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TOPSOIL CHARACTERIZATION

FOR SUSTAINABLE LAND MANAGEMENT

Land and Water Development Division
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ABBREVIATIONS

BD	Bulk Density
BS	Base Saturation
CEC_{eff}	Effective Cation Exchange Capacity
E.	English
EC	Electrical Conductivity (in saturation extract)
Gr.	Greek
L.	Latin
OC	Organic Carbon
OM	Organic Matter
SD	Standard Deviation

METHODS USED

pH:	unless indicated otherwise i.e. pH in H_2O (1:1).
CEC/BS:	Cation exchange capacity/Base saturation using NH_4OAc method.

Chapter 1

Introduction

A common criticism of soil taxonomic classifications is that they are mainly based on the subsoil and do not pay much attention to the topsoil which is the most important part of the soil for food production, for soil management and for degradation control. Topsoils are variable in space and time which makes it difficult to classify them. The understanding of the processes and factors relevant to the status and change of topsoils contributes to recommendations for sustainable land management practices.

Another, more general, difficulty in the use of the existing soil classification systems is the language which is *too technical* and often not comprehensive for farmers, agronomists, foresters and environmental scientists. Most of them are interested in the *application of soil expertise* rather than in the soil itself. They particularly want a system that gives usable and practical information, especially for the identification of sound land management recommendations.

It is proposed to complement the existing soil classifications with a comprehensive system that characterizes soils and:

- accounts for the ecological importance of the topsoil;
- is fertility and management related; and
- is easily understandable for users of soil survey or land use reports.

The topsoil properties can be used either at large-scale level, to provide information to soil users, or at small-scale level, to indicate the topsoil status of areas.

The objective of this study is to develop a draft conceptual framework for the characterization of soils with emphasis on topsoils and their fertility and management related characteristics based upon the Fertility Capability Classification (SANCHEZ et al. 1982; SMITH 1989). This characterization of topsoils does not only identify soil constraints but also provides management recommendations.

In order to bridge the existing gaps identified for conventional classification systems, a review of the topsoils and their characteristics, as mentioned in various already existing classification systems, has been conducted to achieve a meaningful division which can be used for general inventory and for soil and land management purposes (chapter 2).

The factors influencing the topsoil properties are discussed in chapter 3. These factors include: climate, vegetation and organic matter, topography and physiography, mineral soil constituents, surface processes, biological and human activity. Based on the dominant features within the topsoils the topsoil properties and modifiers are defined in chapter 4.

In the next chapter (chapter 5) management requirements per dominant topsoil influencing factor are discussed. A listing of the most common constraints and management options is given without the pretension of being a complete coverage of all possible constraints.

In the last chapter the envisaged further development of the system is discussed.

Chapter 2

Topsoil characterization within existing soil classification systems

2.1 INTRODUCTION

In the existing soil taxonomic classification systems emphasis is put on the subsoil characteristics which are relatively stable over time. Topsoils are variable in space and time which makes it difficult to classify them. But the topsoil is that part of the soil which is most important for food production, soil management and degradation control.

The Fertility Capability Classification system is one of the very few systems which attempts to bridge the gap between soil classification and soil fertility constraints. The system emphasizes the topsoil properties because of their relation to fertility and management.
The soil taxonomic classification systems of FAO, USDA, France, Canada, Germany and the World Reference Base for Soil Resources are discussed with regard to criteria they use which are of interest for topsoil characterization. They represent a selection of widely used classification systems.

2.2 FERTILITY CAPABILITY CLASSIFICATION (FCC)

The *Fertility Capability Classification* (FCC) system was developed as an attempt to bridge the gap between soil classification and soil fertility (BUOL et al. 1975). The system puts more emphasis on topsoil properties because management practices are largely limited to the ploughed layer. The FCC system groups soils according to their fertility constraints in a quantitative manner.

Each soil has properties that are intrinsic. The number of viable management options are confined by these properties. The FCC provides a checklist of identifiable properties which influence the effectiveness of specific management practices. The importance of the property varies with the crop and management system and therefore no priorities are assigned or intended. As a system it is not intended to provide precise enough information for implementation of soil management practices but it can guide the user in the kinds of practices of concern (SMITH 1989).

FCC consists of three categorical levels: *type* (topsoil texture 0-20cm), *substrata type* (subsoil texture 20-60cm), and 15 *modifiers*. Class designations from the three categorical levels are combined to form an FCC unit. The classes within each categorical level are defined in SANCHEZ et al. (1982) and SMITH (1989).

The topsoil characterization as presented in this paper is based on the FCC but expands the number of topsoil influencing features, e.g. organic matter status, land use and erosion/land degradation, to make it even more practical and widely applicable.

2.3 SOIL CLASSIFICATION SYSTEMS

In the *USDA Soil Taxonomy* it is explicitly stated that changes produced by single or repeated ploughing, which mixes the surface soil to a depth of 18 to 25cm, should have the least possible effect on the placement of a soil in the taxonomy. Consequently, in so far as possible, the diagnostic criteria and features should be described and taken into account below these depths (SOIL SURVEY STAFF 1975). Subsoil properties serve as differentiating criteria for the identification of soil types/soil units, thereby leaving little room for attention to topsoil features.

Colour, in combination with other properties, has been used as criterion for subdivision of soils. In the *Revised Legend of the Soil Map of the World* (FAO 1990) and in Soil Taxonomy (SOIL SURVEY STAFF 1975) it is used to distinguish the *mollic A horizon* respectively *mollic epipedon*, and the *umbric A horizon* respectively *umbric epipedon*, from the other A horizons or epipedons. They are separated from each other by the 50 percent base saturation (=BS) limit.

The Revised Legend of the FAO-Unesco Soil Map of the World recognizes four A and one H horizon as topsoils, USDA Soil Taxonomy six epipedons as topsoils (Table 1).

The USDA Soil Taxonomy takes biological activity, especially that of earthworms, into account. At great group and at subgroup level in the Mollisol order the Verm- or vermic adjective is used for mollic epipedons in which 50 percent or more of the volume is wormholes, wormcasts, or filled animal burrows.

The *Réferentiel Pédologique Français* (RPF)(AFES 1990), which replaces the French classification system of the CPCS (1967), distinguishes nine A horizons (eight established and one proposed) (Table 1). They are defined as "*horizons containing a mixture of organic and mineral material, forming below holorganic horizons (if existing), or in the uppermost part of the solum*".

These A horizons contain a number of useful elements (table 1) , i.e. the volcanic topsoils (1) slightly weathered (vitric), (2) allophane dominated (allophanic) and (3) Fe-and Al-humus complexes dominated (andic); the chernic topsoil; and the Anmoor topsoil. The carbonatic A horizon is typical for a Rendzina (compare FAO-Unesco 1978). The calcic A horizon has a confusing name, being non or only slightly calcareous. Essentially, its characteristics are a high BS and accumulation of OM. The aluminic A horizon is under-defined, which is probably due to its provisional status.

Some of the RPF limits used to characterize the different A horizons, such as amount, type and properties of OM, BS status, pH and structural characteristics, are interesting. Compared to the mollic A horizon or mollic epipedon, the amount of OM in the chernic A horizon is much higher, three versus five percent OM versus 0.6 percent OC, and a BS of about 100 percent. Also the other dark-coloured horizons (carbonatic, anmoor and allophanic) have higher OC contents. The RPF limits are useful to separate "special" mollic surface layers, of which the properties as mentioned by FAO (1990) and USDA (1975), are too broadly defined for the present purpose.

The chernozemic A horizon of the *Canadian System of Soil Classification* (CSSC 1978) overlaps partly with the French chernic A horizon. The thickness requirement (10cm, if cultivated 15cm) is adapted to the Canadian conditions. Also the BS limit is set to 80 percent and Ca is the dominant exchangeable cation. In addition to the usual colour and structural requirements the chernozemic A horizon should also have a mean annual soil temperature of higher than 0ºC and a soil moisture regime drier than humid.

In the *Soil Classification System of the Federal Republic of Germany* (MÜCKENHAUSEN et al. 1976; DBG 1985) the definition of the different humus types is interesting in relation to topsoil characterization. The division characterizes the humus types in temperate and boreal climates. The subdivision is based upon (BUNDESANSTALT FÜR GEOWISSENSCHAFTEN UND ROHSTOFFE 1982; KUNTZE et al. 1981):

- biological status;
- location and speed of litter decomposition;
- type of humines;
- stratification of Ecto- and Endohumus horizons identified; and
- chemical status of the soil.

Table 1. Topsoil names of different soil classification systems grouped according to topsoil characteristics.

Soil Classification System: Topsoil characteristics:	FAO	USDA	France	Canada	Germany	WRB	FCC
Deep dark coloured, high/low base saturation	mollic A, umbric A	mollic/umbric epipedon	A carbonaté, A chernique, A allophanique	chernozemic A	Mull	Mollic, Umbric, Chernic	
Man-made	fimic A	plaggen/ anthropic epipedon			Plaggen	Anthraquic, Irragric, Hortic, Plaggic, Terric	
Well-mixed with mineral soil				Mull	Mull		
Typifying humus characteristics, pellets in between mineral particles					Moder		
Raw humus with litter decomposition					Rohhumus		
Wet humus-rich			Anmoor		Anmoor		
Base-rich			A calcique				
Mineralogically determined		Melanic	A vitrique			Melanic, Fulvic	Basic reaction (b), salinity (s), natric (n), x-ray amorphous (x)
Organic	histic A	histic epipedon	horizon holorganique		Moor	Histic, Folic	organic (O)
No particular characteristics	ochric A	ochric epipedon	A typique A jeune			Ochric	

The *World Reference Base for Soil Resources* (WRB) pays specific attention to human-made soils (FAO/ISRIC/ISSS 1998). The Anthrosol soil grouping includes human-made and human-influenced soils. These soils are not recognized in the USDA at the order level and little characterized in the FAO system. The diversity of the expanding areas with anthropogenic soils makes it difficult to define these soils in anything except general terms. Several distinct anthropogenic processes or uses influencing the topsoil have been recognized (table 2).

Plaggen are the example of soils in Western Europe where humans have been manuring soils with heather or forest sods over a long period of time. The original low fertile soils were thus enriched with organic matter (SOMBROEK et al. 1993). Plaggen soils also occur in other classification systems.

Table 2. Anthropedogenic processes (source: FAO/ISRIC/ISSS 1998).

Deep working	Mechanical operations (continuous) extending beyond normal depth of field operations.
Intensive fertilization	Continuous applications of organic/inorganic fertilizers without substantial additions of mineral matter (e.g. manures, kitchen refuse, compost, etc.).
Additions of extraneous materials	Continuous applications of earthy materials involving substantial additions of mineral matter (e.g. sods, beach sand, earthy manures, etc.).
Additions through sediment-rich irrigation water	Continuous applications of irrigation water with substantial amounts of sediments (may also include fertilizers, soluble salts, organic matter, etc.).
Wet cultivation	Processes associated with submergence during cultivation; puddling of cultivated layer; additions of organic manures and fertilizers; usually involving changes in aquic conditions. Diagnostic subsoil features may develop under wet cultivation, depending on depth of water table, texture, presence of organic matter, etc.

Five main soil units are proposed:

- *Hydragric Anthrosols*, i.e. Anthrosols having an anthraquic horizon at the surface and a hydragric horizon in the subsoil. These soils show evidence of alteration through wet-cultivation practices; the sequence comprises a puddled layer, plough pan and an illuvial layer with a combined thickness of at least 50cm;
- *Irragric Anthrosols*, i.e. Anthrosols having an irragric anthric horizon that shows evidence of surface raising through long-continued irrigation with sediment-rich waters, resulting in a light-coloured, uniformly structured surface layer;
- *Terric Anthrosols*, i.e. Anthrosols having a terric horizon, that is they show evidence of surface raising through addition of earthy manures, compost or mud, respectively through addition of sods or soddy materials, and which has, in addition, a base saturation of 50% or more;
- *Plaggic Anthrosols*, i.e. Anthrosols having a plaggen horizon, that is they show evidence of surface raising through addition of earthy manures, compost or mud respectively through addition of sods or soddy materials, and which has, in addition, a base saturation of less than 50%; and
- *Hortic Anthrosols*, all other Anthrosols.

Chapter 3

Factors influencing topsoil properties

The topsoil is strongly influenced by soil forming factors, both externally and internally. The characterization and subsequent stratification of topsoils, therefore, has to take into account all these factors which are interdependent, they are related to each other and influence one another. The factors climate, vegetation and organic matter, topography and physiography, mineralogical soil constituents, surface processes, biological activity and human activity are discussed below.

3.1 CLIMATE

Climate is the dominating factor that influences, directly or indirectly, the topsoil. It has a profound influence not only on the topsoil, but also on topsoil forming factors such as vegetation, topography and human activity. Climatic parameters which are important for the topsoil are temperature, moisture, radiation and wind.

