects such as living and non-living objects. In both hierarchies, the primary level is the most abstract one where (1) many common features are listed, (2) consistent motor programs are employed to interact with or manipulate the examples, and (3) members have similar enough shapes so that it is possible to recognize an archetype shape for objects of the domain. The primary level is also preferred in adult naming, first learned by children, and the level at which entities can be classified most rapidly.

The "Haplo" criteria used in Soil Taxonomy to reflect minimum horizon development is generally not applied in biotaxonomies. In biotaxonomies a species is selected as representative to show the main features of a given taxon ("nomenclatural type" or the element to which the name of a taxon is permanently attached), although it has not any formal taxonomic role. Ideally, a type species best exemplifies the essential characteristics of the genus to which it belongs. In general, this species is one of the most simple in terms of characters. The Haplo entity in soil classification in some respects is similar to the "prototype or canonical effect" described by Rosch (1978) and Rosch et al. (1976). It refers to something that humans consider canonical or typical of a given set of objects with respect to others of the same class. In each great group of the USDA Soil Taxonomy, the less complex assemblage of soil horizons is canonical with respect to others. The Haplo great groups with economic interest (but see section 9 and 10, 14.2, 14.3, and 15.2 on geographic bias) often have the largest numbers whereas the other great groups fall into a mutlifractal structure. Additional great groups may be recognized when they depart from the definition of the "haplo" great group.

The pedosphere contains numerous discontinuities that may not be as obvious as those among biological individuals (Yaalon, 2003). However, the discontinuities between some biological species are more apparent than real. For example, the *Quercus* genus is one among many problematic taxa; some taxonomists claim that it forms a true continuum where the species concept is not applicable to separate members (Van Valen, 1976).

It is reasonable to think that if most of the pedosphere is a set of true continua in nature, the distribution of subclasses in each higher hierarchical taxon would be rather uniform showing high evenness in entropic terms. On the contrary, if the distribution is not uniform, then some degree of discontinuity is likely to exist. The pedosphere fragmentation into classes tends to conform to a Willis curve on the basis of their respective surface areas (Ibáñez et al., 1998).

Many biologists now believe that the species concept is vague and arbitrary (Sattler, 1986; Hull, 1997), and recognize that there is no ideal species concept. Mayden (1997) has counted 26 different species concepts for eukaryotes, while Mishler and Donoghue (1982) claim that all species concepts are biased by the taxonomical groups studied by the proponents. Thus, a pluralism of species concepts exists at this time (e.g. Ereshefsky, 1998; Zimmer, 2008). Furthermore, Sattler (1986) is of the opinion that the discreteness of many biological individuals is more apparent than real and postulates the idea that species are peaks in a continuum. Ibáñez et al. (2005) have also suggested that pedotaxa are peaks in the pedospheric patterned continuum.

Currently it is usual that the architects of taxonomies search the rationale (as objectively as possible) and find the locations of central concepts that guide, from a given hierarchical level, the best arrangement of the objects in the lower levels. For example, some pedologists consider that the Typic Subgroups are the central concepts in the USDA Soil Taxonomy. A related debate is what kinds of criteria must be employed to define them (e.g. rigorous definitions vs. numerical procedures that group the objects based on multiple properties). This central tendency is exemplified by a modal profile with its properties. It seems a difficult task, in view that there are not perfect or complete procedures to reach this objective. In addition it is not the same to carry on a universal classification starting from previous databases samples under the umbrella of a preceding taxonomy than the newer ones. As previously discussed the Rosch prototype effect shows that the human mind tends to consider archetypes (the most simple object belonging to the domain that is being studied) as the primary or basic level to classify the rest of the objects. Once the archetypical taxon has been agreed on the rest are classified according to their similarity/distance with respect to it. It is the case of the "haplo criteria" at the great group level in the USDA Soil Taxonomy. In view of the huge role of archetypes throughout the processes of categorization and managing information it is a matter of debate if the haplo criteria must be eradicated from new universal classification schemes. However this opinion does not mean that inclusion of additional in others levels of a given taxonomic construct are excluded, such as the mentioned central tendency.

The architects of numerical procedures have generally been concerned that in nature the objects to be classified do not fit well to a Gaussian or normal distribution. The Willis curve (see section 13.1) is a clear example of the so-called distributions called long tail, fat tail, or heavy tailed (see Asmussen, 2003; Nolan, 2009 and references therein). These types of curves fit well to power law functions and related distributions. In all of them the mode (the most abundant or 'modal soil profile and/or the most frequent values of their soil properties) usually differ considerably from the "ideal" mean values in contrast to those in a normal or Gaussian distribution, putting into question the statistical role of the statistical mean to characterize a given central tendency. Therefore the most common object in a given universe or population of objects could perhaps be taken into account when proposing taxonomic constructs. In the long tail distributions the statistical mean values might fall into rare or infrequent natural objects (the right side taxa of the Willis curve) of the domain studied, thus being a poor descriptor of a given taxon. The central tendency seems a fuzzy term in view that in different classifications it has different meanings or could correspond to different statistical concepts.

In any case having scientifically sound mean and mode values face another obstacle that is hard to beat. Our globe does not have a harmonized and scientifically sound soil database that covers the global pedosphere. Furthermore different national classifications have made use of different analytical tools to measure the same variable thereby producing values that may differ considerably. In general the best existing databases come from developed countries whose geographical location is biased by the western countries of the northern hemisphere. In contrast large areas of Africa, Latin America and Oceania have been scarcely sampled. If a statistical central tendency is obtained using existing databases, with independence of the analytical problems, the obtained values will not correspond to an objective central tendency at a world level. Thus, if the architects of a new universal taxonomy make use of statistical central tendencies using existing databases these obstacles could be of paramount importance. Statistical procedures could be fully justified after a scientifically sound global soil database is available, but not before. In some regards it would be like building a house starting with the roof. The USDA Soil Taxonomy is probably the most mature construct being applied in many countries of the world. This study also shows that its structure conforms to our working hypothesis. However this taxonomy suffers from some geographical biases as shown by Sojka et al (2003) and corroborated by Ibanez et al (2009). Thus this bias should be detected, listed and eliminated as much as possible with a view to using this taxonomy as a starting point.

Summarizing, currently the use of quantitative tools to obtain the value of central tendencies is very difficult such that it is not possible yet to have scientifically sound values at a worldwide level due mainly to the geographical bias. In contrast, even recognizing the possible limitations of the haplo criteria it is the only one that does not suffer from the bias mentioned above. Furthermore the haplo criteria agree with the cognitive mental images of a central concept according to the studies of Rosch and associates.

After a global soil database is available there are several alternatives to get quantitative central tendencies. From a logical point of view there are no reasons that force us to choose between different alternatives (archetypes, modes, and means) if the taxonomic architecture has been deliberately built for this purpose.

It is intriguing that classical and numerical taxonomies are based on two different conceptual principles. The first one focuses intuitively on archetype taxa, whereas the second one focuses on statistically estimated central tendencies.

13.8. A conclusion

It is concluded that in the absence of taxonomic biases (i.e. geographic, utilitarian) and prototype effects, all taxonomies have the structure of fractal trees (Figure 11). Fractal trees are believed to be the most efficient way for information transmission. Most taxonomic structures do not deviate much from current classifications that are close to being optimal ones.

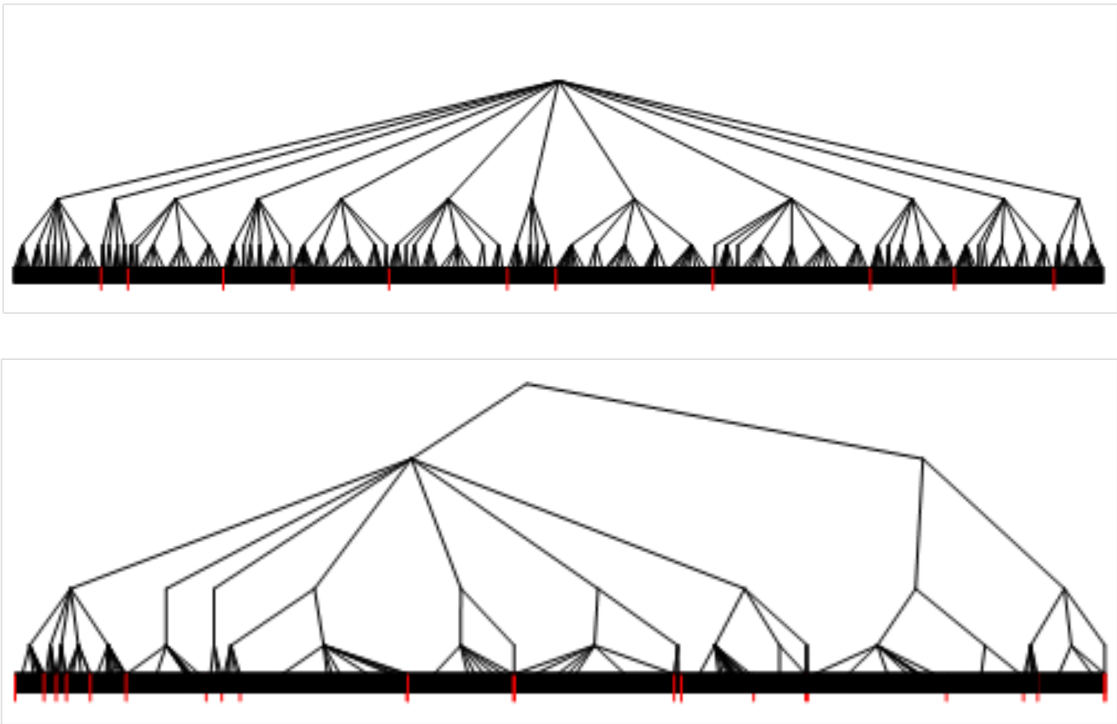


Figure 11. A picture of branching systems in both USDA soil Taxonomy (top) and the Suborder *Tylenchina* of nematodes (bottom) taxonomies After Ibáñez and Ruiz-Ramos (2006)

13.9. Cognitive and Anthropological Evidence

Classification is a basic process of inductive reasoning (e.g. Coley, 1999; Dougherty, 1978). Categorization tasks are of independent theoretical interest and self-contained, but they are also designed to provide the inferential framework for category-based reasoning (López et al., 1997). In addition, an important function of taxonomic classification is enabling generalizations between categories (Osherson et al., 1990). In pedotaxonomies the structure and rationale are intended to show genetic relationships among the categories and their classes.

Many researchers in anthropology, cognitive psychology, biology, and philosophy of science are concerned with similar questions such as: What is the role of the categorization process; How are category schemes linked to reasoning about natural kinds; How do humans perceive, categorize, and reason about living things; Are folk taxonomies approximations to classical scientific taxonomies or are they driven more by utilitarian concerns; and can taxonomies have a universal scope?

Typological thinking is innate to the human mind, since the beginning of historical times (e.g. Aristotle), and it seems intrinsic to all natural resource classifications (Hey, 2001; Krasilnikov, 2002; Ibáñez and Boixadera, 2002; Ibáñez et al. 2005).

There is growing cross-cultural evidence of a common sense assumption that each biological species has an underlying causal nature, or internal essence that is uniquely responsible for the typical appearance, behavior, and ecological preferences of the kind (Atran, 1990; Atran et al. 2006, among others). For these reasons, biological essentialism may be more specialized than mere minimal essentialism, which applies to all objects and their intrinsic properties. However, the vagueness and incompleteness of the species concept could be considered as a refutation to this essentialism.

Most pedological classifications have the same structure as biological ones. Vascular systems, bronchial systems, root systems, stem systems, drainage basin systems, road systems, and the like, have similar geometries (Korvin, 1992). Medin and Atran (2004) mention that because intuitive notions come to us so naturally, they may be difficult to unlearn and transcend. They note that often students and philosophers of biology find it difficult to abandon a common sense notion of species as classes, essences, or natural kinds, in favor of the concept of species as a logical individual – a genealogical branch whose endpoints are somewhat arbitrarily defined in the phyletic tree and whose status does not differ in principle from that of other smaller (variety) and larger (genus) branches. Thus, these authors recognize also a certain degree of artificiality in biological classifications.

Cultural transmission is another way to understand how the human mind intuitively works. Atran et al. (2006, page 126) state that *"human cultures favor a rapid selection and stable distribution of those ideas that (a) readily help solve relevant and recurrent environmental problems, (b) are easily memorized and processed by the human brain, and (c) facilitate the retention and understanding of ideas that are more variable or difficult to learn but contingently are useful or important"* (…) *Nevertheless, its organizational principles remain robust. The sort of cultural information that is most susceptible to modular processing is the sort of information most readily acquired by children, most easily transmitted from individual to individual, most apt to survive within a culture over time (provided adequate input and cultural support), most likely to recur independently in different cultures and at different times.*" This hypothesis is in agreement with the concept of meme discussed in section 11. Atran et al. (2006) believe that folkbiological taxonomy helps humans orient themselves and survive in the natural world. According to Medin and Atran (2004), children have an intuition from quite an early age that the mechanisms underlying essential causes are biological rather than cultural ones.

