

PRINCIPLES OF SOIL CLASSIFICATION

Compendium of lecture notes

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2003

Correct citation: Msanya, B.M. (2003). Principles of Soil Classification. Compendium of Lecture Notes. Department of Soil Science, Faculty of Agriculture, Sokoine University of Agriculture, Morogoro, Tanzania. 61 pp.

PRINCIPLES OF SOIL CLASSIFICATION

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These lecture notes are meant for students majoring in agriculture, forestry and related fields. They have to be supplemented with extra reading to enable students and other readers understand the important concepts in soil classification so that they can classify soils correctly using both the USDA Soil Taxonomy and the FAO-UNESCO soil classification systems. Some coverage has been made on the newly established “*World Reference Base (WRB) for Soil Resources*” Classification System. Some concepts on indigenous soil classification systems are also given, pointing out their salient features including strengths and weaknesses.

IMPORTANT READING MATERIALS

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9. Landon, J.R., 1984. *Booker tropical soil manual. A handbook for soil survey and land evaluation in the tropics*. Longman Group Ltd., 450 pp.
10. Soil Survey Staff, 1951. *Soil survey manual*. *Agriculture handbook no. 18*. *Soil Conservation Service, United States Department of Agriculture, Washington, D.C.*
11. Soil Survey Staff, 1990. *Keys to Soil Taxonomy*. *Agency for International Development, United States of Agriculture, Soil Management Support Services technical monograph no. 19*. *Virginia Polytechnic Institute and State University*, 422 pp.
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Definition of soil classification

Soil classification is the systematic arrangement of soils into groups or categories on the basis of their characteristics. Classification of soils is necessary for the following reasons:

- i. to organise knowledge and thereby contribute to economy of thought
- ii. to bring out and understand relationships among soils and classes of soils being classified
- iii. to remember properties of the soils being classified
- iv. to learn new relationships and principles in the soils being classified
- v. to establish groups or subdivisions (classes) of the soils under study in a manner useful for practical and applied purposes in:
 - a. Predicting their behaviour
 - b. Identifying their best uses
 - c. Estimating their productivity
 - d. Providing objects or units for research and for extending and extrapolating research results or observations

Classification helps us deal with complexity. There are too many soils to consider individually. If we can find some common properties among them, we can make meaningful classes to help us organize our knowledge and simplify our decision-making.

The role of soil classification

According to De Bakker (1970) soil classification serves two main purposes:

- i. Theoretical or scientific purposes, which emphasize the origin of soils and their relationships, and
- ii. Purposes of practical importance, which are aimed at the application in agriculture or other technological uses of soils. For these kinds of purposes soil survey is an essential link to the practical application.

Basically, a soil classification system organises knowledge about sets of soil properties and concepts, and groups them into taxonomic classes. Literature review (Manil, 1956; Stobbe, 1962; Cline, 1963; Smith, 1963; Northcote, 1965; Kovda *et al.*, 1967; Avery, 1973; Beinroth, 1978; Mapping Systems Working Group, 1981) indicates that one of the prime objectives of soil classification is to serve as a base for soil survey. Soil classification provides the vocabulary to describe the mapping units of the legend to a soil map.

Mulcahy and Humphries (1967) distinguished two major types of soil classification. A *special* classification is one devised for a particular purpose, or for a limited number of purposes. Special classifications are based on a small number of characters, although this is not their essential feature. Such classifications are also referred to as *extrinsic*, meaning that they are made with reference to some external criteria. On the other hand, *general* or *intrinsic* classifications attempt to collect all possible information about a population without reference to external criteria.

Soil surveys based on general soil classifications are the most useful in the case of under-developed areas, where there is little agronomic experience, but information about the soils and environmental factors will determine the range of possible users. Special classifications are by definition limited in use to cases where objectives can be adequately defined. In many occasions, a choice between general and special classifications is not open; each has a distinct area of application, the recognition of which will lead to more efficient use of both.