Both in arctic and other high altitude regions as well as subtropical deserts precipitation is too low or absent for establishment of a protective vegetal cover. In the arctic regions the temperatures are low and the alternate freezing and thawing results locally in gravelly and bouldery surface layers in which the coarse fragments have angular shapes. In subtropical deserts, where temperatures are high to very high, the topsoils are predominantly characterized by the impact of wind and/or rainfall.

In other regions climate has a less pronounced influence on topsoil characteristics. In regions where mature tropical rainforest exists, direct sun rays hardly reach the ground surface. The rain is intercepted by the vegetation and reaches the soil surface mainly as stem flow. The canopy reduces wind speed to almost zero within the rainforest. Temperature and humidity hardly fluctuate during the day or during the seasons.

3.2 VEGETATION AND ORGANIC MATTER

Natural vegetation is directly influenced by climate, as mentioned above, and soil type. Fertile soils support generally a more diverse vegetation type (more divers in composition) than less fertile soils, even under similar climatic conditions. However, fertility may also be stored in the actual vegetation as is the case when under rainforest.

Vegetation contributes in several ways to the formation of topsoil characteristics:

- penetrating roots loosen the soil and improve porosity and aeration;
- litter, decaying branches and stems are transformed into organic matter (OM);
- the replenishment of nutrients in the topsoil is largely determined by the chemical constituents of litter; and
- a vegetation cover protects the surface against the impact of raindrops and wind.

Vegetation may eventually be transformed into soil organic matter (=OM) and this when intimately mixed with soil mineral particles:

- enhances aggregation;
- increases structural stability;

- increases water holding capacity;
- contributes to the nutrient holding capacity;
- buffers against potential acidification;
- binds toxic substances to the soil complex, e.g. an excess of Al and Fe; and
- provides the soil with N, P and S and other nutrients which were stored in the above ground biomass.

Some attention should be given to the types of OM or forms of humus. In cool climates the amount of litter production often exceeds the rate of mineralization due to reduced biological activity, resulting in a non or only poorly decomposed OM at the surface. In moist tropical regions the rate of mineralization often exceeds the amount of litter production, despite the large above ground biomass present, resulting in fairly shallow surface layers enriched in humus. Also drainage, both internal and external, plays an important role in the OM cycle. Excess of water together with an anaerobic environment inhibits the decomposition of organic materials and give rise to peat formation. Similarly, waterlogged soils have high amounts of poorly decomposed OM and often a peaty layer on top. Whereas excessively drained soils, on the other hand, often show little OM accumulation, as a combined effect of a low production rate (often only a sparse vegetation is present) and a low amount of soil micro-organisms. Where these kind of soils do have a well-developed vegetation cover, the OM is mainly concentrated on the surface or present in the uppermost part of the topsoil.

The OM type is also determined by the base saturation (BS) which, in turn, is related to the mineral substances in the soil and the rate of leaching (a combined climate/drainage factor). Well-saturated soils show OM intimately mixed with the mineral part, resulting in good aggregation and a well-developed soil structure, while in poorly saturated soils these two are often found apart, with consequently less aggregation and a poorly developed structure. This difference is related to the kind of soil fauna responsible for this mixing which thrives better in well-saturated soils with a neutral or only slightly acid reaction than in soils with a poor saturation and a more acid reaction.

A change in OM also affects physical and chemical properties of the topsoil. OM has an important function in binding soil particles. If the amount of OM is reduced, this binding will become less and structural stability decreases. Also the water holding capacity will decrease when the amount of OM decreases. Soil OM can hold up to 20 times more water than a similar amount of mineral soil particles, so this effect can be fairly drastic. The most important physico-chemical property affected is the CEC. One percent of OM gives the soil about three to four cmol(+) CEC kg^{-1} soil. If a soil contains three percent OM and is taken under cultivation, it may loose about one percent OM in the first years or three to four cmol(+) kg^{-1} CEC. This drop can be very important especially in soils that have a low mineral CEC, like many soils in tropical regions.

In addition, the presence of OM seems to be conducive for the formation of high mineral cation exchangers such as interlayered chlorites or vermiculites, which are often registered, though in small amounts, in topsoils. Decrease in OM will induce also decrease of these clay minerals.

3.3 TOPOGRAPHY AND PHYSIOGRAPHY

Topography and physiography determine to a large extent depth and stability of the topsoils. In upper slope positions, steep topography often entails thin topsoils directly overlying hard rock. However, not only steepness determines the thickness of topsoils. Thin topsoils also occur in relatively flat, but erosion-prone physiographic positions and in positions where accumulation of soluble constituents such as gypsum or $CaCO_3$ have resulted in indurated layers close to the surface. Soil creep on steep slopes is a common phenomenon, as well as other mass movements, such as slumping or avalanching when the soils on the slopes become periodically saturated with water. Throughflow of water, resulting in seepage at the bottom of slopes, occurs frequently and may cause increased leaching in the upper and middle slope regions. These examples indicate that thickness of topsoils in relation to hard coherent layers, either from geological or pedological origin, in relation to their physiographic position, and in relation to mass wasting processes are important.

3.3 MINERALOGICAL SOIL CONSTITUENTS

Mineral soil material with particular characteristics may considerably influence the topsoil properties. The most striking ones are: shrinking-swelling clays, volcanic materials, and sandy textures.

Shrinking-swelling, or expanding, clays influence the topsoil by churning processes: smearing of ped surfaces which is blocking the pores, destruction of roots, and creation of an irregular topography. The churning processes result in deep distribution of OM in the soil and homogenization of the surface layer. The smearing of peds resulting in the blocking of pores causes (1) low infiltration rates when the soil is moistened, (2) ponding at surface and/or (3) surface runoff. The destruction of roots is the result of soil aggregates pushing against each other and movement along shear planes. The resulting irregular topography, gilgai, is evidence of movement of large parts of the soil body causing disruption.

Some properties of volcanic materials may give topsoils particular characteristics. An important property is thixotropy, the smeary and sudden liquid consistence of some volcanic materials. Other properties are of a physico-chemical nature such as a very high P fixation and nutriental disorders.

Sandy soil materials induce characteristics such as low coherence, (almost) absence of soil structure, very high infiltration rates and a CEC that is almost entirely dependent on amount and type of OM.

3.5 SURFACE PROCESSES

Two types of surface processes are distinguished: climate-related and soil-related.

Climate-related surface processes induce water and wind erosion and soil heating. The unprotected soil surface is vulnerable to the impact force of raindrops, causing splash erosion which destroys the soil aggregates. Rainwater at the surface may run off either over the entire surface, resulting in sheet erosion, or in concentrated channels, producing rills and gullies.

Dry bare soil, of which the surface layer is non- or only micro-aggregated, is susceptible to wind erosion and to erosion by occasional whirlwinds. Whirlwinds may develop by differential heating especially in areas with alternating vegetated and bare grounds. When the soil surface is directly exposed to the sun, especially at lower latitudes, soil temperature may rise very high, sometimes over 50º C. This results in extreme dissection, diminution of biological activity and increased vulnerability to wind erosion.

Soil-related surface processes comprise sealing, crusting, hardening, cracking and self-mulching. Poorly aggregated surfaces, especially when the silt content is high, will seal when moistened by rain or irrigation water, thus decreasing the infiltration rate and increasing runoff. When drying these seals may develop into crusts. Crusting will also occur in soils that are high in soluble salt sand where evapo(transpi)ration exceeds leaching. Salts will accumulate at the surface and finally lead to a salt crust at the surface, a feature that is frequently observed in arid regions. Other surface layers, especially but not exclusively clayey ones will become very or extremely hard when drying, inhibiting conventional land preparation practices. Finally, topsoils rich in shrinking-swelling clays will crack upon drying, often becoming very hard, too. A special group in these topsoils are the ones that develop (very) fine granular or crumb structures at the surface which then fill the cracks and are being incorporated in the soil again after swelling.

3.6 BIOLOGICAL ACTIVITY

Biological activity comprises soil faunal and soil microbial activity.

Soil faunal activity entails (TATE 1987):
- physical mixing of OM within the soil profile;
- inoculation of the plant litter with decomposer populations;
- adjustment of soil physical properties to levels more conducive for OM composition;
- physical disintegration of OM;
- direct metabolism of organic components; and
- stimulation of decomposer populations.

Soil microbial activity is responsible for the biochemical breakdown of plant tissue, involving fungi, yeasts, bacteria, etc., thus liberating plant nutrients and synthesizing relatively stable organic compounds which are added to the soil OM fraction.

As both activities are dependent on each other, the characterization of one part should give an idea about the other. Study of soil fauna is, macroscopically, easier than that of microbial activity, therefore emphasis should be on soil fauna.

3.7 HUMAN ACTIVITY

Man makes use of land for a variety of purposes. One of the most important and widespread land uses is agriculture. A replacement of a natural or semi-natural ecosystem by an agricultural, less diverse, agro-ecosystem entails changes in physical and chemical topsoil properties. If land is cleared for agricultural use, the vegetation buffer is removed. This, amongst other things, results in a different soil thermal regime, with higher daily temperature fluctuations in the surface layer, and a different hydrologic regime, in which the topsoil dries out more quickly than under vegetation. Soil microbes living in symbioses with certain plant species disappear as will some of the soil faunal organisms that are associated with these microbes. Other species may appear which are, for instance, related to fertilizers used. The general rule, however, is that soil biological activity will become less diverse, if an area is taken under cultivation.

Clearing of land entails a drop in soil OM content. If topsoils from similar soils under natural conditions and under cultivation are compared, the cultivated ones generally contain about 30 percent less OM. However, this can be manipulated. Examples from Peru show that 15 years of cultivation and careful OM management have increased the OM content in the cultivated topsoil beyond the content of the natural topsoil. An extreme example are the "plaggen" soils in Western Europe, which have been manured with heather or forest sods for a long time and thus enriched with OM with respect to the original soil (SOMBROEK et al. 1993). Removal of the vegetation will expose the surface to the direct influence of rain and wind. With decreasing structural stability the surface may loose its aggregation and disintegrates into small individual particles and very small aggregates which can easily be transported by water or wind. Thus, the surface becomes vulnerable to erosion. This can be enhanced, if the topsoil contains a significant amount of silt-sized particles in the surface layer, which promotes sealing, leads to a reduction of the infiltration capacity and to higher amounts of runoff.

When areas are levelled for cultivation the entire topsoil is disturbed. The topsoil in part of such an area may be removed entirely and piled on top of another topsoil, thus levelling out the surface and profoundly modifying at both places the topsoils.

Other influences by man on agricultural land are as follows:

- *Liming* which quickly modifies such inherent properties as soil pH and Ca/Mg ratios at the sorption complex. Long-term effects may be modification of soil biological activity and changes in soil structure.
- *Fertilizers* affect the nutrient status of the topsoil, usually for the better, but may have side effects such as lowering of soil pH (for instance by some N fertilizers) and nutrient imbalances.
- *Organic manures* modify the nutrient status of topsoils, especially that of available P, and affect C and N content. This also includes the use of green manures and legumes.
- The use of *pesticides* may have short-term benefits, but in the long run their effect may be a problem, if these compounds are residually enriching the topsoil. This is especially so, if they are used in crop rotations and become available at a time when they are harmful for a subsequent crop.
- *Long-term irrigation practices*, especially gravity irrigation, may lead to modification of the topsoil through deposition of sediments and salinization.
- *Submerging lands for rice growing* affects properties such as soil structure which is destroyed through puddling, soil pH, etc.

Other than agricultural activities affect topsoils as well. One may mention here the disturbances caused by mining, urbanization, industrial waste dumping, chemical pollution through rain water (acid rain), radioactive fall-out, etc.

Chapter 4

Definition of topsoil properties and modifiers

A universally applicable topsoil characterization has to take into account all factors and parameters related to topsoil forming factors as outlined in Chapter 3. The topsoil properties and modifiers presented here (alphabetically listed in appendix A), form an inventory of properties that are thought to be important for a comprehensive characterization of topsoils, most of them can be used for soil management recommendations. This inventory is based upon SPAARGAREN (1992 unpubl.), HEBEL (1994 unpubl.) and SANCHEZ et al. (1982). Some of the properties have been directly derived from existing soil classification systems or the FCC system, others are introduced. The newly introduced terms are in line with the legend of the Soil Map of the World (FAO-Unesco 1978; FAO 1990). They have been designed to be used in a pragmatic and tolerant way, i.e. by giving the user the freedom to use those properties which characterize the topsoils for ones purposes. Consequently, there is no key to indicate which property has preference over another.

The topsoil its *lower limit is set at 30cm depth, or at a root growth inhibiting layer whichever is shallower*. This layer can be hard rock, a pedogenetically indurated layer, a chemically unfavourable layer, or a strongly contrasting layer. Litter, if existent, occurs above the topsoil.

The topsoils are grouped by texture and the following dominant features: organic material, organic matter status, physical, chemical and biological features, drainage features, land use, erosion or degradation, external physical conditions, and slope class. In brackets the codes are shown.