In general, indigenous soil classification systems have a hierarchical structure (Barrera-Bassols and Zinck, 2000; Bautista el al., 2005). Indigenous knowledge is community- or ethni-specific, and refers thus to restricted geographic locations. As a consequence, classification schemes are relatively simple and, in most of the cases, do not include more than two to four hierarchical levels (taxonomic depth) (Ortiz-Solorio and Gutierrez, 1999; Barrera-Bassols and Zinck, 2000). Sometimes the upper category corresponds to features related with physiography and/or lithology (parent materials). In other cases they relate to soils only. Barrera Bassols et al. (1996) state that in many Mesoamerican indigenous cultures: "*multi-categorical ethnopedological classifications generally start, at the higher* *level of the system, with a comprehensive realm concept including "all soils", the equivalent of Plantae and Animalae in other natural realms*" Many ethnic cultures have a fine and clear nomenclature to label the units belonging to their soil universe. The Miller rule is seldom exceeded in indigenous classifications. Situations where a soil taxon is divided into more than nine subtaxa are infrequent. Indigenous soil classifications focus on topsoil properties, while scientific classifications give more weight to subsurface diagnostic horizons. Deep soil layers are mentioned when they significantly affect crop production (Barrera-Bassols and Zinck, 2000; Bautista and Zinck, 2010). Generally there is good correspondence between indigenous and scientific soil types (Barrera-Bassols and Zinck, 2000). Some indigenous classifications recognize more soil classes and fragment the local soil cover in a more detailed way than modern international classifications (Bautista and Zinck, 2010). Diagnostic properties used to recognize, distinguish, and classify soils are relatively similar in both the indigenous and scientific approaches. To compensate for the lack of analytical data, local classifications use a large number of surrogate indicators (Bautista et al., 2003). For example, the identification of soils in the Yucatec Maya classification is a natural system based on key properties of the surficial and subsurface horizons that have morphological, genetic, and practical importance. Furthermore, this classification has been found to be more accurate than the scientific classification of the same soils for the purpose of land management and crop production by local people (Bautista and Zinck, 2010).

13.10. A fundamental tension: cognitive vs. natural distributions

Practical, effective, and user-friendly classifications depend on a comprehensive understanding not only of the theoretical foundations of taxonomies but also of the basic principles of human cognition. The basic principles and theoretical foundations of folk organizational schemes were mentioned above.

It is thought that an analysis of the structure of classification systems benefits from a variety of scientific disciplines including information science, cognitive science, anthropology, mathematical analysis, semiotics, artificial intelligence, linguistics, expert systems, and other branches of the knowledge. They contribute to a deeper understanding of how people obtain, store, retrieve, and use information. This may help in designing more effective and more efficient soil classification and information systems.

Although soil and biodiversity inventories commonly have equitability values (see sections 13.4, and 18.1) in the range of 0.3-0.75, values above 0.9 were found in some soil and biological taxonomies (Ibáñez and Ruiz-Ramos, 2006). There seems to be a discrepancy between distributions in nature and distributions in our mental constructs (taxonomies). The latter have higher equitability, thus it is possible that our mind tries to get the maximum equitability subconsciously as Mayr and the MaxEnt Principle demands (see section 13.4). This trend of our mind is contradictory to the less equitable distributions in inventories, and emerges as a 'fundamental tension'. Apparently, our mind processes equitable distributions rather well, but nature seems to have more constraints to achieve distributions that follow the MaxEnt Principle. This discrepancy may be a major difficulty to design better hierarchical taxonomies for information retrieval.

13.11. The magic number seven plus/minus two (cognitive bias)

(...) Regardless of the size of their area of interest and the complexity of its soils, we have found (both in Australia and Britain) a remarkable consistency in a farmer's belief that there are 3 ± 1 soil on his property, and his extension officers' belief that there are about 7 ± 2 soils (usually at family level) in his area. On the whole, the latter appear to remember soil classes in excess of 5-10, not as further classes, but exceptions or as subdivisions of one of these one of these.

Having received this impression in Australia we consulted the Oxford Psychology Faculty and were referred a paper entitled "The magic number seven plus or to minus two" (Miller 1956). Apparently the phenomenon is well known: the memory of recall of phenomena is determined more by the number of categories in which they are grouped than by the breath of these categories. The optimum number of categories for "absolute unidimensional judgments" appear to be seven (Miller finds a mean of 6.59, and rather more for multidimensional categories. In general, people 'impose a categorization on (an) array which, regardless of the apparent complexity of the array, averages to about two bits[4,5] categories of information" (...)

Beckett, P.H.T., Bie, S.W., 1978 (statements taken from page 39)

Basically, a taxonomy is a retrieval information system. Its efficiency in getting a useful and user-friendly representation and organization of the object to be classified, soils in our case, depends upon a comprehensive understanding not only of the theoretical foundations of taxonomies but also of the basic principles of human cognition.

G. A. Miller a psychologist at Princeton University, published in 1956 in Psychological Review a paper on "The magical number seven plus or minus two; some limits on our capacity for processing information". He postulated that there is an upper limit on our capacity to process information on simultaneously interacting elements with reliable accuracy and validity. This limit is seven plus or minus two elements for humans (but see Cowan, 2001 and Hirsch, 2001). The Miller conjecture has been accepted as a theory in cognitive science, and demonstrated that the same limit for processing information also appears in chimpanzees (Premack, 2007). Miller argued that the number of bits of information we can handle in the brief span of working memory, usually a few seconds, is very limited. The span of immediate memory imposes severe limitations on the number of items we are able to receive, process, and remember. He also recognized that by organizing items into categorical units or "chunks", we can at least stretch an apparent short-term memory bottleneck. The information retrieval in our working memory itself breaks down the informational continuum into small individual packets. Each of these mental images or representations lasts for about 125 milliseconds, which means the brain can retrieve eight different mental images per second (Jezek et al., 2011). However, the number of steps needed to select between different mental images grows much faster, in an exponential way, than the increase in the number of images to be compared (Jezek et al., 2011).

Other authors have also pointed out that the breath of the structures with superior performance falls in the range of 7 +/- 2. Thus, Kiger (1984) said that data seem to indicate both preference and performance advantages for broad, shallow trees. As a general rule, the depth of a tree structure should be minimized by providing broad menus of up to eight or nine items each. In essence, Miller's findings that people are only able to make quick, accurate decisions with a small handful of objects at a time has had wide support across experimental psychology studies, and may provide useful guidance in the design of universal classifications.

The Miller Magic Number, also termed Miller's Rule, has been corroborated and/or discussed in a number of several scientific disciplines including: knowledge representation (Heuer, 2008; Brachman et al., 1992), human and animal cognition (Premack, 2007; Premack and Premack, 2002), natural language in cognitive sciences (Fenk-Oczlon and Fenk, 2001), syntactic structure and linguistics (Murata and Isahara, 2001; Murata et al., 2004), language, cross-linguistic comparisons and computational linguistic (Murata and Isahara, 2001, 2005; Fenk-Oczlon and Fenk, 2000, 2003), chaotic dynamics of information processing (Nicolis and Tsuda, 1985; Ishihara and Kaneko, 2004), chaotic brain information storage (Molter, 2005), economically organized hierarchies in dictionaries (Changizi, 2008), the depth/breadth trade-off in hierarchical computer menus (Miller, 1981; Kiger, 1984), analytic hierarchy process (Saaty and Ozdemir, 2003), networks of threshold dynamics (Ishihara and Kaneko, 2004), expert opinion in medical decisions (James and Hammond, 2000), behavioural discrimination processes (Chase, 1983), cognitive and articulatory systems (Fenk-Oczlon and Fenk, 2004), system design methods in software developments (Yourdon, 1989), and web page design (Larson and Czerwinski, 1998).

In most folk taxonomies, the classification process follows the Willis curve with many taxa having only one or two subtaxa, however the large sized taxa seldom exceed the Miller rule. In addition, folk taxonomies usually have a number of hierarchical levels around the Miller number or less (López et al., 1997).

When the number of elements increases past seven, the resulting increase in inconsistency is too small for the mind to single out the element that causes the greatest inconsistency and to scrutinize and correct its relation to the other elements, thereby resulting in confusion. It appears that the mind is sufficiently sensitive to improve large inconsistencies but not small ones. The implication is that the number of elements in a set should be limited to seven plus or minus two. Almost paradoxically, it has also been suggested that the 'human channel' which is so narrow and noisy possesses the ability of squeezing or compressing an almost unlimited number of bits per symbol, thereby giving rise to a phenomenal memory (Nicolis and Tsuda, 1985).

13.12. Folk biology and cognitive science evidence

For their survival, our ancestors strongly depended on intimate interaction with plants and animals, which likely required anticipatory knowledge of at least some plant and animal species (Medin and Atran, 2004).

The term folk biology refers to people's everyday understanding of the biological world. Although soil is a cryptic system and native culture experience does not use the same information as scientists, we can learn about taxonomy from folk biology, anthropology, and cognitive science. The central finding of much research indicates that culturally different groups, including native cultures, agree in their recognition of patterns of resemblance among the collection of different living organisms (Boster, 1996).

13.13. Evidence of soils understood as natural bodies in aboriginal cultures

Whether ancient cultures recognised soil as an independent natural body or as a part of the wider concept of land is a matter of debate. However it is clear that, at least for many of them, soils were managed similar to how current soil scientists recommend and current technologies allow. There are many examples of ancient cultures importing soil materials to a given site (placing them in layers of different texture-including gravels-) and building artificial soils in areas with suitable environments and climate but excluding other conditions like slopes, waterlogging, etc. (Caran and Neely, 2006). There are many examples of elaborate indigenous soil-land management practices such as the Texcoco chinampas (Becerril and Jiménez, 2007), Zapotec technosols in Mexico (Caran and Neely, 2006), Colca canyon terraces in the Peruvian Andes (Denevan, 1986; Denevan et al., 1987; Furbee, 1989; Sandor and Furbee, 1996) and raised fields in French Guiana's seasonally neotropical flood savannas by Barbakoeba and Thémire cultures (part of Arauquinoid tradition) (McKey et al., 2010).

There is evidence that indigenous soil management was sustainable over centuries. For instance, the Amazonian Terra Preta (Glaser and Woods, 2004; Lehman, 2006; Glaser, 2007) or the man-made soils on raised fields (French Guiana) could be cultivated today without any rehabilitation practice (McKey et al., 2010). Thus, we can learn from the experience of local people in recognizing, classifying, managing and even rebuilding degraded soils. Obviously they have the mental and technological capacity to carry on fascinating sophisticated landform-cultural landscapes as occur in the Colca Canyon, among other many sites.

13.14. Folk biology studies on classifications and taxonomies

There are commonalities between a variety of indigenous biological classifications and modern taxonomies. Boster (1987) recognized four universals: (i) the linguistic form of classification; (ii) folk biological categories identify the same objective discontinuities in nature as those recognized in scientific classifications; (iii) culturally diverse native people and taxonomists agree in recognizing patterns of resemblance among a collection of biological specimens; and (iv) the agreement on the patterns of resemblance for a given taxon is based on the characteristics chosen for classifying them.

Medin et al. (1997) asked to what degree do conceptual systems reflect universal patterns of similarity or universal organizing principles of the mind, and to what degree do they reflect specific goals, theories, and beliefs of the categorizer? Their review of biological taxonomies revealed that the genus was the most relevant hierarchical level. Ever since the pioneer work of Berlin and colleagues (Berlin et al., 1966, 1973; Berlin, 1974, 1976, 1992, 1999), ethnobiological evidence has been accumulating and shows that human societies everywhere have similar folk biological structures (Medin and Atran, 2004). Most folk biological systems have between three and six ranks. When the first node (i.e "life") is included, there could be seven ranks as also exist in the USDA Soil Taxonomy (Ibáñez and Ruiz-Ramos, 2006). Classes of the same rank are mutually exclusive and tend to display similar psychological, linguistic and biological characteristics (Medin and Atran, 2004).

Inductive inference allows people to extend knowledge beyond their immediate experience and beyond the information they are given, and it is a crucial part of category formation and use. According to Medin and Atran (2004), inductive inference should be a mainstay of any search for underlying causal principles and its focus should be at the generic species rank in biological systems. Folkbiology studies show that both scientific and folk taxonomies make use of "consensus" among the members of a given community (López et al., 1997). Medin and Atran (2004) conclude that categorization of nature predicts reasoning about nature and that humans appear to be innately prepared to build hierarchical taxonomies which guide their inductions about the world (see also Lévi-Strauss, 1978). An analysis of mathematical structures of classifications shows that induction-based categorization requires hard discontinuities among the objects to carry on hierarchical classifications according to the MaxEnt Principle (Ibáñez et al., 2006).

The early development of scientific taxonomy involved an explicit decision to ignore the ecological setting of the organisms to be classified. This was to enable a worldwide distribution of easily reproducible representations of organisms for ready comparison regardless of an organism's original locale. Thus, in the first instance, although science first ignored ecology to maximize generality across local environments, ecological preferences discern well between morphologically similar species (Zimmer, 2008).

In other words, "*rather than reflecting the objective world as such, the correlation between folk and conventional scientific taxonomies may reflect universal ways in which humans spontaneously apprehend the phenomenally bounded world that they evolved in and for whose representation their cognitive apparatus evolved*" (López et al.,1997, pp.289). Does this imply that ecological, geographical or agronomical considerations could be a constraint to develop more scientifically sound and user-friendly soil classifications? The answer seems affirmative (Ibáñez et al., 2009).