4.1 TEXTURE

Texture of the topsoil, 0-30cm or shallower, is determined using the codes described below. Infiltration is decreasing from sand to clay, whereas water-holding capacity is increasing. In organic soils both infiltration and water-holding capacity are high.

- (**S**) Sandy topsoils
- (**L**) Loamy topsoils
- (**C**) Clayey topsoils
- (**O**) Organic topsoils (further subdivided in paragraph 4.2).

The texture of the *sub*soil is only used if there is a significant textural change from the topsoil, by definition 0-30cm, to the subsoil, defined as 30-60cm. The codes used are similar to the above mentioned except that no organic subsoil is distinguished. Rock or other hard root restricting layers are distinguished by the code **R**.

Gravel can be denoted by using a number and is further subdivided into:

- (**1**) i.e. 15-35 percent gravel or coarser (>2mm) particles by volume to any texture;
- (**2**) i.e. denotes 35-80 percent gravel or coarser particles by volume; and
- (**3**) i.e denotes >80 percent gravel or coarser particles by volume.

4.2 ORGANIC MATERIAL

Internationally, the soil classification systems agree on the boundary between organic and mineral material, as there is little variation in the limits used. The Soil Taxonomy (SOIL SURVEY STAFF

1975) and the Réferentiel Pédologique Français (AFES 1990) describe organic materials as having >18 percent OC (about 30 percent OM) if there is 60 percent or more clay, and >12 percent OC (about 20 percent OM) in absence of clay. Intermediate clay contents yield intermediate percentages. The Canadian System of Soil Classification (CSSC 1978) uses 17 percent OC without differentiating the clay content. The Revised Legend of the Soil Map of the World (FAO 1990) uses 16 respectively 8 percent as limits. There is also uniformity in the literature on a division of organic materials, i.e. hardly decomposed, intermediately decomposed and strongly decomposed poorly drained organic materials (peats), and accumulation of organic debris under well-drained condition, mainly litter. The FCC system distinguishes organic soils at the type level, but does not make any subdivisions. For the characterization of the organic topsoils these four types of materials can be considered at the topsoil texture level.

1. Topsoils with **(1)** ***organic*** *properties* (**O**)[1], i.e. throughout their 30cm thickness they have 18 percent or more OC if there is 60 percent or more clay, or have >12 percent OC in the absence of clay.

Subdivided into:

- **1a.** Organic topsoils with **(2)** ***fibric*** *properties* (**I**), i.e. having 75 percent or more recognizable plant fragments;
- **1b.** Organic topsoils with **(3)** ***hemic*** *properties* (**H**), i.e. having between 15 and 75 percent recognizable plant materials;
- **1c.** Organic topsoils with **(4)** ***sapric*** *properties* (**A**), i.e. having <15 percent recognizable plant materials; and
- **1d.** Organic topsoils with **(5)** ***folic*** *properties* (**F**), i.e. consisting entirely of litter accumulation.

If these adjectives are used they have to be regarded as *modifier* of a histic A horizon or epipedon and therefore should not be used in combination with histic. Note also that this division is a simplification of the classes used in the Soil Taxonomy (SOIL SURVEY STAFF 1975) by leaving out any reference to the pyrophosphate extract colour test.

4.3 ORGANIC MATTER STATUS

In tropical regions under rainforest, topsoils are found that have a high accumulation of OM in the first 10cm. The amounts of OC frequently exceed five percent. Below this depth the amount of OM decreases rapidly, suggesting that mineralization and homogenization only take place in the upper part of the topsoil and that the rapid turnover of OM by the high biological activity prevents the downward movement of organic substances. These topsoils are very fragile, as they loose their OM very rapidly once cleared. Moreover, if these areas are cleared mechanically, the humus-rich topsoil may disappear completely. OM in these soils is extremely important because it contains the bulk of nutrients. The BS in these humus-rich layers is usually in the order of 50-80 percent, while below the humus-rich layer it drops very sharply to levels of less than 20 percent. The OM has also a strong positive effect on soil structure and soil stability and a high water holding capacity.

Counterparts of these topsoils can be found in the tropical semi-arid and subtropical regions with a long, well-expressed dry season, especially under a woodland savanna vegetation. The amount of OM is much lower because the production of plant debris is less, often in the order of two to three percent, but again restricted to the upper 10cm of the soil. Upon clearing, the OM content in the humus layer does not drop as sharply as in the one under rainforest, but it usually drops by about 30

[1] The modifier **O** should only be used if the organic topsoil is not further specified.

percent. Because of the fairly low initial amount a drop of 30 percent may have a dramatic effect on soil fertility (HEBEL 1994; STAHR 1993).

It seems logical to divide the topsoils by distinguishing organic matter status and taking the degree of homogenization into account, this in addition to the in the FCC system already distinguished organic soils. Also the role of the humus-rich layer with respect to soil fertility and soil stability in combination with a thickness requirement, is considered. The following subdivision is proposed:

1. Topsoils with **(6)** ***chernic*** *properties* (**m0**), i.e. 30cm thick, well-mixed, completely mineralized OM and an OC content of at least three percent throughout, blackish colours with moist values of two or less in the first 15cm and moist chromas of <3.5, nearly or completely base-saturated (>80 percent), with a pH of 6.5-8.0, and dominantly granular or crumb structures in the upper part grading towards subangular blocky in the lower parts.

2. Topsoils with **(7)** ***rendzic*** *properties* (**m1**), i.e. throughout their thickness they have well-mixed, completely mineralized OM and an OC content of at least one percent throughout, contain calcareous coarse fragments and overly calcareous materials with a $CaCO_3$ equivalent of >40 percent, blackish colours with moist values and chromas of <3.5, base saturated with Ca *or* Ca and Mg as dominant ion(s), with a pH of 7.0-8.5, and they have granular, crumb or (very) fine subangular blocky structures.

3. Topsoils with **(8)** ***melanic*** *properties* (**m2**), i.e. throughout their thickness, well-mixed, completely mineralized OM and an OC content of at least 0.6 percent (lower mollic limit), blackish colours with moist values and chromas of <3.5, a BS of 80 percent or more with a pH of >6.0, and they have mainly subangular blocky structures.

This last group has been created to cater for dark-coloured and highly base-saturated topsoils which do not meet all the requirements for the chernic topsoils. It is a modification of the French calcic A horizon because they are dark coloured, which is not required in the RPF system. The name is derived from the Canadian System of Soil Classification (CSSC 1978) and from earlier proposals for the Legend of the Soil Map of the World (FAO-UNESCO 1974). The 80 percent BS is introduced here as one of the intermediate BSs to subdivide the range into three instead of two as is done in the Soil Map of the World. At 80 percent BS or more soils seem to be well-buffered and well supplied with nutrients, while below 80 percent nutrient deficiencies start to appear. This subdivision is a tentative one which needs to be looked at into more detail. The other BS value introduced in this context is 35 percent BS, below which Al toxicity becomes a major limitation for crop production, and at which level correction measures become very costly.

4. Topsoils with **(9)** ***brunic*** *properties* (**m3**), i.e. well-mixed, completely or almost completely mineralized OM, an OC content of 0.6 percent or more, brownish or blackish colours with hues of 5YR to 2.5Y, a BS of 35 percent or more and a pH of 5.0-6.5, and they have weakly or only moderately developed structures.

5. Topsoils with **(10)** ***sombric*** *properties* (**m4**), i.e. 30cm thick, well-mixed, completely or almost completely mineralized OM and an OC content of at least three percent, blackish colours with a moist chroma of <2 in the first 15cm and not exceeding 3.5 below, and moist values of <3.5, a BS of <35 percent and a pH of <5.0 (the exchange complex being dominated by H^+) and they have only weakly developed structures.

This kind of topsoil material occurs often in tropical regions with soils with a high amount of acid OM, usually in combination with mineral material which has a low cation exchange capacity. The exchange characteristics in these topsoils are determined by OM. Usually they have a high extractable acidity, but are low in extractable Al, because it is attached to the soil complex by the humus substances. Hence the remark that the exchange complex is dominated by H^+. The OC content of three percent is taken tentatively. This limit is similar to the chernic properties. The adjective sombric is taken from the Canadian System of Soil Classification (CSSC 1978). There sombric is used for dark-coloured Ah horizons that have a relatively low BS. The name has no relation to the sombric horizon as used in the Soil Taxonomy (SOIL SURVEY STAFF 1975).

6. Topsoils that have **(11)** ***para-sombric*** *properties* (**m5**), i.e. similar to sombric properties, but they are less thick and/or have less OC.
7. Topsoils that have **(12)** ***humic*** *properties* (**m6**), i.e. they receive a large amount of organic debris and in which high biological activity prevents the downward movement of the organic substances through a rapid OM turnover at or near the surface, resulting in a humus-rich surface layer of no more than 10cm thick. That layer has, on average, three percent or more OC and a C/N ratio of 12 or more, and is never dry for more than three months during most years. These are the topsoils under tropical rainforest with a thin humus-rich layer that are moist almost all year.
8. Topsoils with **(13)** ***arescic*** *properties* (**m7**), i.e. on average they have <3 percent OM and in which biological activity is restricted to a well-defined rainy season, resulting in a surface layer enriched in humus of no more than 10cm thick. They are dry for more than three consecutive months during each year and have frequently hard-setting properties as well. These topsoils are found in the subtropical regions bordering the rainforest zone under a woodland savanna vegetation. The adjective arescic is derived from L. *arescere* (to wilt) to indicate the prolonged dryness and the subsequent reduced biological activity and production of OM, which is thought to be responsible for the thin humus layers in these topsoils.
9. Topsoils with **(14)** ***modic*** *properties* (**m8**), i.e. poorly mixed, incompletely mineralized OM and an OC content of >0.6 percent, blackish brownish or greyish colours in the hue range of 5YR to 2.5Y, a BS of <35 percent, in extreme cases even <10 percent, and a pH of <5.0, they are usually structureless or only weakly structured.

This group of topsoils includes the podzol topsoils, where the sandier ones have usually extreme low BS and pH around four. These topsoils may be separated at a later stage as topsoils having podzolic properties to indicate that leaching is taking place from the surface horizons. However, if the textures are finer than sandy loam, as is the case in a number of podzols in Canada, the BS is more elevated (around 20-30 percent). The leaching properties typical for podzolic soils cannot be introduced here because it requires evidence of leaching and deposition in the *sub*soil. Therefore, these topsoils have been grouped under modic properties.

10. Topsoils with **(15)** ***para-modic*** *properties* (**m9**), i.e. that are similar to modic surface layers, but that have a BS of <50 percent and a pH of 5.5-6.0 (Mull-like Moder).

All the above topsoil materials are well-drained. Topsoils which are not well-drained are dealt with in paragraph 4.6. Most of the topsoils described have wet counterparts, of which the Anmoor type as mentioned in the Réferentiel Pédologique Français is covering a number.

4.4 PHYSICAL FEATURES

Soil-related surface processes depend strongly on the soil physical properties, on the mineralogical composition and the textural differentiation and the interaction with climate. They may result in sealing, crusting, capping and cracking. The mechanisms behind sealing and crusting, and a characterization of the various seals and crusts, have recently been outlined by CASENAVE and VALENTIN (1989) for the Sahel region. The principal soil parameters that determine the vulnerability to crusting are described as being: (1) the textural differentiation (in general >25 percent silt and about <35 percent sand give the highest aggregate instability); (2) the kind of clay minerals (smectites are more sensitive to dispersion than kaolinitic minerals); (3) the chemical composition (Fe and Al give high stability, gypsum gives more stability than lime, Mg contributes strongly to instability if it exceeds 50 percent BS, while an ESP of 15 to 20 percent promotes already the dispersion); and (4) kind of OM and OM content (CASENAVE and VALENTIN (1989) quote the ratio of MONNIER and STENGEL indicating that if *percentage OM x 100/percentage clay is greater than 7* then OM is really contributing to the aggregate stability). Other soil factors involved are hydrophobia and aptitude to cracking, though both are of minor importance.

The formation of crusts at the soil surface, especially due to the action of raindrops but also as a result of sprinkler irrigation, is a common feature of cultivated soils. Surface crusts are thin, less than 5mm, and are characterized by greater density, high shear strength, finer pores, and lower saturated hydraulic conductivity than the underlying soil (SHAINBERG 1992). Soil crusts have a prominent effect on many soil phenomena, such as reduction of infiltration and increase in runoff, lowering splash erosion, interference with seedling development.

Sealing and crusting properties can also be used in certain physiographic positions to further denude sealing-prone land units thereby actively concentrating the rainfall on adjoining good soils (water harvesting)(SOMBROEK and NACHTERGAELE 1994).

From the above the definition for the vulnerability of topsoil materials to sealing and crusting is as follow:

1. Topsoils which have **(16) *sealing and/or crusting*** *properties* (**r1**)[2], i.e. they have >25 percent silt and <35 percent sand, have a CEC of 24 cmol(+) kg^{-1} clay, and an OM/clay ratio of <0.07, with or without an ESP of 15 percent or more or 50 percent or more exchangeable Mg^{2+} (sodic properties in the Revised Legend of the Soil Map of the World 1990).

They are subdivided (FAO 1993) into:

1a. Topsoils with **(17) *surface seal*** *properties* (**r2**) i.e. the orientation and packing of dispersed soil particles which have disintegrated from the soil aggregates due to the impact of rain drops. They are formed at the very surface of the soil, rendering it relatively impermeable to water.

1b. Topsoils with **(18) *depositional crust*** *properties* (**r3**) i.e. when soil particles, suspended in water, are deposited on the soil surface as the water infiltrates or evaporates. Externally derived materials are always involved in the construction of depositional crusts.

Sometimes the result of compaction by physical forces, e.g. livestock trampling or traffic by agricultural machinery or vehicles, is defined as a structural crust (FAO 1993) whereas here it falls under the defined topsoils with compacted properties (see below).

Pressure may influence the physical properties of the topsoil. Two very different types are distinguished below.

Volcanic ash soils frequently possess a special type of physical property, i.e. thixotropy.

2. Topsoils with **(19) *thixotropic*** *properties* (**p1**), i.e. a smeary consistence and in which the soil material under pressure suddenly becomes fluid.

One special topsoil should also be mentioned here, namely the one that is compacted as a result of the use of too heavy machinery. While natural topsoils show BDs of up to 1.5 Mg m^{-3}, compacted topsoils can reach BDs of 1.9 Mg m^{-3}. One can formulate this as follows:

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[2] The modifier **r1** should only be used if crusting is not further specified.

3. Topsoils with **(20) *compacted*** *properties* (**p2**), i.e. a BD of 1.7 Mg m^{-3} or more.

The properties of a number of surface layers are dominated more by the mineral soil materials than by other characteristics that influence topsoils. These are materials derived from volcanic ash deposits and other volcanic deposits that have a high amount of glass and weatherable minerals, the materials rich in shrinking-swelling clays, and those that have easily soluble components, such as carbonates, sulphates, sulphides and salts.

4. Topsoils with **(21) *vitric*** *properties* (**t**), i.e. >60 percent glass and associated weatherable minerals in the fine earth fraction, that have Al(o) + 1/2 Fe(o) between 0.4 and two percent, that have an OM content between 1-5 percent, a BD between 0.9 and 1.2 Mg m^{-3} and a P retention capacity of <85 percent.

Many topsoils, especially though not exclusively, the clayey ones, become very or extremely hard when dry or are hard-setting. These topsoils are difficult to work when in dry condition. Several types exist: the ones that are clayey and churn, the ones that are clayey and crack, the ones that are clayey only, and the ones that are not clayey. In the FCC system the soils with very sticky plastic expanding clays are distinguished but there is no further subdivision. Four different topsoils can be defined:

5. Topsoils with **(22) *self-mulching*** *properties* (**v1**), i.e. fine aggregates that are very or extremely hard when dry, 30 percent or more clay throughout, and when dry both cracks 3cm wide at the surface extending down to at least 30cm depth and a fine or medium-sized granular structure at the surface with or without fills of surface materials inside the cracks. The occurrence of the granular structure is important for management purposes. It indicates that large clods will disintegrate into fine and medium granules through repeated wetting and drying. Therefore these topsoils, if cultivated, should be ploughed at the end of the rainy season when the topsoil is drying out and moisture content is still such that the soil material is not yet hard or harder.

6. Topsoils with **(23) *mazic*** *properties* (**v2**), i.e. very or extremely hard when dry, 30 percent or more clay throughout, cracks when dry that are at least 3cm wide at the surface, and that have very coarse prismatic structures, or are massive.

7. Topsoils with **(24) *duric*** *properties* (**v3**), i.e. very or extremely hard when dry, 30 percent or more clay throughout, and they have coarse subangular blocky or prismatic structures, or are massive.

8. Topsoils with **(25) *hard-setting*** *properties* (**v4**), i.e. hard to extremely hard when dry, and that have coarse subangular blocky structures, or are massive. These topsoils may have a thin surface layer of <10cm thickness which is enriched in OM and that do not show the hard-setting characteristics.

4.5 CHEMICAL FEATURES

Chemical features can be grouped as those related to soluble or easily soluble compounds, those related to acidity and those related to Al-toxicity and P-fixation. Groups of topsoil properties which are related to soluble compounds are:

1. Topsoils with **(26) *gypsic*** *properties* (**y**), i.e. they have in some topsoil layer five percent or more gypsum.

2. Topsoils with **(27) *calcic*** *properties* (**b**), i.e. they have, on average, 15 percent or more $CaCO_3$ equivalent, or 15 percent or more (by weight) distinct $CaCO_3$ concentrations.

3. Topsoils with **(28) *natric*** *properties* (**n**), i.e. they have an ESP of 15 or more, or that have 50 percent or more exchangeable Na plus Mg.

4a. Topsoils with **(29)** ***halic*** *properties* (**l**), i.e. within 100cm from the surface an EC of >15 dS m^{-1} at 25º C at some time of the year, or >4 dS m^{-1}, if pH exceeds 8.5.

4b. Topsoils with **(30)** ***salsic*** *properties* (**s**), i.e. within 100cm from the surface an EC of >4 dS m^{-1} at 25º C at some time of the year. The adjective salsic is derived from L. *salsus*, brackish, indicating intermediate salinity.

Organic and mineral soils that accumulate under estuarine settings can accumulate relatively high levels of sulphur. In the presence of calcium carbonate these soils do not become extremely acid, in its absence the artificial drainage of these soils can lead to the production of sulphuric acids which leads to an extremely low soil pH.

5a. Topsoils with **(31)** ***sulfic*** *properties* (**c1**), i.e. they have 0.75 percent or more S (dry weight), mostly in the form of sulphides, and less than three times as much $CaCO_3$ equivalent as S.

5b. Topsoils with **(32)** ***jarositic*** *properties* (**c2**), i.e. they have common distinct yellow jarosite mottles.

Acid soils can roughly be grouped into those soils that do not have an acidity which retards the growth of crops and those that do have an acidity which retards the growth of most crops or inhibits crop growth. The main cause of acidity is aluminium saturation. This causes P-fixation which may affect plants sensitive to Al-toxicity unless lime is applied. Mn-toxicity may occur on some of these soils (SANCHEZ et al. 1982). The properties defined apply to the plough layer.

6a. Topsoils with **(33)** ***high Al saturation*** *properties* (**a**), i.e. >60 percent Al-saturation of the effective CEC within 50cm of the soil surface, or >67 percent acidity saturation of CEC by sum of cations at pH 7 within 50cm of the soil surface, or >86 percent acidity saturation of CEC by sum of cations at pH 8.2 within 50cm of the soil surface, or pH < 5.0 in 1:1 H_2O within 50cm, except in organic soils where pH must be less than 4.7.

6b. Topsoils with **(34)** ***acid*** *properties* (**h**), i.e. 10-60 percent Al-saturation of the effective CEC within 50cm of the soil surface, or pH in 1:1 H_2O between pH 5.0-6.0.

Soils that are high in silicate clay content and crystalline iron oxides retain a significant amount of P in a form that is not immediately available for plant uptake (ROOSE 1981).

7a. Topsoils with **(35)** ***high iron oxides and hydroxides*** *properties* (**i**), i.e. in the presence of iron oxides and hydroxides precipitation of P occurs which is gradually converted into crystalline iron phosphate. Percentage free Fe_2O_3 divided by percentage clay > 0.25 and more than 35 percent clay, or hues of 7.5YR or redder and granular structure. This modifier is only used in clay soils and it applies only to the first 20cm of the topsoil or whichever shallower.

With respect to the specific chemical properties of volcanic materials reference is made to the Réferentiel Pédologique Français (AFES 1990). The allophane A horizon of this system represents a mild weathering environment in which at least part of the bases are retained, Al is bound to silica to form allophane, thus rendering it immobile, and optimal conditions are created for biological activity, mineralization of OM and stable structural development (see MIZOTA and VAN REEUWIJK (1989)). Topsoils derived from and dominated by volcanic materials are:

7b. Topsoils with **(36)** ***allophanic*** *properties* (**x**), i.e. Al(o) + 1/2 Fe(o) of two percent or more in the fine earth fraction, Si(o) of 0.6 percent or more, pH (NaF) is >9.4, a BD of 0.9 Mg m^{-3} or less and a P retention capacity of >85 percent, that have a Al(p)/Al(o) ratio of <0.5, pH of >5, and KCl-extractable Al of <2 cmol(+) kg^{-1}, that have dark brown colours (value 3, chroma 3.5 when moist), an OC content of five percent or more with stable organo-mineral complexes, dominated by allophane, that have a fine very friable crumb or granular structure with fuzzy microstructures, non or slightly plastic, and a high biological activity.

7c. Topsoils with **(37)** ***opalic*** (*or* ***alic***) *properties* (**o**), i.e. Al(o) + 1/2 Fe(o) of two percent or more, Si(o) of <0.6 percent, Al(p)/Al(o) of >0.5, KCl-extractable Al of >2 cmol(+) kg^{-1}, and pH of <5. The adjective opalic (from opaline silica, a precipitate in supersaturated silica solutions, which may occur in these kind of topsoils) used is preferred over alic (indicating a high amount of exchangeable Al) as opalic reflects more the volcanic nature of the soil material.

Soils with a low ability to retain nutrients against leaching, especially during the growth cycle of an annual crop, can be defined as follow:

8. Topsoils with **(38)** ***low nutrient retention*** *properties* (**e**), i.e. CEC less than 4 meq/100g soil by sum of bases plus KCl extractable Al (CEC_{eff}), or CEC < 7 meq/100g soil by sum of cations at pH 7, or CEC < 10 meq/100g soil by sum of cations plus Al plus H at pH 8.2.

The weathering of minerals in the soil form the basis for a sustainable K supply. Soils with a low ability to supply K can be defined as follow:

9. Topsoils with **(39)** ***low K reserves*** *properties* (**k**), i.e. less than 10 percent weatherable minerals in silt and sand fraction within 50cm of the soil surface, or exchangeable K < 0.20 meq/100g, or K less than two percent of sum of bases (if bases < 10 meq/100g).

4.6 BIOLOGICAL FEATURES

Only a few biological activity criteria are introduced here. Important for topsoils are mesofaunal activities, especially by earthworms, termites and ants. Their activities have different effects on the surface layers. Earthworm activity results in homogenization of the topsoil and even subsoil layers, mixing of the OM with the mineral particles, creating well-developed and stable granular and crumb structures, and improving porosity and drainage.

Termite activity concentrates on removal of especially clayey particles from the topsoil, thus impoverishing it. The occurrence of a sharp increase in clay content in many tropical soils where termites are active, is at least partly attributed to this removal. In addition to this, termites create large chambers in the topsoil and termitaria on the surface in sizes varying from small needles to up to 5m high mounds. Furthermore, they are notorious for attacks on crops and a rapid turnover of organic residue left at the surface.

Ant activity is usually much more localized and less destructive than that of termites. Only where ant colonies are living the topsoil is considerably affected. Therefore, no need is felt to separate topsoils on the basis of ant activity.

It should be noted that other burrowing animals may have a very localized influence but this is not distinguished at present.

Consequently, two types of topsoil materials are proposed based on the biological activity:

1a. Topsoils that have **(40)** ***vermic*** *properties* (**f1**), i.e. 50 percent or more of the volume consisting of worm holes, worm casts, or filled animal burrows; and
1b. Topsoils that have **(41)** ***termitic*** *properties* (**f2**), i.e. 10 percent or more of the volume consists of termite chambers and channels, while the surface is covered by 10 percent or more termitaria.

The ten percent limit used is much lower than the 50 percent used with the vermic properties. However, expert knowledge shows that at this level termite colonies have such a size that they can do harm to crops. Also the ten percent cover is from experience as at this level mechanized agriculture is seriously affected.

4.7 DRAINAGE FEATURES

In paragraph 4.2 topsoils dominated by organic matter status in well-drained positions were discussed. Peats which are not well-drained are separately distinguished. This modifier is also used for mineral soils with a high water content.

1. Topsoils with **(42)** ***hydric*** *properties* (**w**), i.e. that consist either of organic materials with a BD of 0.1 Mg m^{-3} or less, or mineral materials that have an n-value of >0.7.

Wetness is, to a large extent, governed by physiography. Two types of water saturation are distinguished: (1) saturation caused by groundwater, either permanently or periodically; and (2) saturation caused by water stagnating on a subsoil layer. Water in the topsoil will affect the biological activity, bring about reductive or reductive-oxidative conditions, and may influence the chemical composition through dissolved compounds. Reduction and oxidation directly affect the biological activity by creating anaerobic and aerobic conditions, respectively, and mobilize otherwise insoluble compounds like Fe and Mn (hydr-)oxides.