All national soil classifications have a hierarchical structure ranging from with 3 to 8 categorical levels (Krasilnikov et al., 2009) (Table 5)

Regrettably, as far as we know no ethnopedologic classification has been analysed relative to the range of the Miller rule (see section 13.11) or if taxa are ever divided into less than five subtaxa throughout a system.

Systems used by soil surveyors and soil taxonomists as a whole have fractal-like structures (Ibáñez et al., 2009). Developing and using fractal structures are subconscious activities of the human brain that reflect both nature and our way of processing and representing information. Because the standards of many natural resource maps are similar to pedological ones, it seems that scale-invariant information processing is intuitive to human beings and that a more rigorous formalization of survey taxonomy architectures may help practitioners to improve their products (Ibáñez et al., 2009).

Classification	Number of taxonomic Levels
WRB	2(3)
USA	6
Canada	5
France	2(3)
United Kingdom	4
Germany	6
Austria	5
Switzerland	7
The Netherlands	4
Poland	6
Czech Republic	8
Slovakia	7
Hungary	4
Romania	7
Bulgaria	3
Former Soviet Union	6
Russia	8
Azerbaijan	7
Belorussia	8
Latvia	3
Lithuania	4
Ukraine	6
Israel	4
China	4
Japan	5
Brazil	6
Cuba	4
Australia	6
New Zealand	6
Ghana	6
South Africa	3

Table 5. Number of hierarchical levels of national soil taxonomies (after Krasilnikov et al., 2009)

13.15. How our mind works and the magic number seven: a collective mental experiment using PCs

In physics there is the custom to carry on mental experiments to show the strong and weak points of a given argument, conjecture or hypothesis. It seems plausible that mental experiments could also be corroborated analytically.

Consider organizing documents in a PC, personal computer. Imagine that you begin with "0" documents and several months latter you have 1,000 documents stored. If you do not make folders, then you can order the documents by alphabetical order, date, type of files (doc, pdf, jpg, etc.). Then you have a “flat classification”. Very soon the retrieval of the information that you require in a given moment becomes very time-consuming. It is not a user-friendly information system. The information flux is not efficient. Then, the most common operation consists in the creation of thematic folders. In other words, you are categorising the documents; you are generating categories and classifying the documents according to topics. If you stop the procedure at this step, you have a classification with two hierarchical levels: (i) folders and (ii) document files. The FAO Soil keys and, to some respect, the WRB have this kind of structure. It is the simplest hierarchical classification. However with time the number of documents that you archive is going to grow, while new topics appear requiring new folders. Furthermore, the number of documents per folder is going to be more asymmetric with time because you might give preference to some kinds of documents that are more interesting than others. At a given stage, the documents in the folders of interest will be excessively numerous making the retrieval of information tedious and time-consuming. It is then necessary to divide the folders of interest into subfolders hierarchically nested in the former. This results in a three-level hierarchical classification. Possibly, some topics do not require more than one hierarchical level. It is also possible to store documents different in nature in one folder that works like a “Pandora box”. This is to avoid creating many folders of small size that make the information system inefficient.

As the number of folders and files grow, the “intuitive” action consists in adding new hierarchical levels. However, too many levels and folders might be a drawback to the logical development of the system, although computer operations do not impose limits. Additionally, some interdisciplinary documents could fit in more than one folder, which requires making membership decisions. How many levels? Is it possible that most people have an innate tendency to stop at the magic number seven plus minus two? A mental experiment that could be considered as a conjecture is very easy to put in practice and be corroborated or refuted.

It is common that some documents could be deposited in different folders. The reason is that some documents could be considered objectively interdisciplinary in nature or they (like intergrades in pedological soil classifications) could fall in other folders in your "ad hoc" PC categorization. Then you crash against the "continuum dilemma". In these situations you can put the same documents in two or more folders or not, but there is always some uncertainty in your decisions. In short, when we try to create a user-friendly, efficient retrieval information system, we "intuitively" make use of having hard classes and a hierarchical classification. Unconsciously, as the number of folders to be handled increases, we build a broader and deeper hierarchy.

A mental experiment could be put in practice if many members of a given institution or institutions agreed with such an initiative. Are pedologists interested? Notice that the information is not needed for each PC, only the files/folders hierarchical structures delivered by the group of potential participants in this experiment. It is probable that we would detect very interesting regularities of how pedologists would organize their information.

Usually in scientific taxonomic classifications all basic entities are included at each categorical level, however, in our mental experiment some high level taxa could have more sublevels than others. Some sound scientific classifications have the same problem. It is termed the Gregg Paradox (Gregg, 1954) (see sections 4, 10, 13.15 and 16.3). Pedological classifications seldom exhibit this paradox.

Therefore this mental exercise tends to create branching fractal structures as occur in nature where the Gregg paradox is usual. However in general the architects of natural resources taxonomies prefer to eradicate this paradox, reinforcing our conjecture that our mind tends to embrace more symmetrical geometries, probable as a consequence of an innate cognitive bias.

14. Toward an optimum structure for universal hierarchical soil classification: background

14.1. Use of international codes of nomenclature

Universal classifications allow specialists of the same discipline to communicate. Pedology requires a precise and simple system of nomenclature used by experts worldwide to rank and label taxonomic soil units and their groupings. Such a nomenclature system would, and should, facilitate correlation among national and local soil classification schemes.

An acceptable international nomenclature code (see section 8) would further assist in accepting or rejecting the use of names which may cause error or ambiguity and prevent useless creation of names.

"Ad hoc" classifications will be essential to solve certain specific problems typical of applied research (e.g. ecosystem classifications, biocenoses according to biomass production, soil quality, etc.) Georeferenced soil information systems allow additional soil data collection and the acquisition of further data supplied by new technologies (satellite imagery, DEMs, sensors of various kinds, etc.). Because of their applied role, such classifications need to be independent of any universal soil taxonomy. The nomenclatures of applied classifications are specific to the desired interpretations and are not named as groups of soil taxa, rather they are named by their interpretation groupings.

There are taxa and subtaxa in some biological classifications that greatly exceed our channel memory capacity. In such cases with large size taxa, biotaxonomists break the higher taxa into two or more optional classes to make more user-friendly taxa with respect to the number of subtaxa. The hierarchical levels in the International Code of Botanical Nomenclature (Saint Louis Code) (Greuter et al., 2000) are seven (see section 8). This structure follows the Miller Rule that suggests seven levels for the hierarchical depth of a given taxonomy. These categories are mandatory, whereas superfamilies, subgenera, etc. are flexible categories. It should be possible to do the same in pedological taxonomies.

Some classes in the USDA Soil Taxonomy, such as for instance the Mollisols, Alfisols, and Aridisols, have large numbers of subtaxa at the great group level, which makes them less user-friendly than others.

Because some pedons have problems to be identified and classified, use can be made of flexible taxa, similar to those used in some biotaxonomies. In general, biotaxonomists do not use fuzzy logic procedure to identify taxa (Kay, 1975). Biometrics is sometimes used in theoretical work to obtain order in a given taxon, but they are not commonly used to classify the biodiversity of an entire domain (see section 4).

The International Code of Botanical Nomenclature provides clear rules to specify hybrid taxa, including hybrids between two or more taxa at the same or different hierarchical levels as was showed in section 8. The International Code of Botanical Nomenclature also states that "The principal ranks of nothotaxa (hybrid taxa) are nothogenus and nothospecies. These ranks are the same as genus and species. The addition of "notho" indicates the hybrid character". As soils show frequently overlapping properties or a combination of features common to several taxa, the experience of biotaxonomists may be supportive in further defining, classifying, and naming "intergrade" soils.

The USDA Soil Taxonomy handles the hybrids between taxa mainly at the subgroup level. The central concept is represented by the "haplo", or in a few cases by the last listed "other", great group. Soils departing from these central concepts at the subgroup taxa level are either intergrades with other soil classes or specific diagnostic features common to other taxa, or extragrades whose properties have not been used previously (e.g. lithic subgroups). The 'haplo' concept is often considered unconsciously as a 'prototype or archetype' as described by Rosch and colleagues. The modifier names used indicate the major diversity from the 'haplo' concept, and correspond "somewhat" to the ideas of the International Codes of Nomenclature guidelines for naming hybrids.

The botanical code also provides a means to classify fossil plant taxa which are treated as morphotaxa (see section 8). The code also has specifics for naming morphotaxa and hybrid morphotaxa. It is possible that the experience of biotaxonomists may be useful for pedologists in classifying paleosols. Paleosoils are generally thought to be "buried" and so designated in their horizonation. Some are exposed on the present surface in which case the properties are used to recognize and assign them to appropriate taxa at all corresponding levels. The buried soils, the Paleosoils, are commonly handled as specific stratigraphic units in geological classifications.

When large soil databases are available, pedometric tools could be used to design more formalized classifications, or to solve some specific problems. Pedometrics and perhaps fuzzy logic (see section 4) are also useful tools to develop "ad hoc" classifications with purpose-oriented objectives, such as precision farming in relatively homogeneous landscapes. It is well to remember that such interpretive classifications are not soil taxonomic classifications, rather they are groupings of soils into various attribute classes often ranking the groups for specific pragmatic purposes.

14.2. US Soil taxonomy structure

The mathematical structure of the USDA Soil Taxonomy seems to be an unconscious/conscious compromise between the sciences that tell us how to obtain an efficient information system and our cognitive, utilitarian and cognitive biases (Ibáñez et al., 2009).

The conceptual structure conforms to the MaxEnt Principle, Mayr criteria, and fractal physics (Ibáñez and Ruiz-Ramos, 2006; Ibáñez et al., 2006). Entropic analysis shows that the human mind tries to use an equitable retrieval information system according to the above mentioned tests. However, in nature the Willis curve effect (i.e. a few taxa with many members and many taxa with only a few members) deviates from the properties that produce the best information systems. Soil (as well as living organisms) conceptual classification systems have high evenness values in contrast to the results of field soil and biodiversity inventories, thereby creating tension between mental constructs and observations in nature. The USDA Soil Taxonomy shows a geographic bias in that the numbers of taxa or subtaxa are associated with their extent in a given geographical area (Ibáñez et al., 2009) (Figure 5). If soils were fully biological bodies, then Willis or Burlando would likely have said that they conform to the concept of evolution of species of a given genus.

Subtaxa per taxa	Mean	Mode	Nº Taxa into the Miller Rule
Suborders/Orders	5.3	5	78%
Great Groups/Suborders	5.0	5	53.1%
Subgroups/Great Group	7.7	4	40%
Haplo taxa	12.7	16 & 9	21.6%
FAO 1988 Keys two hierarchical levels	5.1	6	81.7%

Table 6. Taxa ratios of the USDA Soil Taxonomy (1998) and the Miller rule.

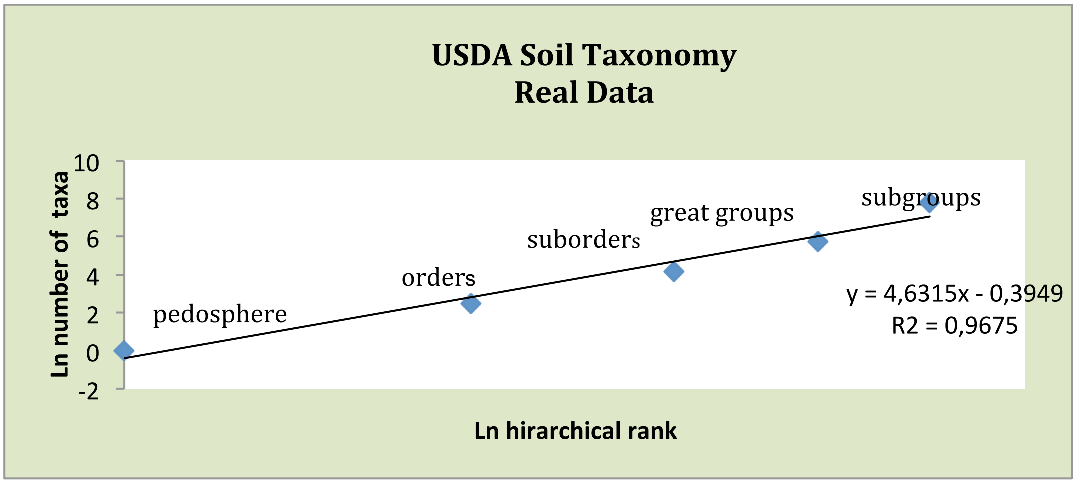
In the 2010 Keys to the Soil Taxonomy (Soil Survey Staff, 2010) the number of Subgroups per Haplo Great Group range from 1 in the Inceptisols (Wassents) to 34 in the Xerolls (Haploxerolls). This more or less is another symptom of a utilitarian bias because of interest or use of the objects of a given Great Group (see sections 4, 10, 13.5 and 17.3). It seems true for the Mollisols (34, 31.18,15), but the Aridisols also have high numbers (Haplocalcids 21, Haplocambids 22, and Haplargids 19). However Aridisols is a soil Order widely spread in the USA covering large areas (geographical bias). In addition many of them under irrigation commonly have high crop production.

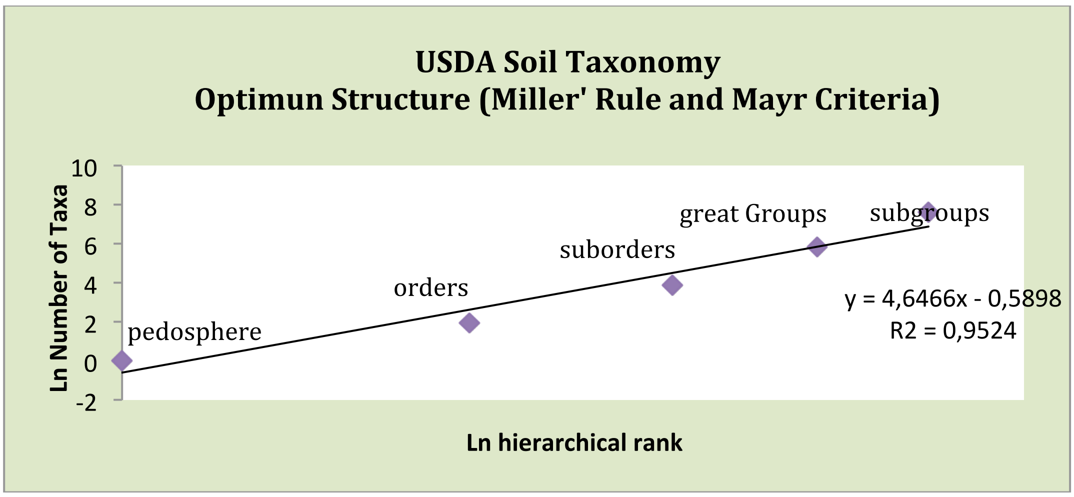
The Miller rule is evident in the USDA Soil Taxonomy (Soil Survey Staff, 1998). Taxa having 8, 7 or 6 subtaxa are the most numerous (Table 6). The mean size of subgroups in nearly all orders falls within the range 9-5, which conforms to the Miller Rule. Miller (1956) indicated that the magic number seven plus/minus two is a cognitive tendency and that some taxa could have higher or lower values. The prototype effect reflecting the cognitive bias is shown by the large size of the "Haplo" great group taxa (Table 6), however they range from 1 to 34. The number of hierarchical levels also falls in the range predicted, taking into account families and soil series. The new version of the Russian classification (Shishov et al., 2004) has eight hierarchical levels. Figure 12 shows that both the USDA Soil Taxonomy and a hypothetical taxonomy with an iterative fragmentation of seven subtaxa per taxa and five and 7 hierarchical levels fit very well to power law distributions with similar statistical values, constants and exponents. Figure 13 shows the same analysis of the *Tylenchina* Suborder (plant parasitic nematodes) with similar results. These taxonomies are the same as those used by Ibáñez and Ruiz-Ramos (2006), Ibáñez et al. (2006) and Zhang and Zhang (2008) for the comparison of pedological and biological taxonomies. Both classificatory structures seem to follow the same pattern, conforming to the Miller rule if the above mentioned biases are taken into account.

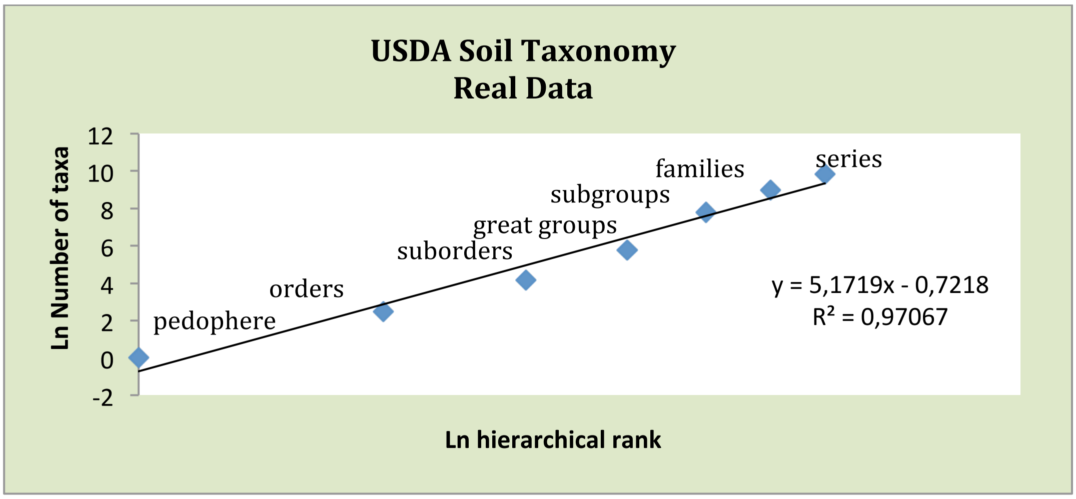
The USDA Soil Taxonomy's utilitarian bias is shown by the large subtaxa sizes in the Mollisols, indicating a mollisolic bias, as also seems to occur with soil quality standards (Sojka et al., 2003). When geographic, utilitarian and cognitive bias coincide in the same Suborder, deviations of the Miller rule are much more exaggerated, effecting the fractal and multifractal structures of the whole taxonomic construct (Ibáñez et al., 2006). The area and size of the some Haplo great group taxa deviate from the Miller Rule and produce a less user-friendly and efficient classification in terms of our cognitive capacity channel (Ibáñez et al., 2006). This is thought to be generated by the prototypic effect when used in the lower levels.

However these results also could be interpreted in terms of hybrid or intergrades as a consequence of the prototype effect. In other terms, the "haplo" suborders with their many subtaxa is an example of how Soil Taxonomy handled the hybrid issue. Haplo is the simplest taxon in a suborder, and all the subgroups of this simple taxon and of its associates are soils that have additional properties most of which are those of other taxa, except some ones like the 'lithic' subgroups. It is likely that both perspectives are related to the dominance of a few individuals as the main architects of the USDA ST (namely Guy Smith and others) (e.g. Soil Survey Staff., 1951) when they handled the hybrid, or intergrade diversity.

Thus Figures 12 and 13 corroborate the rationale of our working hypothesis with respect to the structural analysis.







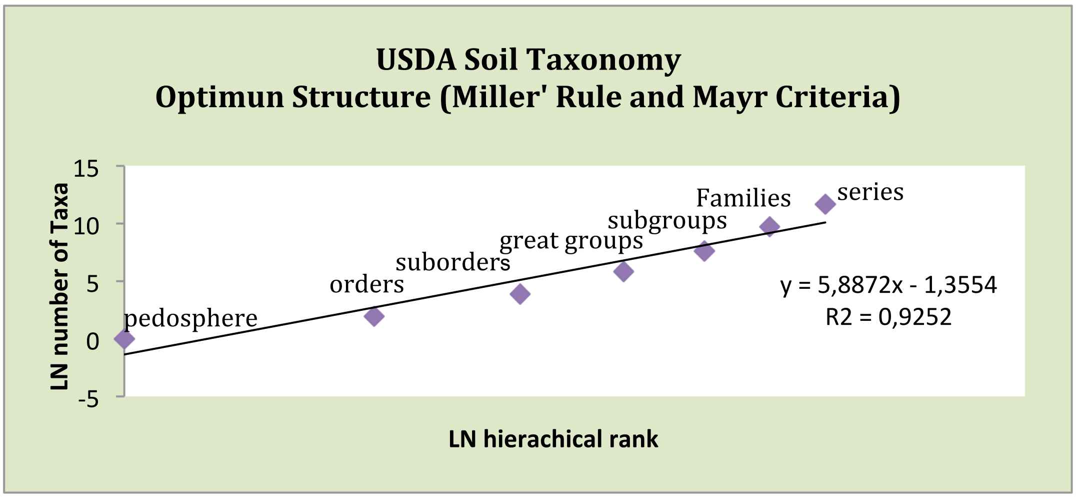


Figure 12. Comparison of a hypothetical taxonomy with an iterative fragmentation of seven subtaxa per taxa and seven hierarchical levels, and Real USDA ST structure. Both plots fit very well to a power law with similar statistical values.

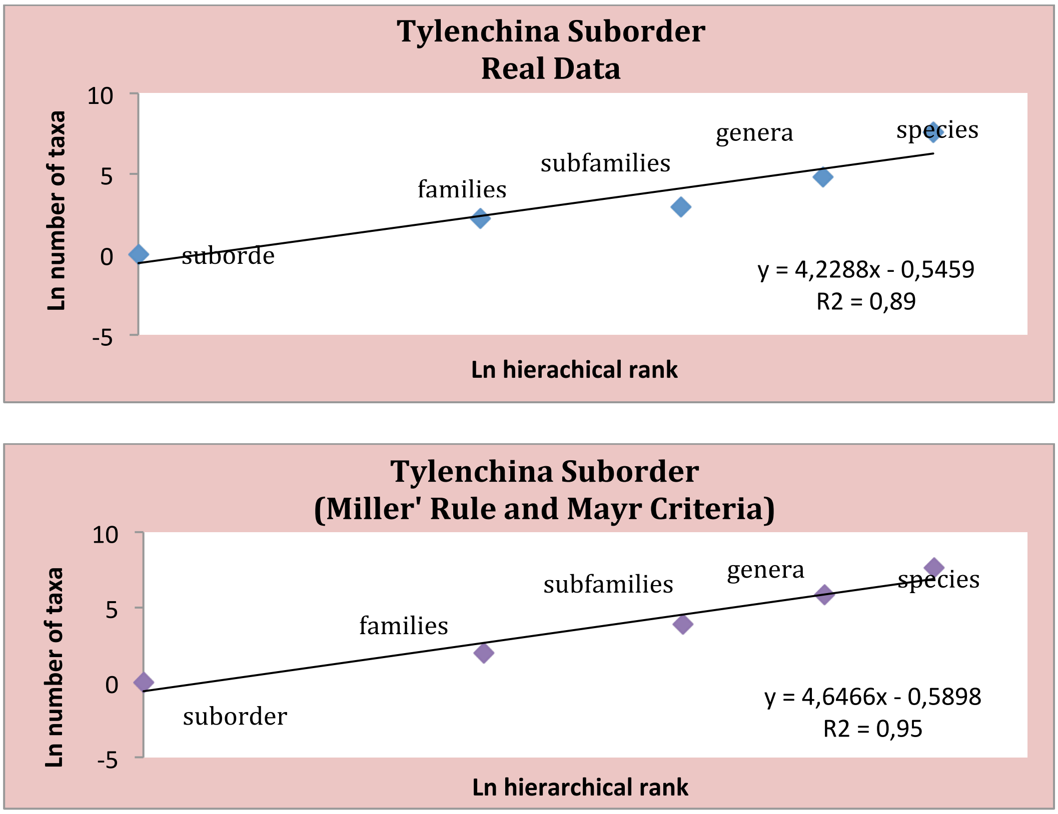


Figure 12. Comparison of a hypothetical taxonomy with an iterative fragmentation of seven subtaxa per taxa and five hierarchical levels, and real *Tylenchina* suborder (Nematoda) structure. Both plots fit very well to a power law with similar statistical values

The Gelisols and Histosols deviate most from this trend; they have less ramified structures because they traditionally have less agronomic interest. The WRB (1998) soil classification frame with only two hierarchical levels does not fall within the Miller rule.

The families per subgroup and series per family in the USDA Soil Taxonomy have not been fully analyzed because (i) there are no data on a worldwide scale at these lower hierarchical levels, and (ii) the strong geographical bias of these taxa suggests (Guo et al., 2003; Ibáñez and Effland, 2009) that they might be considered as geographical races rather than true species or formal taxa (Ibáñez and Effland, 2011). It does, however, demonstrate that the genetic model of soils, particularly the relevance of parent material variability, is a useful criteria and it illustrates the bias of local geography and geomorphology for soil survey on the global distribution of soils. However, if the architects of a universal soil classification decide to include in its structure taxa-like races, it is recommended that they consider a globally accepted lithological classification of parent materials. However, at this time there is no such official taxonomy of lithologies that we are aware of.

Table 8 shows the number of taxa that would appear if the magic number rule were used for the branching of subtaxa per taxa in seven items and for establishing the number of hierarchical levels. Considering that the upper node (level 0) of the hierarchy is the full pedosphere, the sixth hierarchical level would contain 117,644 pedotaxa and a seventh level would provide for 823,543 classes. Finally if an eighth level was included the exorbitant number would be 5,564,801. Notice that the last figure by far exceeds the number of species currently identified in the biosphere, as well as many estimates using predictive modelling of the full species number that may exist in the world.

Usually, biodiversity surveys are concerned with a few taxa, not the whole tree of life. For instance, there are 197 genera and 4300 species of nematode phytoparasites that are harmful to crops (A. Bello and M. Arias, *pers. com.*) All of them are members of the order *Tylenchida* with the exception of some genera that pertain to the order *Dorylaimida*. It is common that biotaxonomists are experts in taxa that often concern a few thousands of species. In contrast, soil taxonomists who usually are also soil surveyors, deal in general with a large variety of taxa. Therefore, a universal soil taxonomy likely would be better if it contained only a few thousand or tens of thousands of pedotaxa at the lowest level of the hierarchy to keep the system workable.