Recognition of the effects of alternating reductive and oxidative conditions caused by fluctuating groundwater is given in the Réferentiel Pédologique Français (AFES 1990) by the separation of their *Anmooric* A horizon. This, however, is only one of the specific wet surface layers and therefore as such unsuitable to be adopted for a system of world-wide characterization of topsoils. In the FCC system the modifier *gley* exists to describe both the reductive or the redoxic environment.

A combination of reductive and oxidative conditions, combined with an indication about the causes of wetness, and other topsoil properties is the best approach to subdivide these topsoils.

2a. Topsoils with **(43)** ***reductive*** (reduced) *properties* (**u**), i.e. permanently saturated with groundwater, neutral blueish or greenish colours, usually poorly structured with little or no mixing of OM with the mineral soil particles under wet conditions, a neutral or only slightly acid reaction, they may show mottling around roots ("rusty root channels"), and they may or may not have a histic surface layer.

2b. Topsoils with **(44)** ***redoxic*** *properties* (**o**), i.e. periodically saturated with groundwater, that have high chroma mottles on ped faces, evidence of biological activity such as mixing of OM with mineral soil particles, or animal burrows and excreta, and they have under wet conditions a soil reaction ranging from strongly acid to alkaline (pH of 5.0-8.5).

4.8 LAND USE

Land use activities have influenced the surface layer(s) in large areas as is recognized by WRB (FAO/ISRIC/ISSS 1998). The modifications result from ploughing, subsoiling, construction of artificial drainage, land shaping, etc., to chemical and physical modifications by use of fertilizers. Also accumulation from mines, town refuse, fills from urban developments and contamination by atmospheric fall-out led to modifications of topsoils. Human activity has led to erosion and degradation by over-exploitation of land resources. The influence by human on topsoils can best be expressed in terms of physical and chemical influences.

Chemical influence on topsoils in the form of century long additions of heather, grass or forest sods mixed with farmyard manure applied regularly to very infertile soils in Western and Northwestern Europe has led to very typical topsoils. In Ireland a mixture of sea sand and dung was used to fertilize the soil (CONRY 1969). In this way "new", man-made topsoils were built: thick, brown to black, rather sandy but very fertile topsoils with, characteristically, a very high P_2O_5 content. These soils are known in Germany as "Plaggenesch" and in The Netherlands as "Enkeerdgrond". The practice has been abandoned with the introduction of chemical fertilizers in the 19th century. These kind of practices have resulted in:

1. Topsoils which have **(45)** ***plaggen*** *properties* (**a1**), i.e. produced by centuries-long manuring with earthy admixtures that have >250 mg kg^{-1} soil extractable P_2O_5 in one percent citric acid.

The limit in P_2O_5 content originates from the upper limit of the mollic epipedon in the Soil Taxonomy (SOIL SURVEY STAFF 1975), which is maintained in the Revised Legend of the Soil Map of the World (FAO 1990). Data from The Netherlands, however, show that this figure is much higher in almost all these topsoils, in many cases more than 1000 mg kg^{-1} soil. On the other hand, the same data show that in a number of these topsoils the P_2O_5 content near the surface is lower than in the subsoil. This is probably due to management change whereby the "sod fertilizer" was replaced by chemical fertilizers. Since then P fertilizers have most likely not been used and, consequently, P levels have dropped. As the present limit clearly separates the P levels in "natural" topsoils (SOIL SURVEY STAFF 1975) from the "artificial" ones, it is thought to be better to retain the 250 mg P_2O_5 kg^{-1} soil rather than to introduce a higher one with a chance that some of these topsoils would not meet this requirement. The plaggen properties correspond with WRB's *plaggi-cumulic* or *terri-cumulic*.
In the Near and Middle East centuries of irrigation have resulted in thick irrigation sedimentation covers. These covers are also reported from Southern Italy (SEVINK et al. 1984). WRB distinguishes irrigation deposits with homogenization through ploughing as *irragric*. This practise has resulted in:

2. Topsoils which have **(46)** ***cumulic*** *properties* (**a2)**, i.e. they show an accumulation of fine sediments resulting from continuous irrigation.

Land shaping and land levelling have resulted in thick accumulated topsoils. They are found on the lower side of man-made terraces or in large levelled areas, topsoils of broadbed-furrow systems on Vertisols and other man-raised surfaces made to improve drainage. The only common characteristic these topsoils have, is that they show levels of OM that are similar to the surface layers of undisturbed soils nearby. It is proposed to group these topsoils as:

3. Topsoils which have **(47)** ***aggeric*** *properties* (**a3**), i.e. they consist of accumulated surface materials as a result of land shaping or land levelling. The adjective aggeric originates from L. *agger*, accumulated earth.

A special type of topsoil occurs in areas where both land levelling and subsequent very specific management is found, i.e. in areas where wetland rice is grown. Here we find:

4. Topsoils which have **(48)** ***puddled*** *properties* (**a4**), i.e. saturated with water for at least part of the year and subject to puddling in most years. They show signs of reduction-oxidation processes such as rusty root channels, dominantly pale reduction colours, Fe/Mn concretions, mottling due to segregation of Fe, or a combination of these. They are loosely structured when submerged but becoming massive or showing platy structures when dry.

These topsoils are widespread in East, Southeast and Southern Asia, but also occur in other parts of the world. They form under long continued cultivation whereby the topsoil is puddled. Through this technique soil structure, if present, is destroyed and often an impermeable layer below the puddled layer is formed. The puddled layer plus the impermeable layer ("plough pan") are considered the topsoil. The WRB distinguishes these topsoils under anthraqu*ic*.

The WRB also distinguishes *hortic* Anthrosols which are characterized by deep cultivation and application of organic manure and intensive fertilizers. This type of surface layers which are physically influenced by humans are:

5. Topsoils which have **(49)** ***altaric*** *properties* (**a5**), i.e. consist of a mixture of former surface and subsurface soil materials, as such recognizable as separate chunks as a result of deep disturbance of the topsoil by human activity (e.g. through deep ploughing, subsoiling, etc.). They occur in areas under high level management all over the world, but not in large, coherent areas. The adjective altaric is derived from L. *altus*, deep, and *arare*, to plough.

Growing in importance and covering sometimes large areas are wastes from mines, fills from urban developments and other areas disturbed for non-agricultural uses. Here we find:

6. Topsoils that have **(50)** ***urbic*** *properties* (**a6**), i.e. formed by an accumulation from mines, town refuse, fills from urban developments, etc.

Attention should be paid to organic topsoils that develop after draining wet organic materials, this in addition to the organic topsoils mentioned in paragraph 4.2 and 4.6. Peats that are drained or reclaimed otherwise change irreversibly. The changes include subsidence, shrinkage, oxidation and mineralization of the organic substances, oxidation of reduced mineral compounds and subsequent acidification, and homogenization by biological activity. Upon drainage subsidence will take place, the rate being dependent on the water content of the organic materials, which is related to its degree of decomposition. "Raw" peaty materials with a high amount of fibres tend to have lower bulk densities and higher water content than the more decomposed ones. Consequently, the rate of subsidence will be larger in "raw" peats than in decomposed peats. Drained peats not only shrink in vertical direction (subsidence), but also in horizontal direction and therefore develop wide cracks. Again, the rate of shrinkage is dependent on the water content and the type of organic material. The process of ripening has been described extensively by Dutch soil scientists in the early 1960's (PONS 1960; VAN HEUVELEN et al. 1960; JONGERIUS & PONS 1962). They have distinguished two types of surface layers that develop upon drainage, depending on the original environment. In oligotrophic peats the development of a "moder" type of surface layer is favoured, in meso-or eutrophic peats the surface layer becomes more the "mull" type. Consequently, a *modifier* for drained peats has been formulated as follow:

7. Topsoils with **(51)** ***drained*** *properties* (**a7**) are organic artificially drained topsoils which show proof of physical ripening, indicated by subsidence and the formation of shrinkage cracks.

4.9 EROSION OR DEGRADATION

Accelerated erosion is human-induced, e.g. deforestation, over-exploitation, improper land management, etc. To establish whether a soil has been affected by human-induced erosion is sometimes difficult, especially if the rate of erosion has been reduced and has been taken over by the rate of soil formation. In these cases information from the surroundings may be helpful: nearby non-eroded similar soils, deposits at the foot of slopes, or local sources, etc.
These topsoils also include the topsoils on terraces from where the original surface layer has been removed for levelling purposes. Then they are very often associated with topsoils with aggeric properties on one side and, sometimes, with shallow topsoils on the other side.

1. Topsoils having **(52)** ***truncated*** *properties* (**d1**), i.e. consist of former subsoil materials which have been exposed by removal of the original surface layer(s) either through accelerated erosion or through land shaping.

Many parts of the world have been or are affected by accelerated erosion. An increase in population followed by an increased pressure on the land resources often induces large-scale soil erosion because usually the more marginal lands are taken into cultivation.
The surface processes affecting the topsoil have been divided earlier in climate-related and soil-related processes. Climate-related processes are those processes that are a direct response of weather conditions acting on the surface. They include erosion caused by rain and wind, and the effects of radiation such as extreme temperatures and extreme desiccation.
A division for topsoil characterization in relation to water erosion based upon JANSEN et al. (1994):

2. Topsoils with **(53) *slightly eroded*** *properties* (**d2**), i.e. some evidence of damage to surface horizon by sheet erosion but no direct visible evidence, or development of individual rills. Removal of soil to a depth of 10cm.

3. Topsoils with **(54) *moderately eroded*** *properties* (**d3**), i.e. clear evidence of removal of all or substantial part of surface horizons by sheet erosion to a depth of 10 to 30cm, or by a rill network (less than 30cm), or by terracette erosion with still well-vegetated parts in between the steps, or by landslips with subsurface exposition to limited depth.

4. Topsoils with **(55) *severely eroded*** *properties* (**d4**), i.e. clear removal of soil by sheet erosion of all surface horizons exposing subsurface, or by gully erosion (defined as channels of more than 30cm) which may cut into subsurface horizons and/or underlying parent material, or by terracette erosion with clearly reduced vegetated parts in between the steps, or by landslips/slumps which expose subsurface to a considerable depth. Removal of soil to a depth of more than 30cm.

Wind or aeolian erosion is more difficult to deduce. Usually nearby deposits lack to estimate the amount of eroded materials, and signs at the surface indicating wind erosion are usually absent. Only if nearby areas occur protected from wind erosion, an idea can be obtained about the amount of topsoil removed. One class is proposed:

5. Topsoils with **(56) *wind-eroded*** *properties* (**d5**) have lost topsoil materials due to wind-action.

Chemically and physically degraded topsoils cover a wide range. Comprised are those topsoils that due to long-term occupancy have been depleted from nutrients, that through the use of acidifying fertilizers have become less productive, that have become saline through irrigation, that have a degraded structure and porosity as a result of compaction, that have become unproductive through encroaching desertification, etc. The study on **GL**obal **A**ssessment of **SO**il **D**egradation (GLASOD) by ISRIC (1991) and the one by FAO/UNDP/UNEP (1994) show that the phenomenon of degradation is more widespread than previously assumed.

Some of the topsoils involved are already mentioned earlier, namely the topsoils that have capping or sealing properties or topsoils that are subject to erosion. These properties may be inherent to the topsoil or have natural origins, they can also be human-induced through structural decline after cultivation. However, no need is seen at present to separate human-induced capping or erosion from the same phenomena naturally present or occurring. It will always be difficult to make a proper assessment of human-induced topsoil degradation as for one needs to have an idea about the original status of the topsoil to establish the amount and degree of degradation. Therefore, much is dependent on the interpretation of the data available and knowledge about the past of an area or region. For the purpose of this characterization of topsoils a mere indication that chemical or physical degradation is suspected, would, for the time being, suffice:

6. Topsoils with **(57) *chemically degraded*** *properties* (**d6**), i.e. the topsoil possesses such adverse chemical properties (in terms of acidity, available nutrients such as N, P, S, K, and the presence of toxic Al levels, i.e. an Al saturation of >25 percent, presence of a high amount of soluble salts, as expressed by an EC of >6 dS m^{-1} at 25º C) that a yield decline of 30 percent or more is observed, compared to original yield levels, or that nutrient deficiencies are observed in the plants.

At a later stage this definition could be improved by introducing a second class of severely chemically degraded topsoils, i.e. the topsoil possesses such adverse chemical properties that a yield decline of 70 percent or more is observed, compared to the original yield levels, or that severe nutrient disorders or strong deficiencies are observed in the plants. This severely chemically degraded class could then be characterized by, for example, being strongly acid, an Al saturation level of >60 percent, an EC of >15 dS m^{-1}, etc.

7. Topsoils with **(58) *physically degraded*** *properties* (**d7**) can be described as topsoils that are physically degraded, i.e. the topsoil possesses such adverse physical properties (in terms of low porosity, high BD, strong platy structures or being massive, occurrence of crusts, reduced infiltration) that a yield decline of >30 percent is observed.

Like with the chemically degraded topsoils, a second class may be brought in at a later stage to indicate severely physically degraded topsoils that possess such adverse physical properties that yields decline with >70 percent, or that make cultivation impracticable.