Level 1 = Pedosphere	
Hierarchical Level	Number of Taxa
1 (pedosphere)	1
2	7
2	49
4	343
5	2401
6	16807
7	117644
8	823543
9	5564801

Table 8. Number of Taxa according to the Miller Rule (hierarchical subtaxa per taxa and hierarchical deep).

14.3. The structure of several national soil classifications in comparison with the US Soil Taxonomy

It should be interesting to compare the structure of the USDA ST with other national classifications. During the elaboration of the monograph edited by Krasilnikov et al. (2009) some data of several soils classifications were obtained (Tables 9, 10). Regrettably these data only have two complete national soil classifications; the Dutch and Chinese ones. In any case total and partial data were fit to power laws as shown in Figure 13. In view that in three cases only data of two hierarchical levels were available, thus, the fits to regression model do not have statistical significance. However, the analysis permits some interesting conclusions.

The range of variation of data and bifurcation ratios in different national soil classifications is rather high, whereas all of them fit well to power law distributions.

National Soil Classification (SC)	Taxon/number				Hierchical levels
Dutch SC	Orders-5	Suborders-13	Great Groups-25	Subgroups-60	4
Chinese SC	Order-14	Suborders -39	Groups 138	Subgroups-588	4
German SC	Branches -4	Class-22	Types-56		6
Ghana SC	Orders-3	suborders-8	Great Groups-17	Families-42	6
Russian SC	Ttunks-3	Sections-27	Soil types-227		8
Brazilian SC	Orders -14	Suborders -44	Great groups-155		6
Canadian SC	Order-8	Great Groups-8	Subgroups-208		5
Japanese SC	Great groups-10	Groups-31	Subgroups-118		5
Australian SC	Orders -14	Suborders-84	Great groups-657		6
Poland SC	Sections-7	Orders-14	Types-35		6
Belgium SC	Types-22	Subtypes-66			?
Hungary SC	Main Types-9	Types-37			4
Cuban SC	Groups-15	Types-39			4

Table 9. Some data of National Soil Classifications (source Richard Arnold)

National Soil Classification	Bifurcation Ratios	Bifurcation Ratios	
Dutch Soil Classification	Suborders/Order	Great Group/Suborder	Subgroups/Great Group
	2.60	1.92	2.40
Chinese Soil Classification	Suborder/Order	Group/Order	Subgroup/Group
	2.79	3.54	4.26
German Soil Classification	Class/Branch	Type/Class	
	5.5	2.54	
Ghana Soil Classification	Suborder/Order	Great Group/Suborder	Family/Suborder
	2.67	2.13	2.47
Russian Soil Classification	Section/trunk	Type/Section	
	9.0	8.41	
Brazilian Soil Classification	Suborder/Order	Great Group/Suborder	
	3.14	3.54	
Canadian Soil classification	Great Group/Order	Subgroup/Great Group	
	3.88	6.71	
Japanese Soil Classification	Groups/Great Group	Subgroup/Group	
	3.10	3.81	
Australian Soil Classification	Suborders/Order	Great Group/Suborder	
	6.0	7.82	
Poland Soil Classification	Order/Section	Type/Order	
	2	2.5	
Belgium Soil Classification	Subtype/Type		
	3.0		
Hungary Soil Classification	Type/Main Type		
	4.11		
Cuban Soil Classification	Type/group		
	2.60		

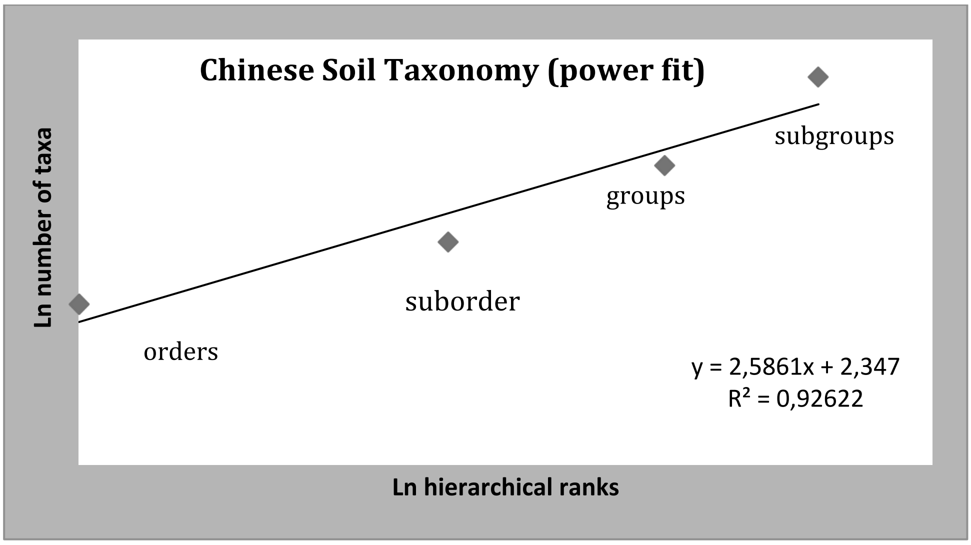
Table 10. Bifurcation ratios for several for several hierarchical levels of some data of National Soil Classifications (source Richard Arnold).

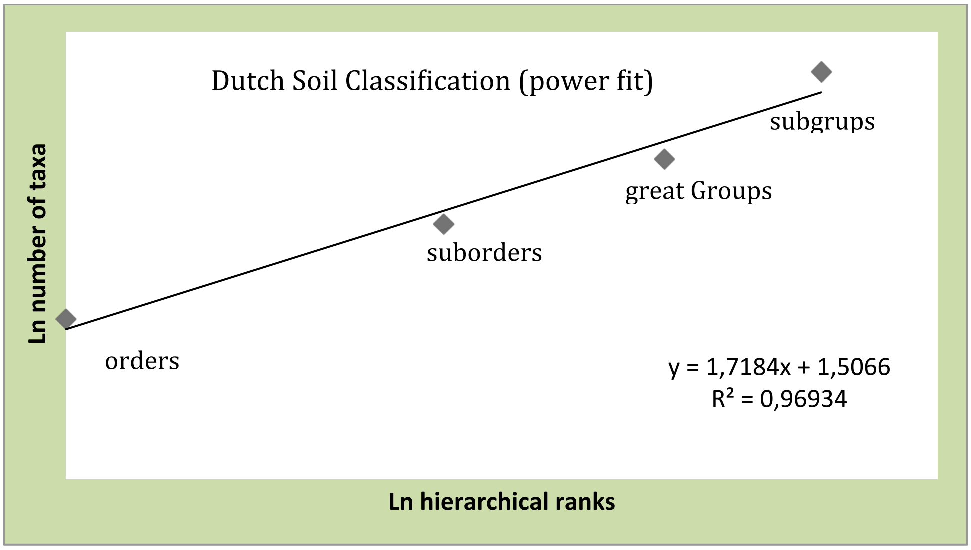
The USDA ST highest hierarchical level exceeds the values recommended by the Miller rule. However except in the case of the Russian and Australian classifications bifurcation ratios values are low, suggesting that these constructs could be condensed more. For national classifications with information from all hierarchical levels, the number of pedotaxa at the lower hierarchical level is quite low, not reaching the figure of a thousand.

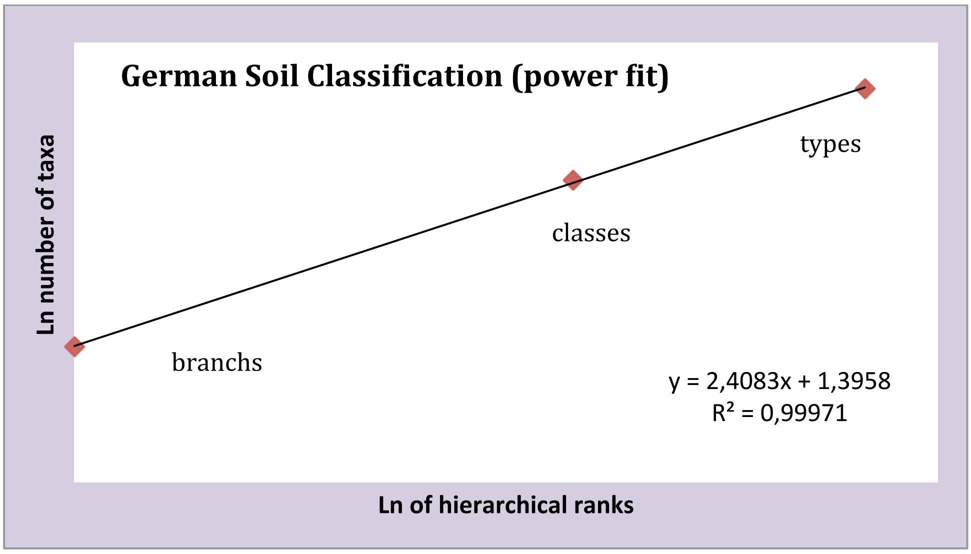
It is not possible to analyze in more depth taxonomic constructs due to a lack of necessary information. For example, it would be interesting to analyse if the number of edafotaxa in the lower hierarchical levels of a classification is related to the surface or extension of each country (see section 9 and figure 5), even where this trend does not occur with the highest ones (the latter seems that not suffer a geographic bias).

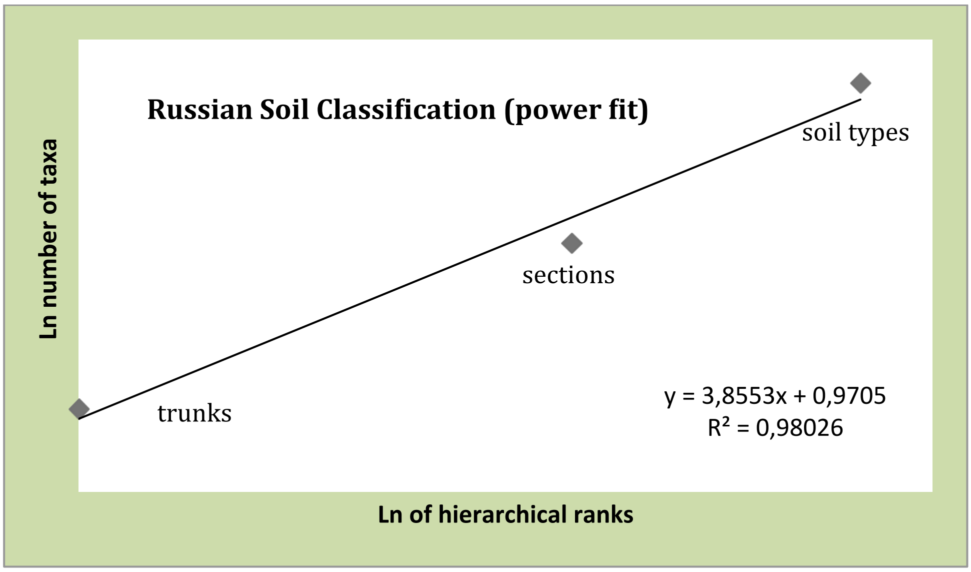
In most cases the bifurcation ratios seem to indicate that most of the classifications could be condensed more. Special mention can be made of the Russian classification with a low number of hierarchical levels (4) but whose structure conforms to the rule of Miller.

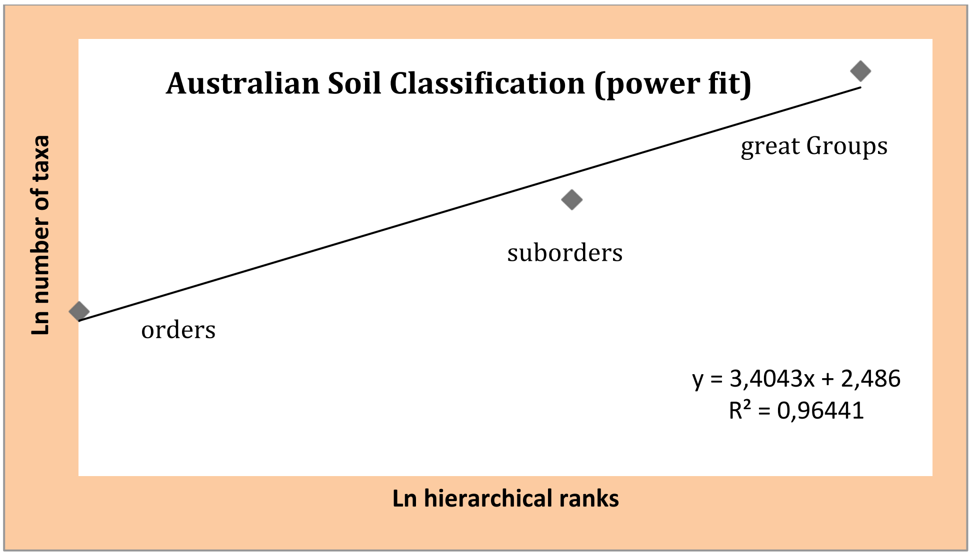
A more detailed analysis of the classifications offers a surprising result. In several of the national constructs (as also happens in USDA ST) the number of subtaxa by some soil taxa tends to be fragmented in a very equitable way, but at the same time distinct from the others. A hypothetical example: in a single classification a suborder is subdivided into five groups and each of them into five subgroups (5,5,5,5,5), whereas in another each is divided only in 2 (2,2,2,2,2). This pattern might indicate the existence of several working groups that agree on a set number of subtaxa/taxa but do so without any agreement with other working groups. If such patterns were noted it would be prudent to recommend adopting the Mayr criteria (see section 13.4).

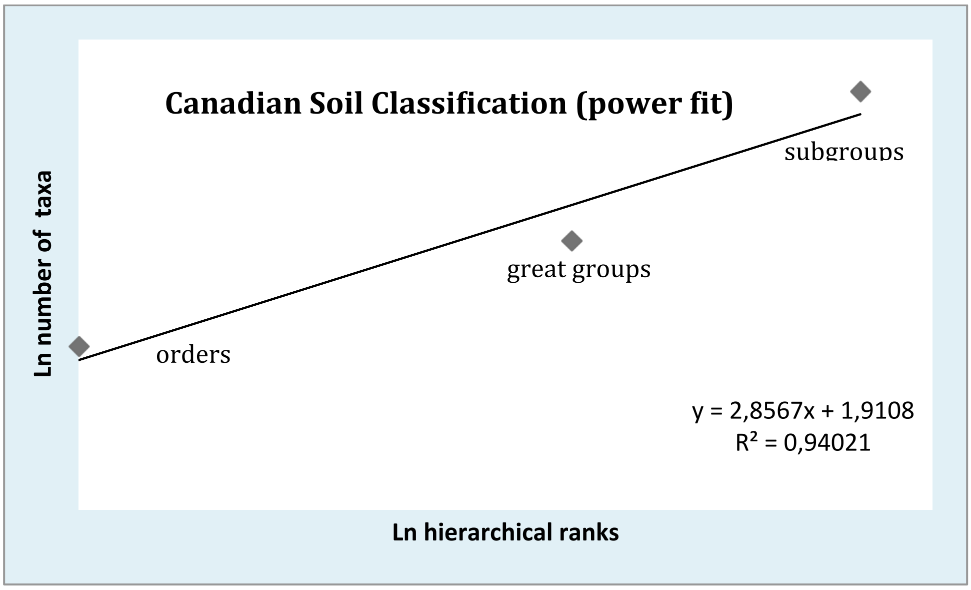

Chinese Soil Taxonomy (power fit)
subgroups
groups
suborder
orders
y = 2,5861x + 2,347
R² = 0,92622
Ln number of taxa
Ln hierarchical ranks

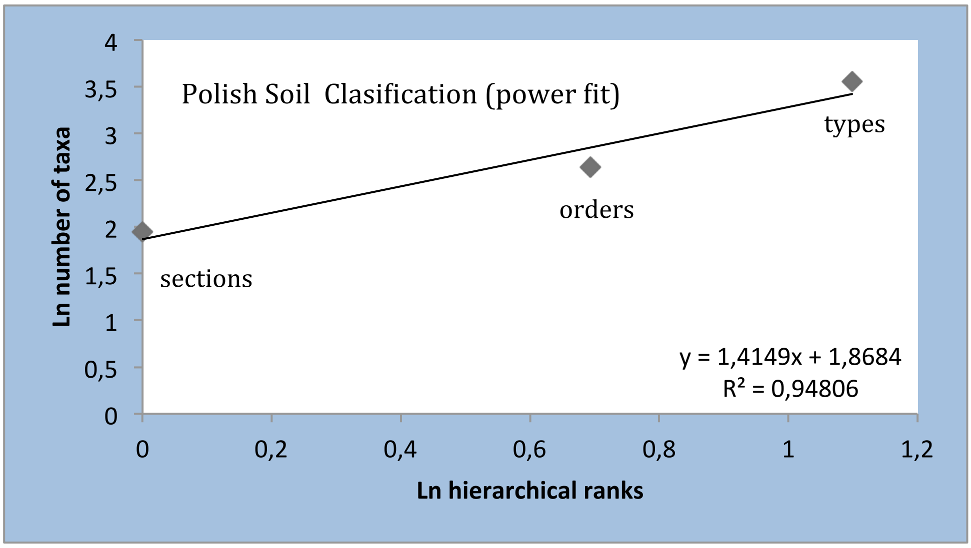

Dutch Soil Classification (power fit)
subgrups
great Groups
suborders
orders
y = 1,7184x + 1,5066
R² = 0,96934
Ln number of taxa
Ln hierarchical ranks

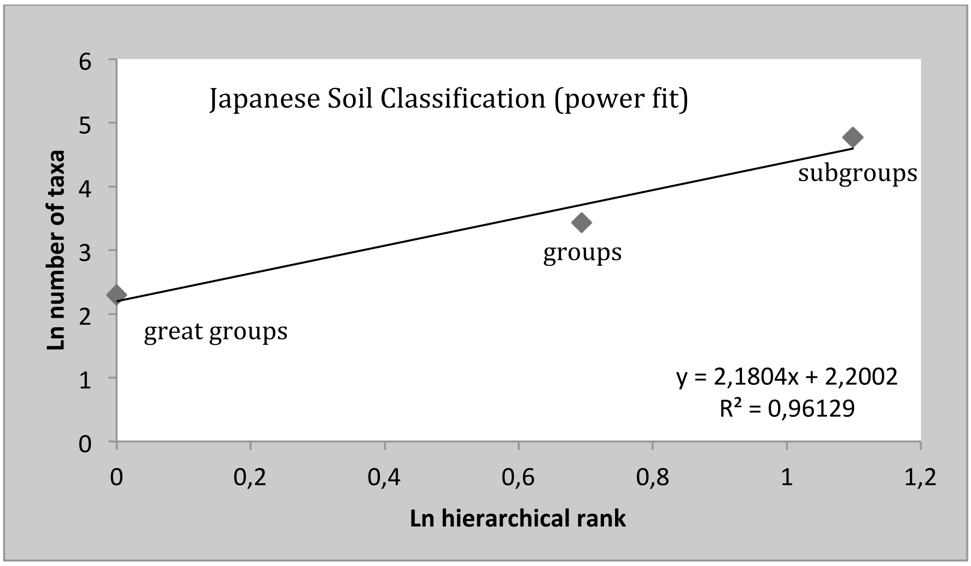

German Soil Classification (power fit)
types
classes
branchs
y = 2,4083x + 1,3958
R² = 0,99971
Ln number of taxa
Ln of hierarchical ranks

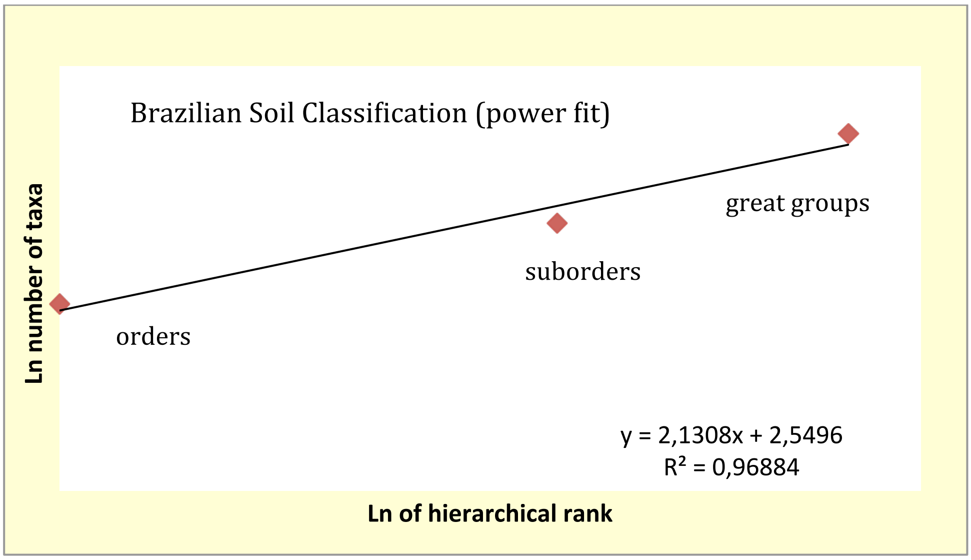

Russian Soil Classification (power fit)
soil types
sections
trunks
y = 3,8553x + 0,9705
R² = 0,98026
Ln number of taxa
Ln of hierarchical ranks


Australian Soil Classification (power fit)
great Groups
suborders
orders
y = 3,4043x + 2,486
R² = 0,96441
Ln number of taxa
Ln hierarchical ranks


Canadian Soil Classification (power fit)
subgroups
great groups
orders
y = 2,8567x + 1,9108
R² = 0,94021
Ln number of taxa
Ln hierarchical ranks


Polish Soil Clasification (power fit)
types
orders
sections
y = 1,4149x + 1,8684
R² = 0,94806
Ln number of taxa
4
3,5
3
2,5
2
1,5
1
0,5
0
0
0,2
0,4
0,6
0,8
1
1,2
Ln hierarchical ranks


Japanese Soil Classification (power fit)
subgroups
groups
great groups
y = 2,1804x + 2,2002
R² = 0,96129
Ln number of taxa
6
5
4
3
2
1
0
0
0,2
0,4
0,6
0,8
1
1,2
Ln hierarchical rank


Brazilian Soil Classification (power fit)
great groups
suborders
orders
y = 2,1308x + 2,5496
R² = 0,96884
Ln number of taxa
Ln of hierarchical rank

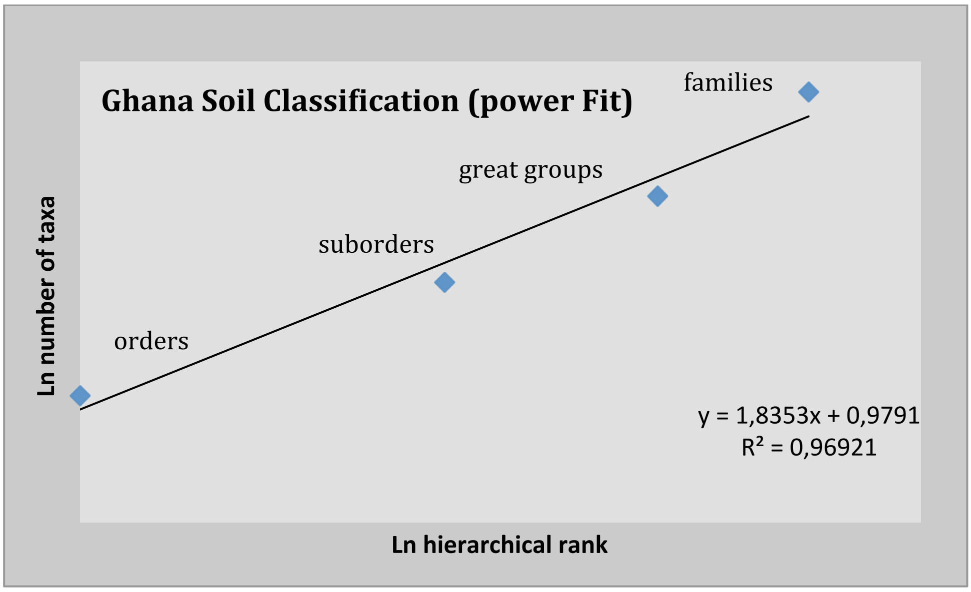


Figure 13. Some data on the structure of several national soil classifications.

15. Toward an optimum structure for universal hierarchical soil classification: proposal

15.1 Working assumptions

Based on criteria found in the literature about classification and taxonomy, several working assumptions can be suggested for the structure of a universal soil classification system as follows:

- Miller's concept that 7 +/- 2 as a mental constraint on the human span of correct judgment, short term memory, and attention is meaningful for the design and testing of systems. Miller wasn't sure if these three aspects were aspects of a single process or were separate ones. This remarkable number is relevant to the design of efficient and effective information structures, as well as for dictionary structures as mentioned by Changizi (2008).

- Symbols have meaning because of their correspondence to real objects. Concepts are internal representations of external reality, thus thoughts can be considered to be the 'disembodied' manipulation of abstract symbols. Soil profiles or pedons are symbols representing soils that can be mentally manipulated.

- It is commonly believed that, in the perceived world, information-rich bundles of perceptual and functional properties and attributes occur that form natural discontinuities, and that basic separations of domains are commonly made at these discontinuities. For instance, bodies of earthy materials recognized as soils differ from non-soil bodies.

- Studies in ethnoscience reveal that some form of taxonomic hierarchy is basic to the classification of the biological and pedological worlds by humans. Taxonomy is a system by which categories are related to one another by means of class inclusion. Humans inherently organize soil-related information into hierarchies.

- Hierarchies based upon relationships of the morphological structure of objects are consistently represented among biological classification systems by diverse human groups, and generally coexist with various functional and other non-morphological hierarchies. The same may be said for most soil classification schemes. Many other systems are ad hoc interpretive schemes that serve pragmatic concerns.

- The most basic level of classification for any given domain is largely a reflection of objective reality, and this is generally consistent across human populations. Another viewpoint is that, within a given domain, importance is primarily a function of human attention to, or indifference toward, the membership of that domain. Both of these concepts can give rise to ambiguity and uncertainty in classification. Such biases generally distort taxonomic structures and may divert them away from fractal and multifractal ones.

- The greater the inclusiveness of a class (taxon) within a taxonomy, the higher is the level of abstraction. Based on a coupling of taxonomic and linguistic criteria with behavioral criteria, folk generic distinctions represent the underlying fundamental units of any ethnobiological classification. A pedological concept of basic soil units equivalent to the biological genus (generic) distinctions differs among existing soil classifications.