4.10 EXTERNAL PHYSICAL CONDITIONS

Two extreme climatic conditions lead to the development of topsoils with a number of features which sets them apart from other topsoils in the world: topsoils formed under arctic and arid conditions.

1. Topsoils with **(59) *arctic*** (polar and high altitude) *properties* (**t1**) posses the common feature that they are frozen for a long period annually, that the presence of ice is responsible for uneven ("hummocky") surfaces that are frequently encountered in these regions and for the churning of topsoils (cryoturbation), and that biological activity is almost zero or absent.

In addition, it is proposed to use mean annual soil temperature at 10cm depth as indicator for these topsoils, to include the drier arctic regions where insufficient moisture is available to produce cryoturbation. It is a depth which is frequently used to measure soil temperature. The limit proposed here is a mean annual soil temperature of 0º C or less. On this basis topsoils which have arctic properties are defined as containing ice for the greater part of the year, or having a mean annual soil temperature at 10cm depth of 0º C or less. In this way the earth regions where agriculture is virtually impossible, except for a few crops like vegetables which have short growing periods of two to three months, are distinguished.

Topsoils under arid conditions exhibit usually the following number of features:
(1) low amount of OM, due to scarcity or lack of vegetation; (2) aptitude to slaking, due to the prolonged extreme dryness; (3) weak structures and soft consistence in the surface layer; (4) elevated monovalent cation content; and (5) no cultivation possible without irrigation (from soil management point of view). These topsoils are defined as follow (expanded definition compared to FCC):

2. Topsoils with **(60) *arid*** *properties* (**t2**), i.e. (NACHTERGAELE et al. 1994):

- dry for most part of the year, which results in a strong moisture deficit, extreme temperature and high winds (one factor alone or in combination with the others);
- OC content less than 0.6 percent in the surface 18cm if texture is sandy loam or finer, or 0.2 percent or less if texture is coarser, the OC content may be higher if the soil is periodically flooded, or if it has an EC of 4 dS/m or more somewhere within 100cm of the surface;
- base saturation always more than 75 percent;

- evidence of aeolian activity in one or more of the following forms:
  - the sand fraction in some subhorizon or inblown material filling the cracks contains a noticeable proportion of rounded or subangular sand particles;
  - wind-shaped rock fragments on the surface;
  - aeroturbation;
  - evidence of wind erosion and/or deposition;
- both broken or crushed samples have a Munsell colour value of 3 or more when moist and 4.5 or more when dry, and a chroma of 2 or more when moist;
- desert pavement, i.e. accumulation of rock fragments, which is usually embedded in a loamy vesicular crust that has a polygonal network of desiccation cracks which extend into the underlying horizons;
- a weakly to moderately developed structure, usually platy at the surface with vesicular pores, and granular, crumb or subangular blocky below; and
- a consistence that is soft when dry.

4.11 SLOPE CLASS

Slope is an integral part of the land surface. Drainage, runoff, erosion, etc. are influenced by it. Therefore, slope classes referring to the *dominant* slope in an area are indicated which can be interpreted in relation to other properties (FAO 1990a):

(**a**) Level to gently undulating: dominant slopes ranging between 0-8 percent;
(**b**) rolling to hilly : dominant slopes ranging between 8-30 percent; and
(**c**) Steeply dissected to mountainous: dominant slopes are over 30 percent.

4.12 EXAMPLES OF TOPSOIL CHARACTERIZATION

Below some examples are given of how the topsoil characterization can be used to identify fertility related and management related soil characteristics. More examples are given in appendix B.

Example 1:

Eutri-grumic Vertisol with an natric, clayey, crusting and self-mulching topsoil **C n r1 v1**
Loc.: Hag Abudalla, South Gezira, Sudan
Thickness: 30 cm
Ref.: FAO (1985), p. 196/8

0-4 cm	Ah1	Dark greyish brown (10YR 4/2, moist) clay; soft platy crust on surface underlain by strong medium granular structure; slightly hard dry, friable moist, sticky and plastic wet; calcareous.
4-25 cm	Ah2	Very dark grayish brown (10YR 4/1.5, moist) clay; strong coarse prismatic parting to moderate medium and coarse subangular blocky; extremely hard dry, friable moist, sticky and plastic wet; calcareous.
25-45 cm	B	Very dark grayish brown (10YR 4/1.5, moist) clay; moderate medium subangular blocky, parallelepiped; very hard dry, firm moist, sticky and plastic wet; calcareous.

	Particle size distribution				OC	N	C/N	pH		$CaCO_3$
cm	CS	FS	Silt	Clay	%	%		paste	H_2O	%
0-4	9	11	25	55	0.13	0.045	3	8.1	8.9	1.3
4-25	7	12	24	57	0.41	0.035	12	8.2	8.9	1.4
25-45	9	12	23	56	0.47	0.035	13	8.4	9.3	1.2

cm	Exchangeable bases Ca	Mg	Na	K	CEC	EC	SAR	ESP
	cmol(+) kg^{-1} soil					dS m^{-1}		
0-4	nd	nd	4.12	1.5	55	0.16	5	7
4-25	nd	nd	7.81	1.4	57	0.60	4	14
25-45	nd	nd	13.79	1.1	52	1.32	10	27

Note: self-mulching is used as this is not directly implied by *grumi*.

Example 2:

Hapli-gleyic Cryosol with a silty, redoxic, organi-brunic topsoil **L O m3 o**
Loc.: 6 km NW of Fairbanks, Alaska, USA
Thickness: 30 cm
Ref.: Rieger S. et al. (1979), p. 40

0-12 cm	O	Very dark brown (10YR 2/2) mat of moss and roots.
12-20 cm	Ahg	Very dark greyish brown (10YR 3/2) and dark grey (5Y 4/1) silt loam; weak very thin platy, parting to weak very fine granular; friable moist; many roots.
20-40 cm	Bg	Dark grey (5Y 4/1) silt with many medium distinct dark brown mottles; weak very thin platy, parting to weak very fine subangular blocky; friable moist, non-sticky wet.

cm	Particle size distribution Sand	Silt	Clay	OC %	N %	C/N
0-12	nd	nd	nd	36.38	1.212	30
12-20	8	76	15	11.51	0.399	29
20-40	4	80	17	1.62	0.081	20

cm	PH H_2O 1:1	Exchangeable bases Ca	Mg	K	Na	CEC (NH_4OAc)	Extr. ac.	BS
		cmol(+) kg^{-1} soil						%
0-12	5.4	nd	nd	nd	nd	nd	nd	nd
12-20	5.7	24.3	11.8	0.5	0.3	40.5	27.2	91
20-40	6.9	14.7	7.6	0.1	0.4	22.3	6.4	100

Note: the combination of organic and brunic becomes "organi-brunic"; arctic is not used as this is implied by Cryosol; redoxic is used to indicate periodic saturation as evidenced by the reduction colours and many mottles; organi-brunic is used to indicate the thick (>10 cm) mat of moss and roots on top of a brunic layer.

Example 3:

Hapli-calcaric Regosol with a natric, clayey, severely eroded calcic topsoil **C n b d4**
Loc.: Torremegia, Badajoz Prov., Spain
Thickness: 30 cm
Ref.: ISRIC, monolith nr. E 11

0-4/6 cm	Ap	Yellowish red (5YR 4/6, moist) gravelly clay; weak to moderate fine crumb; hard dry, friable moist, sticky and plastic wet.

4/6 + cm   Ck   Pink (7.5YR 7/4), dull brown (7.5YR 5/3) and brown (5YR 5/2) very heterogeneous, strongly calcareous clay; structureless; friable moist.

	Particle size distribution				OC	N	C/N	pH	
Cm	CS	FS	Silt	Clay	%	%		H_2O	KCl
0-6	7	19	21	53	0.88	0.07	13	7.9	7.1
6-20	1	5	14	80	0.44	0.05	9	8.3	7.3

	Exchangeable bases				CEC	BS	Exch.	$CaCO_3$
	Ca	Mg	K	Na	(NH_4OAc)		Ca/CEC	
Cm	cmol(+) kg^{-1} soil					%		%
0-6	16.7	1.3	0.88	?	20.0	94	84	37.0
6-20	12.0	1.0	0.35	?	14.5	92	83	56.9

Note: strong-clayey is used as the average clay content of the topsoil is more than 60 percent. Calcic is used to indicate that the entire topsoil has more than 15 percent $CaCO_3$ equivalent, which is not implied in calcaric. Neither brunic nor melanic apply.

Example 4:

Haplii-gleyic Solonetz with a clayey, termitic, hard-setting and natric topsoil **C v4 n f2**
Loc.: South Nyanza District, Kenya
Thickness: 30 cm
Ref.: Wielemaker and Boxem (Eds) (1982), p. 177

Note: medium termite activity observed.

0-8 cm   Ah   Very dark (greyish) brown (10YR 2.5/2, moist) clay loam; strong fine subangular blocky; hard dry, firm moist, sticky and plastic wet.

8-30 cm   Bt   Very dark brown (10YR 2/2, moist) clay; strong coarse prisms coated with a very thin sprinkling of grey (10YR 6/1, dry) silt loam or loam on prism tops and along cracks; very hard dry, very firm moist, very sticky and very plastic wet; plentiful fine and medium roots.

	Particle size distribution			OC	N	C/N	pH
Cm	Sand	Silt	Clay	%	%		H_2O
0-8	32	30	38	2.1	0.50	4	5.2
8-30	26	32	42	0.9	0.09	10	6.0

	Exchangeable bases				CEC	BS	ESP
	Ca	Mg	K	Na	(NH_4OAc)		
Cm	cmol(+) kg^{-1} soil					%	
0-8	19.2	6.8	0.8	0.9	42.0	66	2
8-30	10.8	5.1	0.5	6.1	34.4	65	18

Note: Despite being a Solonetz, natric is still mentioned as that property reaches into the topsoil.

Chapter 5

Management requirements

The management requirements are given per interpreted topsoil property or group of properties. A complete listing of all possible combinations is not given because only a limited number of combinations of topsoil properties will be found in any area under consideration. At large scale, however, interpretation of the topsoil properties in relation to farming systems, local expertise or crops could be a valuable extension tool.

A brief description of each soil fertility or management constraint identified is given below. The management requirements are based on SANCHEZ et al. (1982), SMITH (1989)

5.1 TEXTURE

The sizes of the mineral particles profoundly affect the physical properties of soils: drainage, the water-holding capacity and the ease with which the soil can be cultivated. Coarse-textured soils and gravelly soils do have a low soil moisture storage capacity because of their high porosity and high infiltration rates as well as excessive internal drainage. This low moisture storage capacity has a considerable negative effect on crop growth and yields in semi-arid and sub-humid areas, where rains are often variable in time and space and dry spells within the main cropping season are frequent, because excess moisture from previous rains cannot be stored sufficiently long in the soil profile.

Combinations of topsoil and subsoil textures such as **SC**, **LC**, **LR** and **SR** should be given high priority with respect to soil conservation. Soils with an angular blocky to prismatic clayey layer, abruptly underlying a much lighter textured topsoil which has a poor massive structure are prone to water stagnation just above the transition to the clayey layer or claypan. In this layer active destruction of clay particles takes place and its environment is unsuitable for roots because of the lack of oxygen. In the presence of high amounts of exchangeable sodium the clayey layer has low stability. Pasture and paddy rice cultivation are the most appropriate uses. Puddling or bunding to obtain an anaerobic mud layer is hardly necessary, it is already there.

The clayey (**C**) topsoils possess a high potential for runoff if sloping and they are difficult to till unless in combination with **i**. Topsoils with more than 15 percent coarse fragments in the subsurface layer which are cobble size, may suffer from equipment damage if subsoiling operations are performed.

5.2 ORGANIC MATERIAL

For management purposes and in terms of water available to plants the volume of solid particles is much less in organic soils (**O**; **I**, **H**, **A** and **F**) than in mineral soils and the amount of water retained at very low tensions is much greater for organic soils (FAO 1988b). The total pore space in fibric organic topsoils is high which allows a high rate of water movement because of the large pores usually present. These large pores collapse on progressive decomposition and total pore space also decreases. On drainage the porosity of organic soils changes drastically. The organic soils need usually drainage for agricultural land use, which may lead to subsidence (see also paragraph 5.7) a great problem when attempting to sustain agricultural activities. Waterlogged and anaerobic conditions in the organic material become aerobic when drained. These aerobic conditions lead to biological oxidation or mineralization of the organic deposits. Subsidence has several serious consequences (FAO 1988b): drainage must be regularly adapted to new levels; rooting systems, particularly of perennials, become exposed; top-heavy crops such as coconut palms and oil palms start to lean over and are partly up-rooted; roads and other structures become unstable which influences the accessability of the terrain.

Micronutrient deficiencies may occur and high herbicide rates are usually required for organic topsoils. Organic soils may be acid, the various management requirements are described in paragraph 5.5. The use of lime and fertilizer to enable crop growth changes the microbial activity and hence the rate of mineralization. The use of fertilizers tends to quicken decomposition (FAO 1988b).