- Analysis of everyday scientific work reinforces that classification is a social activity occurring in space and time, and does not eliminate uncertainty and inconsistency but tends to minimize contradictions. Mutually exclusive categories and classes may exist in abstraction but seldom in external reality. This is a major cognitive concern in constructing taxonomic schemes.

- Clue validity as it relates to inclusiveness is a probabilistic concept. The validity of a given clue 'x' (diagnostic, characteristic, or property) as a predictor of a given category, or class 'y' (the conditional probability of y/x) increases as the frequency with which clue 'x' is associated with category 'y' increases, and decreases as the frequency with which clue 'x' is associated with categories, or classes other than 'y' increases. Appropriate and consistent ways to handle partial class memberships (overlapping criteria) in a taxonomy are crucial to consistency in the development and application of a classification scheme.

- Pedological classification commonly uses the following principles: purpose of the scheme; domain to be considered; basic entities of the domain; rationale (definitions used) of the scheme; hierarchical structure that includes all taxa at all levels; defined diagnostic properties and methods of observations; consistent nomenclature; and a means for maintaining the system. (Cline, 1941; Arnold, 2001; Arnold and Eswaran, 2003).

15.2. Suggested guidelines

If further advances toward a universal soil classification are to be achieved, the following ideas may be useful for consideration. Principles should be explicitly stated and followed.

1 The purpose of such a system should be to consistently recognize and provide identity to otherwise unidentified soils throughout the world.

2. The system should be independent of size and extent of soil bodies, that is, it should be free of geographic bias as far as possible. There is, however, a distinct disadvantage of recognizing a soil profile or pedon as a soil because the potential number of soils may be very large. Entities important to society will be the source of more information than others and will commonly distort certain taxa. This utilitarian bias should be avoided or at least minimized because the scheme serves as a universal scientific language. Paying attention to these influences will lead to future refinements of the overall system. The system may be limited because a definition of soil establishes the domain and human cognitive bias affects the recognition of distinct fundamental units of the domain.

3. The system should emphasize diagnostic properties and features that provide consistent identity. These most likely are morphological features. The use of properties specifically designed to emphasize agricultural or environmental interests should be avoided as these are more appropriate for interpretive classifications rather than a basic universal classification. Such societal biases should be avoided as much as possible, although correlations with interpretive-use properties of soils enhance the utility of a basic system. Utilitarian classifications can often be developed using universal taxonomies together with other sources of information about properties, attributes, and environmental conditions. Most utilitarian schemes are not soil taxonomies, however the taxa of soils may be members of the various interpretive classes.

4. An important objective should be to have efficient storage and retrieval of information. Therefore, measures such as entropy may be useful in overall structure design.

5. Use a nested hierarchy that has reasonably uniform branching from top to bottom. Seven plus/minus two categories (levels) and seven plus/minus two classes (taxa) for each

higher class (taxon) are recommended, as far as practical. This takes into account the suggested constraints of our humanness.

6. Have an accepted scientific rationale for the system that defines the levels (categories) of the hierarchy and that provides a list of diagnostic properties and features of soils used at each level. This reduces some ambiguity and uncertainty and makes identification keys easier to develop and apply.

7. Have useful options within the existing structure to recognize and identify soils that are intergrades, hybrids, or paleosols with overlapping diagnostic properties and features. Partial class memberships (fuzzy classes) are very common in external reality, so nomenclatural codes for consistent recognition and naming greatly reduce uncertainty of placement.

8. Have a universal soil nomenclature. As names are short-hand means of recognition and communication, it is vital to have accepted protocols for providing names that can be followed, used, or even proposed, by interested persons.

9. A universal soil classification will need data storage and tracking mechanisms to maintain an up-to-date system.

16. Other impacts beyond magic numbers

16.1 Complexity among categories

In previous sections structural criteria to build efficient hierarchical soil classifications guidelines were discussed. There are other important aspects that should also be taken into account; for example, how features, properties and analytical variables should be ordered in a hierarchical classification.

The higher hierarchical levels of a given taxonomy should divide the patterned soil continuum in a way that permits easy recognition of the lower ones. For example, similar to the case of animals and plants, higher hierarchical levels of a universal soil classification (USC) should be discernible without problems by non-expert people using mainly visual and tactile criteria. For example, organic soils versus mineral soils, incipient soils (e. g. Entisols) versus more developed soils, etc. must be recognizable. This rationale allows the teaching of major kinds of soils to non-expert people and children. The use of analytical data at the higher levels of the system should be limited to those which can be easily determined in the field. Criteria that demand the use of sophisticated instrumentation such as micromorphology to recognize argilic horizons should not be included as definitive, rather they may be used as descriptive information.

Moving from the top to the bottom of a taxonomy generally requires more experience and training as well as more complex analytical tools. This process needs to be gradual, as far as possible. Access to complex analytics could be difficult for students and experts of developing countries. If such properties are used in the higher hierarchical levels a deep gap may be generated in experts of different countries depending of their economy and technical development. Observing this protocol would permit most interested people to recognize the major classes. Obviously this can be a difficult task and some exceptions will be inevitable, as also occur in biological classifications.

Another aspect refers to discriminating between static and temporal properties. Temporal, or transient properties change quickly over time and, therefore, should not be considered as definitive properties at the higher levels of a hierarchy. They may be useful as phases of taxa for attributes or properties that are not definitive for the taxa at these more abstract levels. Temporal properties are generally very useful in interpretive use and management classifications.

16.2. Paradigm shifts

It is matter of debate if new societal demands of soil information require new protocols and initiatives or a true paradigm shift likely will be necessary. Both strategies might be needed and important for a final product. The IUSS has taken the initiative of creating a Working Group in charge of preparing a Universal Soil Classification. Likewise the United States and the European Union have launched an ambitious program termed the "Earth Critical Zone" (Brantley et al., 2006). The contents of these initiatives do not differ much from the proposal by Ibáñez and Boixadera (2002), who urged a paradigm shift as well as an universal soil classification. Brantley et al. (2006) state that: "*Shallow soils and soil structures have been extensively characterized and classified by soil scientists. In contrast, the structure of deep soil horizons (earthy layers) down to unweathered bedrock is generally poorly documented. Can we develop a unified approach to characterize the environmental conditions and mechanisms that produce differences in soil types and individual horizons over the full weathering or soil profile?*

The old but ongoing request to focus on the soil-regolith interface was summarized by Ibáñez et al. (2002). Cremeens (1994) stated that: "*The regolith materials are normally considered by soil scientists to be the rocks and minerals underlying the solum (the object of interest) and largely ignored"*. Furthermore, Buol (1994) (in Brantley et al., 2006) proposed an interesting framework on how to describe regolith horizons that is compatible with the current description of soil horizons. In any case the agronomic paradigm (with a strong utilitarian bias) of soil science prevails and has markedly influenced conditions pedologic history (see sections 9 and 14.2).

Most of these non-structural issues will likely be faced by those working toward a new universal soil classification.

16.3. What natural bodies to classify?

The current demand of soil information is beyond that required in the past. While the USDA Soil Taxonomy has been incorporating hydric soils, the WRB (2006-2007) has incorporated more new manmade soil materials and urban soils. The incorporation of subaqueous soils was already proposed by Kubiena in the 1950s (Kubiena, 1995). There are also requests to include the soil-regolith of other planets such as Mars (e.g. Targulian et al., 2010) and initiatives that claim the need for a classification of the whole soil-regolith-vadose zone-groundwater earth surface system such as the Earth Critical Zone Program (e.g. Wilding and Lin, 2006). To meet these challenges, it would be necessary to re-define what is soil (Ibáñez and Boixedera, 2002). If these concerns are taken into account, any universal soil classification will be quite different and much more complex that any existing ones.

New natural/artificial soil and soil-like entities might lack accurate scientific background and, therefore, their classification may be less precise than the rest of the pedological hierarchy. One should be careful not to create a Gregg paradox, that is where not all branches of the hierarchy will have the same number of hierarchical levels except in specific cases that we describe in this book, such as ontological categories of "soil-like bodies" (e.g. Mars soil-regolith, oceanic floors, etc.). When future studies enrich the information currently available, new arrangements and additional hierarchical branches could be added step by step to these of "like soil bodies" (Figures 14)

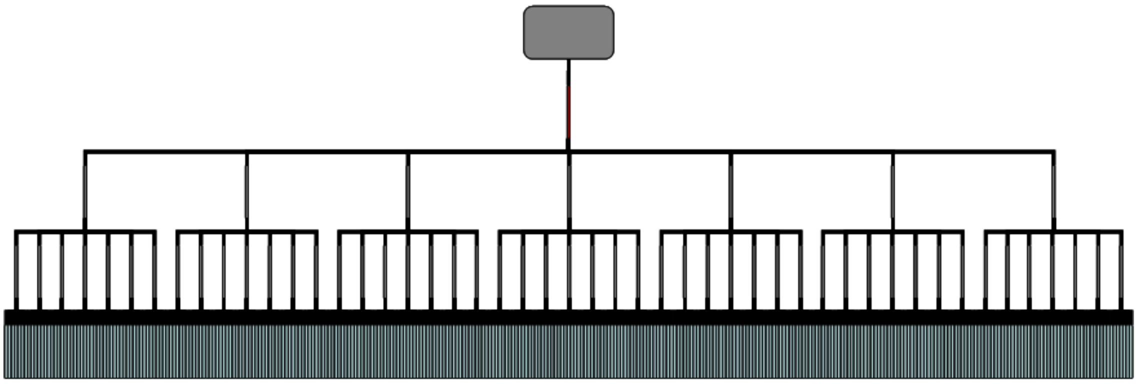


Figure 14. A Symmetrical Classification following the Miller' Rule

If the regolith of Mars were to be incorporated in a universal soil classification scheme, for the sake of coherence other terrestrial materials such as truncated regoliths, sand dunes, landslide sediments, superimposition of layers of fine sediments, many quaternary deposits, etc., should also be considered for inclusion, perhaps as exotransons (Targulian et al., 2010). Likewise, non-mobilised regoliths could display different layers or horizons (exositons) (Targulian et al., 2010), but there is no sound evidence that they are products of biogeochemical processes. In the case that exositons are only the result of geochemical processes, the model would require a new definition of soil. Regoliths more than two kilometres deep (e.g. Borgonie et al., 2011) might be the product of biogeochemical cycles but are not yet considered as soils. Likewise it is probable that many of the Mars exositons could be deep soil oceanic or lake floors, whereas the same natural bodies are not considered soils on the Earth. There are conceptual inconsistencies.

For these reasons, it seems desirable to discuss additional ways to distinguish between the above mentioned and other natural bodies that currently are considered pedotaxa. For example if an additional hierarchical level called "kingdoms" for example (as ontological categories) were proposed, then to carry on a coherent USC, it would take clarification to develops the relationships of other novel natural bodies, such as Mars regolith and other natural structures that have not traditionally been considered as soils.

If pedology paid attention to “soils” on Mars, one might wonder why sea floors are not considered in view that they are also the product of the interaction of biosphere-lithosphere-hydrosphere-atmosphere, while the two latter are not part of the Mars geosphere at the present stage of knowledge. The study and classification of sea floors in a USC would have theoretical and practical importance for the preservation of biodiversity, understanding of global biogeochemical cycles, biosphere structure and dynamics, and oceanic sediment management (e.g. impact of undersea ore mining). The driving forces of the sea floor structures and dynamics vary with depth and sea floors are very different from the aerial and subaqueous soils that currently are considered in USDA Soil Taxonomy or the WRB (NCSS, 2005; Soil Survey Staff, 2010). These environments do not receive solar radiation, are cold and poor in oxygen, and exposed to increasing pressure with depth. The following example of the genesis of methane hydrate in the sea floor is illustrative.

Methane hydrate or methane clathrate is a solid similar to ice in which a large amount of methane is trapped within a crystal-like structure of water (Max, 2000). The building blocks consist of a gas molecule surrounded by a cage of water molecules (e.g. Pellenbarg and Max, 2000). Methane clathrate occurs as cement filling the pores of marine sediments as well as in layers and nodules of pure hydrate (Buffett, 2000). Hydrates seem to reduce permeability, so that hydrate-cemented sediments act as seals for gas traps (Pellenbarg and Max, 2000; Buffett, 2000). These structures are stable at the temperatures and pressures that occur in ocean-floor sediments at water depths greater than about 500 meters (e.g. MacDonald et al., 1999). In some instances, methane hydrates possess unique acoustic properties. Methane clathrate bodies can grow up to 40 meters tall and several hundred meters across. "Pingos," small dome-shaped, ice-cored hills, are found in many sites of the Arctic continental shelf (Paull et al., 2007). Hydrates may cause landslides on the continental slope (e.g. MacDonald et al., 1994). Climate change causes methane clathrate structures to become unstable, emitting huge amounts of methane bubbles to the atmosphere and thereby contributing to climate warning (e.g. Pellenbarg and Max, 2000). Furthermore, it is possible that methane clathrates could be a major reservoir of carbon in the shallow geosphere (Kvenvolden, 1988). Deep sea-floor sediments have a fascinating structure and dynamic, much more complex than previously thought. Therefore if Mars "soils-regoliths" are incorporated in a USC scheme, deep undersea "soils" also have merit to be considered as a classificatory body.

An elaboration of an expanded universal soil classification that considers the whole soil-regolith, deep oceanic sediments and extraterrestrial soils would need the contribution of experts in these domains. At this time it is not likely feasible without strong financial and logistical support from relevant and reputed international institutions. Such expansion to include non-terrestrial entities would involve extrapolation of properties in space and time that would pose many other problems of sampling, analysis, and conceptual taxonomic development.

16.4. Participatory research in the development of inventories and classification

Over centuries, amateurs have collaborated with professionals in the inventory and classification of new biotaxa (e.g. in ornithology, mycology, entomology, etc.), as well as minerals and rocks. If fact many new species were discovered by amateurs. The same is true for minerals and rocks. More recently, this type of activity has expanded to other areas of knowledge such as astronomy. The Internet has attracted the interest of citizens in general by awarding prizes to those who provide appropriate solutions. Scientific policy makers are now encouraging this type of activity because they improve the culture and interest of citizens for scientific inquiries.

This activity is termed "*participatory research*" (e.g. Cornwall and Jewkes, 1995; Park, 1999; Pimbert, 2011). According to Cornwall and Jewkes (1995):

“*Research strategies which emphasize participation are increasingly used in health research. Breaking the linear model of conventional research, participatory research focuses on a process of sequential reflection and action, carried out with and by local people rather than on them. Local knowledge and perspectives are not only acknowledged but form the basis for research and planning. Many of the methods used in participatory research are drawn from mainstream disciplines and conventional research itself involves varying degrees of participation. The key difference between participatory and conventional methodologies lies in the location of power in the research process. (…), Participatory research raises personal, professional and political challenges which go beyond the bounds of the production of information*”.

Participatory research in soil classification suffers from shortcomings that do not happen with the study of selected biotaxa by amateurs. However, common citizens might be interested in working with soil scientists, as soils and pedology become more popular in the mass media (depending in part on the success of the Global Soil Partnership –GSP and the desirable Intergovernmental Panel on Soils) (FAO, 2011). Participatory research with the collaboration of indigenous communities has grown in pedology in recent years (e.g. Barrera-Bassols et al., 2009).

Moreover, the training of farmers in short courses might assist in soil inventories. To aid such an effort non-scientifically complex nomenclature of pedotaxa (vernacular names), as well as taxonomies that increase in complexity from the top to the bottom are preferable to scientific names. Given pedotaxa may have distinct vernacular names in different areas, and this raises the question of harmonizing non-technical denominations worldwide. For example Bautista and Zinck, (2010) showed that Maya people have their own nomenclature and soil classification and working with them it was possible to correlate scientific and indigenous classifications without serious difficulties. In this respect Internet social networks and blogs on the Internet are very useful instruments for a permanent dialogue between citizens and scientist in participatory research.

The concept of parataxonomists only partially overlaps with the tasks carried out by amateur citizens. The former is a relatively new figure in the frame of biodiversity inventories but has had a great success at the practical level. According to Janzen (2004), a parataxonomist is:

(…) *a resident, field-based, biodiversity inventory specialist who is largely on-the-job trained out of the rural work force and makes a career of providing specimens and their natural history information to the taxasphere (Basset et al., 2004), and therefore to a multitude of users across society.´ Any large inventory effort will benefit from a team of parataxonomists, not only through the large quantity of material and information they will gather and process, but through its among-year and within-season continuity*". In this context "taxasphere" (Janzen 1993) is a collective of scientists advocating the study of taxonomy of a given natural resource.

Janzen (2004) specified other features and activities of parataxonomists more or less as follows: "*Parataxonomists' accuracy increases substantially with pride of workplace ownership, experience, and detail and continuity of iterative feedback from users of specimens and information. Being drawn from the pool of rural workers into activities that are normally the privilege of university-educated citizens, parataxonomists require continuous mentoring and encouragement to compensate for their potential social isolation from their former peer groups and the defensive disdain with which they may be treated by more elevated social classes. Parataxonomists are a key element in setting up wild biodiversity for non-damaging sustainable development, not only through finding and making biodiversity available, but also by being employed locally by its development. The parataxonomist is to the neighbouring forest as both a literate person and a reference librarian are to a library. Parataxonomists do not necessarily work physically with taxonomists (…). They often build their own reference* *collections. Their expertise is in collecting specimens, mounting them, and performing preliminary sorting of the specimens to morphospecies*."

Soil inventories likely could gain a lot if this type of amateurs/professional were accepted in the field of soil science. A clear and simple taxonomy would help the parataxonomist gather relevant information.

17.0. Concluding remarks about a meta-analysis of taxonomies and soil classification

17.1. Soil Concepts

- Historical aspects of soil use from the Paleolithic to Mesolithic era included how humans changed from hunter/gatherers to farmers/ranchers and the development of land/property rights and ownership. Communities were established and also wars ensued about territorial control.
- Much later the Industrial Revolution accelerated discoveries throughout the world. Many natural soils were now becoming "anthropogenic entities", and modifications of so-called 'natural fine earthy materials' on the terrestrial portions of planet Earth were common place.
- For the most part soil surveys and classification were nationally sponsored and supported dominantly by agricultural interests. Efforts at global consensus and correlation were undertaken in the mid-20th century by international organizations and professional societies.
- Attempts to integrate scientific disciplines in earth and biological sciences in the 21st century are now opening an era of expanded concepts and questions about what is soil, what should it be, and is it of interest mainly as science or as a functioning medium needed for a sustainable environment.

17.2. Taxonomies

- Only after a definition of soils is agreed upon will it be possible to develop a logical structure based on a sound scientific rationale.
- To include other than "soil-like bodies" such as natural disaster deposits and extraterrestrial "soils" it would be important to have the participation of experts in these other branches of science.
- Many principles of soil taxonomies have been known for a long time. They haven't changed much. What is new are comparisons among national systems and with biological and geological taxonomies.
- Folkbiology and ethnopedology studies show that native people who are in strong contact with nature detect taxa that are equivalent to scientific ones, as the core of their taxonomies.
- In many biological and pedological classification schemes, the number of subtaxa (classes) per taxa of a given category falls in the range of the Miller "magic numbers".
- The Miller rule explains that separating a continuum into more than 9 classes results in mental confusion and generates mistakes in classifying objects.
- Taxonomies should be efficient information systems and this involves taking advantage of our cognitive biases especially the short term memory ones known as the 7+/-2 Miller Rule.
- Biological and pedological classifications have the same topological structure in terms of entropy, statistical distribution, fractal, and multifractal models.
- Many biological and pedological taxonomies are organized in a manner that optimizes (maximum efficiency) of the flow of information as retrieval information systems. However, geographical and utilitarian (such as agronomic or

environmental) and cognitive bias (prototype effect) divert them from fractal structures toward multifractal ones.

- Some numerical techniques are available to evaluate structural evenness (entropy for example), bifurcation ratios, and power law distributions which are scale independent. One intent is to provide more easily remembered structural patterns, and another is offer suggestions for the design of a universal soil taxonomy.
- Principles guiding the development of a universal soil classification should be clearly stated. Without an explicit purpose there is no accurate means of evaluating such a system.

17.3. Utility of a universal soil classification

- It has been suggested that utilitarian biases, such as agricultural use or geographic dependency, have caused a lack of attention to genetic principles of soil development which have guided soil classifications in the modern era. Bockheim and Gennadiyev (2000) identified 17 soil-forming processes and linked them with diagnostic horizons, properties, and materials at the high categories of orders and suborders of ST and with the major 1988 soil groups of WRB. They suggested that soil forming processes "(…) *not only illustrate the diversity of global soils but also show the genetic underpinnings and enhance the understanding of complex soil taxonomic systems."* However, if extra-terrestrial soils and/or deep ocean soils are included, the suggested soil forming processes would have to extended, modified or changed.
- In developing an international code of pedological nomenclature it should be possible to segregate horizon nomenclature, designations and definitions for other independent task groups. Such a code should also facilitate correlations of national systems of soil classification. Such an effort would need to also consider the diversity of laboratory and other soil observation methods.

- The demand for soil information requires agreement on technical standards, measurement norms, and information about management and monitoring of soil systems. Developing a harmonized, suitable and efficient universal soil data base will likely be a major constraint and cause a loss of scientific rationality. Taxonomy is a language of communication among scientists, technicians and users but it is not a product that can directly solve specific demands of all users. Such specific needs commonly require ad hoc interpretive classifications and these are vital for practical applications of techniques involved in the large diversity of uses and management practices throughout the world.
- For the most part, cultural transmission of information is the flow of discrete units called 'memes'. A given taxonomy is essentially a cluster of pedotaxa-memes, or ped-memeplexe. It should be an efficient and user friendly system to facilitate communication among experts. The details needed for this suggest that a Universal Soil Classification can not solve all demands of information about the functioning and degradation processes which soils are undergoing. National and local experts will have to develop pragmatic interpretive classifications which can be applied to site-specific needs.
- It may be possible that initiatives like the Global Soil Partnership (GSP) will be able to create necessary working groups to address many of the technical standards needed to solve the current and future societal demands for relevant information about soil functioning.

18. Appendices

18.1. Some notes about mathematical tools used in this text

The bifurcation ratios (BR) of the USDA Soil Taxonomy and the *Tylenchina* suborder of plant parasitic nematodes were calculated to compare the branching systems tested. The BR measures the number of branches (subtaxa) or growth of a higher level taxon and were calculated for the taxa of all the hierarchical categories (Ibáñez and Ruiz-Ramos, 2006).

The actual entropy and the maximum entropy were computed to obtain the evenness for examples of both pedological and biological taxonomies. Among several entropy indices, the most used in ecology is Shannon's Index that comes from the Theory of Information (Margalef, 1958; Magurran, 1988). Shannon's Index is used in this study because it is used worldwide and easy to calculate.

Entropy or the Shannon Diversity index is equated with the amount of uncertainty that exists regarding the taxa (objects) of an individual selected at random from a population (i.e. each hierarchical level of a classification). The more taxa there are and the more even their representation, the greater the uncertainty and hence the greater the entropy. Information content, which is a measure of uncertainty, is therefore a reasonable measure of diversity (Margalef, 1958; Ibáñez et al., 2000; Martín and Rey, 2000).

In addition this equation has very close mathematical connections with that developed by Boltzmann to determine the entropy of thermodynamic systems (see Ibáñez and Ruiz-Ramos, 2006 and references therein). The mathematical expression of the actual entropy for each hierarchical level of a given taxonomy is as follows:

$$H' = \sum_{i=1}^{i=n} p_i \times \ln p_i \qquad (1)$$

where (in this study case) p_i = the frequency of each subtaxon size in a given taxon, and the maximum entropy $H_{\max}$ = ln p_i. The evenness (E) values varying between 0 and 1 are obtained by dividing the actual entropy H' by the maximum entropy Hmax. E values close to one mean that a greater evenness has been obtained and that the system is nearing its maximum efficiency. This indicates that all taxa have the same number of subtaxa at each hierarchical level. In mathematical terms, the following condition is fulfilled:

$$H' = H_{max} = \ln S \qquad (2)$$

where S is the richness in objects (number of subtaxa). The relation between entropy observed and maximum entropy may be used as a measure of evenness E and can be mathematically expressed by the algorithm:

$$E = H'/H_{max} = H'/\ln S \qquad (3)$$

The E index can take any value between 0 and 1, where 1 represents the situation in which all taxa or objects are equiprobable (e.g. when they occupy the same area), and E tends to 0 when there is a highly non-uniform distribution of relative abundance (i.e. where one object dominates over all others). There are also other ways to calculate the evenness values (Magurran, 1988).

In a pure fractal system, taxa of all hierarchical levels branch into the same number of subtaxa (Ibáñez and Ruiz-Ramos, 2006).

Several useful references about these tools

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Title: MAGIC NUMBERS: A META-ANALYSIS FOR ENLARGING THE SCOPE OF A UNIVERSAL SOIL CLASSIFICATION SYSTEM

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Abstract

Categorization of the world around us in discrete classes is an innate capacity of the human mind to organize the information and carry on languages in all past and present cultures. Likewise our cognitive apparatus organize these categories in a hierarchical way. Recently the authors of this monograph demonstrated that the breaking of the continua of biological and pedological entities in order to carryon taxonomies follows the same mathematical rules: an iterative fragmentation according to fractal rules. For this reason both biological and pedological taxonomies have similar topological structures. However these mental constructs divert little bit of the expected fractal values by utilitarian, geographic and cognitive bias. It can recognize two type of cognitive bias, termed the prototypic effect and the constraints of humans to process the information to do not exceed our channel memory capacity. Therefore the fractal fragmentation and our channel memory capacity determine the structures of taxonomies to get efficient information systems. On this working hypotheses the authors shows in this monograph a set of rules that should be follow to could efficient and user friendly information systems. Furthermore, current biological and pedological taxonomies and possibly classification of other disciplines, was carry out by experts conforming to the above-mentioned rules in an intuitive way. In view that there is not a science of the taxonomies the authors offer a set of rules to assist in this task. The steps to carry on hypothetical Universal Soil Taxonomy is used as example.

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