The cropping system influences the amount of compaction of the organic topsoil surface. Regular harvesting, particularly when heavy machinery is used, makes heavy demands on surface structure and consistency. Where annual crops are grown in the tropics, there are usually short fallow periods in which the surface temperature of the exposed organic topsoils can reach 70^{o}C as organic material is a poor conductor of heat. Bare surfaces together with low humidity and high temperatures can lead to spontaneous fires. A permanent ground cover would prevent this.

5.3 ORGANIC MATTER STATUS

Soil organic matter (**m0-m9**) is central to the maintenance of soil fertility: mineralization of N, P and S, the soil's ability to hold nutrients cations, structural stability and water holding capacity are all affected by OM content. Nutrients can be easily supplied where fertilizers are available.

Organic matter is one of the most important aggregate stabilizing agents in the soil. The very high OM decomposition rates in the warmer climates make it difficult to maintain high carbon levels in cultivated soils (GAISER 1993; PIERI 1989). A decrease in OM increases the erosion risk. Water erosion preferentially removes soil colloids, including humified OM. Decreasing OM content also increases the susceptibility to crusting, which further enhances the erosion risk. The soil erosion risk is also increased by the reduction of soil faunal activity which decreases with decreasing OM content. Improvement in soil organic matter content by fallowing, growing suitable legumes and grasses for a sufficient period, is also effective in improving soil structure and alleviating soil compaction. Fallowing by regeneration of natural vegetation is a slow and inefficient system and generally requires many years for complete topsoil recovery. Fallowing with specially planted grass or legume species or woody perennials is an efficient method. Addition of manures may be required to establish a good vegetative cover.

OC content and aggregate stability are subject to seasonal variation. The positive effect of OM on structural stability is more pronounced on sandy than on more finely textured soils. OM applications such as organic manures and incorporation of crop residues, are useful in maintaining and improving the topsoil physical properties and in counteracting the adverse effect of exchangeable sodium. Continuous arable cropping causes more structural deterioration on silty and poorly drained soils.

5.4 PHYSICAL FEATURES

***Sealing and Crusting Properties* (r1-r3)**
In the regions where topsoils with these properties occur rainfall is modest though sufficient to provide economic yields in rainfed agriculture if the rains can fully penetrate and be stored in the soil. The soil surface usually remains bare over long periods and at the onset of the (intensive) rains

sealing and crusting are widespread. Sealing occurs when the soil surface is wet or moist, while crusting occurs when seals dry out and harden.

Management measures to avoid surface sealing, thus to avoid crusting, comprise:

- protecting the soil surface with crop residues and/or cover crops. Most crops do not produce enough residues to cover the surface sufficiently which makes the growing of cover crops a necessity. The standing cover crop protects the soil surface and is in itself a protection;
- tillage techniques, e.g. minimum tillage or no tillage;
- crop rotations which result in higher aggregate stability, i.e. more complex crop rotations then compared with monoculture or double cropping systems;
- applications of lime and gypsum. This measure is usually applied with the primary objective of reducing aluminium toxicity in acid soils but also affects soil aggregation. Lime shows short-term detrimental effects on aggregation and therefore gypsum may be an interesting alternative which is also more economical though long-term effects may not develop as strongly when compared to lime (ROTH 1992); and
- the improvement of seedling emergence (FAO 1993).

Sealing-prone soils can also be used to concentrate the rainfall (water harvesting) on adjoining more productive soils.

Compaction **(p2)**
Soil compaction is a result of traffic by agricultural machinery or livestock trampling resulting in an increased bulk density. This bulk density can be lowered by appropriate measures such as ploughing which helps to keep the upper soil layers porous at least for a short time to allow root development and infiltration. Topsoils with low-activity clays have slight or negligible shrink-swell capacity. Decline in soil organic matter content, degradation of soil structure and drying accompanied by high soil temperatures encourage consolidation and compression. If topsoils are susceptible to compaction, as many land preparation or other activities as possible should be carried out in one single pass. Or manual instead of mechanized land preparation and harvesting methods should be used. Deeper ploughing operations can be performed to lower the bulk density of compacted subsoil and to improve aeration and infiltration. The smearing and compacting action of the plough sole gives rise to pore discontinuity that inhibits water movement and root development. Therefore it is often recommended to plough at different depths, in this way a ploughpan created earlier will be broken with the next deeper ploughing.

Vitric **(t)**
Topsoils with this property contain materials rich in shrinking-swelling clays (to be discussed), they have easy soluble components (discussed earlier) and a high amount of weatherable minerals.

Soils With High Shrink-Swell Capacity **(v1-v4)**
Vertisols are characterized by their high content of clay with shrinking and swelling properties. Tillage is difficult when topsoils are either too dry or too moist. The range of soil moisture conditions at which these soils can be tilled is very narrow. Land preparation therefore, can only be executed during a short period of time at the beginning of the rainy season or irrigation season. These are chemically rich soils, having a large reserve of nutrients and generally moderate amounts of organic matter, even below the topsoil. P-deficiency is common.

Topsoils formed from basic or ultrabasic rock (**v** without **b**) are likely to have Ca/Mg imbalances, and Mg/K imbalances as well (SMITH 1989). The topsoils may be subject to high runoff amounts (slopes >5 percent) after cracks have sealed, even when slopes are nearly level (BEEK et al. 1980). Conservation measures which reduce runoff are recommended. Topsoils with **v** and **t2** properties are prone to exhibiting root limiting BD values even when moisture is optimum. Tillage practices that reduce BD and minimize compaction should be emphasized. Waterlogging and poor passage may be prevented by the sowing of seeds more deeply in a dry seedbed ahead of the rains, or growing crops on a raised bed, or by drainage or construction of waterways.

Annual crops should be grown on these soils rather than perennial crops because the roots of most trees and shrubs will break during crack development in the dry season, and the stems are often inclined in different directions due to the shrink-swell process (SOMBROEK and NACHTERGAELE 1994).

5.5 CHEMICAL FEATURES

Alkalinity, Sodicity and Salinity
Soil fertility problems related to a high amount of soluble or exchangeable cations (Ca, Mg, K and particularly Na) result in a number of fertility problems that require specific soil management interventions and in some cases expensive and lengthy treatment. Salt-tolerant crops may be grown when salt is not excessive.

1. *Gypsic properties* (**y**)
   Presence of this soluble salt requires leaching and special management. The potential productivity of gypsiferous soils is related to the depth of the gypsic layer. In soils with a gypsic layer below 60cm depth the plant roots penetrate freely and the soil volume for nutrients is adequate (FAO 1990b). Fertilization of these soils improves both plant growth and yields. In shallow soils, with a gypsic layer near the surface, the soil volume is limited and fertilization becomes of special importance for plant growth.

   Improvement in the productivity of gypsiferous soils under rainfed conditions can be approached dependent on other topsoil properties by: soil terracing, harrowing, increasing the OM content, subsoiling and fertilization (FAO 1990b).

   Crops tolerant to 40 percent of gypsum in the soil without a significant decrease in yield are: alfalfa, trifolium, wheat, barley, lentil, oat, tomato and onion. Semi-tolerant crops which show tolerance to 20 percent of gypsum in the soil without significant decrease in yield are: broad bean, sugar beet, sorghum, maize, soybean and sesame. Semi-sensitive crops which show tolerance of up to 10 percent of gypsum in the soil without significant yield decrease are: cotton, groundnut, potato and sunflower (FAO 1990b).

2. *Calcic properties* (**b**)
   Calcite has a low solubility but its reactions with water have a profound effect on soil properties through the control it imposes on soil pH. The application of rock-phosphate and other non-water-soluble phosphates on these soils should be avoided. Potential deficiency of certain micronutrients, mainly iron and zinc. Choice of suitable crops or varieties together with suitable fertilization and if necessary micronutrients are management techniques of primary importance.

3. *Saline soils* (**l, s**)
   Many soils of the flatlands in arid and semi-arid regions are strongly saline throughout or at some depth. In areas with high evaporation and sediments with high-capillary rise a contact between saline groundwater and the rooting zone results in a high salinization hazard.

   Presence of soluble salts requires drainage and special management for salt-sensitive crops or the use of salt-tolerant species and cultivars (table 3). Total reclamation of saline soils is often impractical because of the lack of high quality water for irrigation and leaching. Wetland rice production may be an economical alternative. Continuous flooding helps to leach salts out of the root zone. Where enough irrigation water of good quality is available salts can be leached unless there are high percentages of sodium in the soil which will result in structure collapse and pan formation (SOMBROEK and NACHTERGAELE 1994).

Surface applications of gypsum will slowly introduce exchangeable calcium. A slight excess of boron in the irrigation water or in the soil solution can cause toxicity to a variety of crops. Boron is taken up by the crop where it is accumulated (FAO 1988a).

4. *Natric properties* (**n**)
High levels of sodium require special soil management practices for alkaline soils, including use of gypsum amendments and drainage (BEEK et al. 1980). Reclamation requires the replacement of Na^+ on the exchange complex by Ca^{2+} and leaching of Na^+ out of the root zone. Soil permeability and internal drainage must also be improved so the displaced sodium ions can be leached out of the root zone. Common mineral amendments used are: gypsum, phosphogypsum, calcite and other acid-forming salts like iron and aluminium suphates, lime-sulphur and pyrites. Application of phosphogypsum improves soil aggregation, decreases structural slaking and increases infiltration capacity, thus reducing runoff and soil erosion.

The selection of sodium tolerant crops (table 3) may be an alternative where leaching of sodium is impractical.

Appropriate tillage aims to improve drainage, increase leaching and improve soil porosity. Natric topsoils often have a massive structure which makes deep ploughing to 80cm depths and extensive soil loosening necessary to reclaim these soils. Deep tillage and use of crop residue mulches can also help to redistribute salt within the soil profile (GAISER et al. 1994).

Table 3. Sensitivity of major crops to salts (FAO, 1988a)

Major crop	Sensitivity to salts
Field crops	
Maize	Sensitive
Soybean	25% of varieties tolerant
Sorghum	Tolerant
Millet	Sensitive
Groundnut	Sensitive
Rice	Tolerant
Cassava	Sensitive
Cowpea	Sensitive
Beans	Very sensitive
Mungbean	Sensitive
Wheat	Semi-tolerant
Cotton	Semi-tolerant; Sensitive at germination
Forage crops	
Wheat grass	Tolerant
Clover (berseem)	Semi-tolerant
Alfalfa	Semi-tolerant
Vetch, meadow	Sensitive
Trees	
Leucaena	Sensitive
Rubber	Sensitive
Cacao	Sensitive
Oil palm	Sensitive

***Peat and Cat Clays (Acid Sulphate Soils)* (c1-c2)**
Usually water-saturated or flooded, these soils may generate sulphuric acid when drained. These soils should be kept water-saturated or reclaimed by shallow, intensive drainage and managed with plants tolerant to high water table or flooding. A good water management is essential for reclamation of these types of soils and where this is not feasible the soils should be used for other types of land uses such as forestry or fisheries (BEEK et al. 1980). The water management requires two types of management: at individual farm level and for the area as a whole.

***Aluminium Toxicity* (a)**
Soil management interventions aim to neutralize the toxic effect of aluminium by lime application. Even then, aluminium toxicity affects root growth and inhibits nodulation in legumes. Sensitivity to high levels of Al (table 4) also causes drought stress to many crops because their roots cannot go deep enough to tap moisture from the subsoil. For this reason it is quite common for crop yields to be reduced as a result of short-duration dry spells (ten days or less).

Another constraint is the friable consistency which imparts an easy workability during cultivation, it also entails ease of desegregation of a bare soil under the impact of high-intensity rainstorms, compaction under heavy machinery and the formation of surface caps which block infiltration of water or promote erosion. These side effects are favoured by the removal of the organic topsoil as result of land clearing practices (DE PAUW 1994).

The requirements for liming are high unless an **e** modifier is also indicated. This modifier is desirable for rapid dissolution of phosphate rocks and for good latex flow in rubber. Mn-toxicity may occur on some of these soils. Topsoils combined with organic matter (**O**) at surface or subsurface will although limed re-acidify with time.

Acid Soils, Non- or Slightly Al-toxic **(h)**
Human population density has been relatively low in regions with acid soils due to the low fertility of the soils and the high incidence of pests and diseases (SOMBROEK and NACHTERGAELE 1994). This situation is changing rapidly. The traditional shifting cultivation systems are replaced by continuous cultivation.

Low to medium soil acidity may affect sensitive crops like alfalfa or cotton, but acid soils which do not have a high percentage aluminium saturation can be very productive with adapted crops, pastures and trees, or (in combination) with liming.

Soils where Al saturation approaches 60 percent have an increased probability of inherent Mg deficiency. If the area is subject to short-term drought periods deep incorporation of lime may reduce significant crop yield reductions. Soils where Al saturation is between 10-60 percent have variable residual effects of liming but the topsoils will re-acidify with time.

Table 4. Sensitivity of major crops to aluminium.

Major crop	Sensitivity to aluminium
Maize	high
Soybean	moderate to high
Sorghum	moderate to high
Millet	low to moderate
Groundnut	moderate
Rice	low to moderate
Cassava	low
Cowpea	low to moderate
Bean	moderate to high
Mungbean	high
Wheat	moderate to high
Cotton	high
Grasses	
Brachiaria	low
Andropogon	low
Panicum	moderate to high
Legumes	
Centrosema	moderate
Stylosanthes	moderate
Kudzu	moderate
Mucuna	low to moderate
Crotolaria	high
Trees	
Leucaena	high
Rubber	low to moderate
Cacao	high
Oil palm	low to moderate

Source: de Pauw (1994) adapted from Caudle (1991).

High Phosphorous Fixation:

1. *By iron* (**i**)
   These soils require high levels of phosphate fertilizers or special P management practices. The use of high quality rock phosphate is especially indicated as partial or total substitution for water soluble phosphate fertilizers. Sources and method of P fertilizer application should be considered carefully: large initial broadcast and incorporated applications of P fertilizer will provide residual benefit for several years and may provide long-term monetary savings if P costs rise due to inflation; banded applications decrease P fixation but concentrate root development around the bands which may reduce root proliferation and crop yield in areas that have short term droughts.

   In minimum input cropping systems P fertilization should be directed towards the use of minimal P rates applied in bands or pockets together with the use of low P requiring crops. Broadcast application may be best for pasture fertilization.
   These topsoils usually do not have problems with regard to controlling erosion or runoff unless already eroded.

2. *By amorphous materials* (**x**, **o**)
   Usually occur in soils of volcanic origin. Volcanic soils, although generally very fertile and able to store high amounts of moisture, generally suffer from phosphorous fixation by these

amorphous materials and from low organic N mineralization rates. High levels of phosphate and nitrogen fertilizers are required despite high contents of organic nitrogen in the soil.

The soils are usually very friable, have low bulk density, have a high organic matter content and are resistant to erosion because of their high porosity and high inherent structural stability, but the presence of impervious substratum layers may cause massive landslides (SOMBROEK and NACHTERGAELE 1994).

Extreme Low Nutrient Retention **(e)**
These soils suffer from a combination of low organic matter content and an unfavourable clay mineralogy dominated by kaolinitic clays, resulting in an extremely low cation exchange capacity. Soil management interventions to remedy these constraints are bound to be expensive and often unprofitable as they imply a change in the clay-humus complex through considerable organic matter and/or high activity clay inputs. The use of mineral fertilizers is not recommended in these soils in their natural state, as nutrients are not retained by these soils due to the low capacity to retain nutrients. In addition, leaching causes big nutrient losses when lime and fertilizers are applied therefore, heavy applications of these nutrients and of N fertilizers should be split. There is potential danger of overliming.

Topsoils with both **S** and **e** modifiers are vulnerable for leaching of nutrients below major portion of the root zone during the growth cycle of annual crops. This is not a problem for topsoils low in CEC with an abrupt textural change (e.g. **SL**, **SC**, **SR**, **LC**, **LR** and **CR**).

Low Potassium Reserves **(k)**
The ability of the soil to supply most of the potassium needs on a sustainable basis for high potassium using crops is poor. Potassium fertilizers must be added. Usually the K fertilizer rates are low on newly cleared land but they increase with time. Generally these soils have also limited capacity to retain nutrients and the potassium, calcium and magnesium added can be easily lost.

Seasonally wet soils have higher organic matter contents than their well-drained counterparts. CEC due to organic matter allows a greater proportion of exchangeable and solution K in the soils solution. Topsoils with both **k** and **a** modifiers need liming to increase the available K, to reduce leaching and to improve K use efficiency.

5.6 BIOLOGICAL FEATURES

Termites (**f2**) influence topsoils both in a positive and a negative way. Some species promote aeration of the soil, others build castle-like high mounds provoking runoff and they can also remove clayey particles from the topsoil. They can attack crops and are responsible for a rapid turnover of OM. The density of their mounds may affect mechanized agriculture.

Earth worms (**f1**) promote the formation of soil aggregates and perforate already-formed surface crusts, thus enhancing infiltration.

5.7 DRAINAGE FEATURES

Hydromorphic Soils (Wetlands) **(w,o,u)**
The cause of hydromorphy is variable and may be due to temporary or permanent flooding, a high groundwater table during parts of the year or stagnating water on the surface of the soil. Tillage operations are impaired on these soils at least during part of the year. Drainage interventions and flood protection schemes are the most appropriate soil management practices that may be recommended, depending on the cause of the hydromorphic situation. Once empoldered or drained

they are often highly productive but may then also show or develop management problems because extremely heavy texture, development of clay pans, sodic pans or high salinity (see chemical properties). Some of these soils have potential for adapted crops such as rice.

Sometimes artificial drainage is not feasible because the soils occupy low-lying areas or basins with restricted outlets. N losses are increased if the soils are intermittently flooded and drained. Wetland soils combined with the $CaCO_3$ modifier (**b**) may suffer, when flooded, an increase in CO_2 partial pressure and a decrease in soil reaction.

Coastal wetlands pose specific problems, especially those which have a peaty surface layer (see organic matter status and peat and cat clays).

5.8 LAND USE

Some of the anthropic influences (**a1-a8**) on the soils result in desired topsoil properties such as accumulated fertility, land-levelling or construction of drainage (**a1**, **a2** and **a7**). Other influences result in environmental damages: erosion (see paragraph 5.9); use of sewage sludge or refuses (**a6**) which contain heavy metals which are present in soils naturally in trace amounts but may be toxic to plants or animals at increased concentrations. Both erosion and soil pollution are changes in soil properties which are extremely difficult to reverse.

5.9 EROSION OR DEGRADATION

Increasing land pressure on formerly sustainable agricultural systems leads to degradation of productive capacity as a result of decreasing organic matter contents, deteriorating structural condition, or declining nutrient levels (STOORVOGEL and SMALING 1990). The major forms of degradation are due to displacement of topsoil (water and wind erosion)(**d1-d6**) or deterioration without displacement (chemical and physical degradation)(**d7-d8**).

This results not only in the loss of the most fertile part of the land (topsoil with its concentration of nutrients), but also in deposition elsewhere which might have a beneficial effect locally, but more commonly leads to silting-in of rivers and dam sites.

Erosion should be prevented by taking conservation measures as described by FAO (1994b, 1983), HUDSON (1992, 1981), MORGAN (1986) and SCHWAB et al. (1981) among many others. The main aims in erosion control are:

- improve aggregation and encourage a large proportion of water-stable aggregates, this can be done by raising soil organic matter content, thus encouraging biological activity, and by encouraging rooting in the topsoil;
- reducing and/or preventing raindrop impact on the soil surface;
- reducing runoff rate, amount and velocity by avoiding surface crusting or sealing, and by encouraging stable and continuous pores in the soil.

5.10 EXTERNAL PHYSICAL CONDITIONS

***Arctic* (t1)**
Crop production is only possible in lower latitude areas under greenhouse conditions. Temperature limitations combined with drainage properties may be beneficial where a high water table during winter can be maintained, draining the soil a few weeks prior to tillage can allow earlier planting and

warmer subsurface temperatures. Where there is no high water table soil warming can be achieved with the use of plastic films.

***Arid* (t2)**
Moisture is limited during the dry season unless soil is irrigated. A leaching factor should be included to prevent salts from accumulation in the root zone. The planting date should take into account the flush of N at onset of rains. Germination problems are often experienced if first rains are sporadic or when the soil temperatures are high. Practices like planting after the soil has been moistened, mulching or decreasing seedbed roughness may help to decrease soil temperature.

In areas where rainfall is too limited to produce a crop every year a fallow period to allow storage of sufficient moisture for crop production once every two or three years may be effective. This practice can only be followed if erosion is under control because prevention of vegetation regrowth during the fallow period assist water accumulation in the soil.

5.11 SLOPE

In general, mountainous areas have been sparsely populated with farming systems adapted to the harsh environment. With increased population pressure farmers are pushed out of the more fertile areas into these ecological fragile areas. As a consequence the inherent ecological fragility is often tried beyond capacity. This results not only in a serious loss of soil material from the fields, but also in large-scale negative effects downstream (SOMBROEK and NACHTERGAELE 1994).

Agricultural production on slopes greater than 15 percent is not recommended. Conservation measures such as contour ploughing, grass strips, terrace benches, waterways, etc. are necessary to control runoff. Prevention of erosion is essential since treatment of its consequences is a costly affair. Steeper slopes should be kept under a permanent protective vegetal cover.

References for soil conservation practices are mentioned in paragraph 5.9.

5.12 EXAMPLES OF TOPSOIL-RELATED MANAGEMENT REQUIREMENTS

The management requirements for the examples given in paragraph 4.12 are given below.

Example 1:

Eutri-grumic Vertisol with an natric, clayey, crusting and self-mulching topsoil **C n r1 v1**
Loc.: Hag Abudalla, South Gezira, Sudan
Thickness: 30 cm
Ref.: FAO (1985), p. 196/8

Management Requirements
The natric property indicates a topsoil with high levels of sodium which requires gypsum amendments and drainage. The combination of clayey, crusting and self-mulching topsoil properties indicates a topsoil which is susceptible to runoff and its range of moisture conditions at which this soil can be tilled is narrow. It is a chemically rich soil suitable for growing annual sodium-tolerant crops because roots will break during crack development in the dry season due to the self-mulching properties.

Example 2:

Hapli-gleyic Cryosol with a silty, redoxic, organi-brunic topsoil **L O m3 o** Loc.: 6 km NW of Fairbanks, Alaska, USA Thickness: 30 cm Ref.: Rieger S. et al. (1979), p. 40

Management Requirements

This topsoil consist of well-mixed organic matter and almost completely mineralized OM, a BS of 35 percent or more which may indicate that aluminium toxicity may limit crop production, and it is periodically saturated with groundwater. Tillage operations are impaired on this soil due to periodical water saturation. Depending on the feasibility drainage may result in a highly productive soil which needs careful water management.

Example 3:

Hapli-calcaric Regosol with a natric, clayey, severely eroded calcic topsoil **C n b d4** Loc.: Torremegia, Badajoz Prov., Spain Thickness: 30 cm Ref.: ISRIC, monolith nr. E 11

Management Requirements

This topsoil combines natric and calcic properties. Due to its low solubility calcite can not replace sodium on the exchange complex. This topsoil also shows poor infiltration capacity which has caused severe erosion. The use of phosphogypsum may increase its infiltration capacity.

Example 4:

Hapli-gleyic Solonetz with a clayey, termitic, hard-setting and natric topsoil **C v4 n f2** Loc.: South Nyanza District, Kenya Thickness: 30 cm Ref.: Wielemaker and Boxem (Eds) (1982), p. 177

Management Requirements

This topsoil combines hard-setting properties with natric properties. The topsoil is hard to till when dry and is likely to have a massive structure which can also be deducted from the natric properties. Appropriate tillage where drainage is improved, leaching increased and soil porosity is improved is required. Deep ploughing to 80cm depth or more is impaired by the presence of more than 10 percent of termitaria on the surface. Therefore crop residue mulching would be more practical but for the presence of termites which are notorious for a rapid turnover of organic residue left at surface.

Chapter 6

Further developments

The presented characterization of surface layers is only the first step towards a comprehensive and sound insight in the topsoils of the world. It has been based on existing soil data, specialized studies in literature, and experience, all of which cannot cover the entire globe. As one of the first steps for further development a topsoil database should be established which contains information which will serve as feedback to the proposed system. At the moment the system has not been tested and more refined definitions of the properties and modifiers may be needed regarding:

- *OM status*: degree of decomposition, mixture with the mineral particles and the different forms of humus;
- *biological activity*: kind of soil fauna, record of their activity, a rating of amount of disturbance, and rooting;
- *soil surface characteristics*: kind and thickness of seals and crusts, evidence and amount of erosion c.q. deposition;
- *physical and chemical parameters*: build-up of the cultural profile (if any), porosity and bulk density, aggregate stability, infiltration and through-flow rate, water storage, drainage, soil structure, organo-mineral complexes, texture, base status and soil pH;
- *drainage features*: reducing/redoxing, duration;
- *record of past and present land use*: i.e. a record of anthropic influences.

Through this database it will be possible to group individual topsoil properties into sets of characteristics which can be matched with the already distinguished and defined topsoil properties.
The topsoil database will be geographically referenced to enable future linkage to a Geographical Information System (GIS). This linkage is important as it will enable future users to inform them on topsoil conditions in a region. It will also enable linkages to a number of already existent software packages in land resources assessment.

The draft framework as it is presented here should evoke comments and discussion from the international community which should lead to a further refinement of ecological important and fertility-related characteristics of the topsoils in an easily understandable and practical way.

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