SOIL CLASSIFICATION SYSTEMS

There are many soil classification systems in the world, most of which being national and others international in terms of their usage. The following is a list of the most prevalent systems of classification:

- i. United States Soil Classification System (also referred to as Soil Taxonomy)
- ii. FAO-UNESCO Soil Classification System
- iii. World Reference Base (WRB) for Soil Resources
- iv. USSR Soil Classification System
- v. Natural System of Soil Classification of Kubiens (1953)
- vi. ORSTOM Soil Classification System. ORSTOM is French and stands for **Office de la Recherche Scientifique et Technique Outre-Mer** (Bureau of Scientific and Technical Research Abroad)
- vii. British System of Soil Classification
- viii. Australian System of Soil Classification
- ix. Canadian Soil Classification System

The first two systems enjoy a very wide international recognition. The ORSTOM system serves mostly the French-speaking tropical countries.

There is no general agreement on the classification of tropical soils. The classification system used in the United States is more comprehensive than the other systems. However, this system now known as the SOIL TAXONOMY, is not completely satisfactory especially for tropical soils. Modifications aimed at improving the system for classification of these soils are still being made. The wide range of climate, past and present in the present day tropical countries makes it very difficult to classify them satisfactorily.

THE USDA SOIL TAXONOMY (Soil Survey Staff, 1975; 1999)

An introduction to the US Soil Classification (SOIL TAXONOMY) will be given here. The SOIL TAXONOMY is a multi-categorical and hierarchical system of classification. *Multi-categorical* means many levels or categories; *hierarchical* means arrangement with grades from top to bottom.

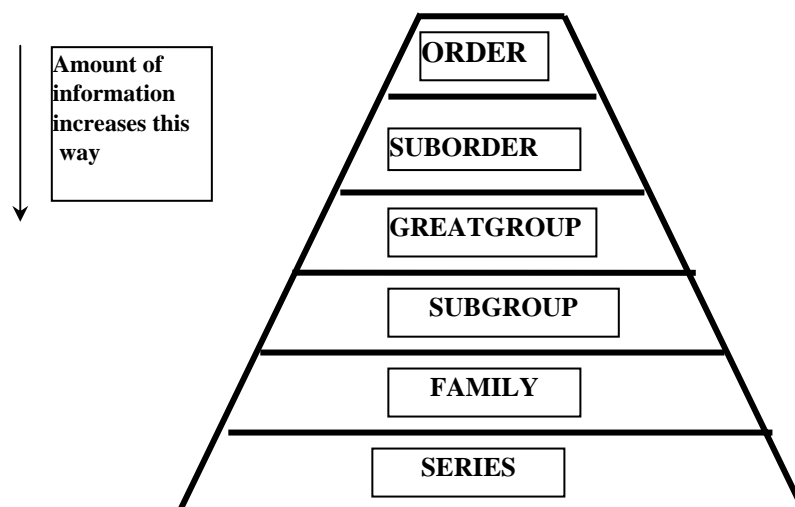


Figure 1. The categories of the USDA Soil Taxonomy

The levels of the system are ORDER, SUBORDER, GREATGROUP, SUBGROUP, FAMILY and SERIES arranged from top to bottom in that sequence (see Figure 1). The amount of information required to classify soils at the various levels differ from level to level; it increases from order to series.

Objectives of establishing the Soil Taxonomy

This classification system was developed with the objectives to:

- Organise *soil series* in increasing general-groups for interpretations. (Note: soil series were established from many years of mapping)
- Support semi-detailed and reconnaissance mapping directly with the defined classes
- Facilitate correlation within and among regions: the more similar the soils, the closer they should be in the classification
- Organise knowledge on relationships among soils

The nature of differentiating characteristics of the categories of Soil Taxonomy

ORDER:	Soil forming processes as indicated by presence or absence of major diagnostic horizons (key horizons used to identify soils)
SUBORDER:	Subdivision of orders according to the presence or absence of properties associated with wetness, soil moisture regimes, major parent materials, and vegetation effects as indicated by key properties, organic fibre decomposition stage e.g. in Histosols.
GREATGROUP:	Subdivision of suborders according to similar kind, arrangement, and degree of expression of horizons, base status, soil temperature and moisture regimes, presence or absence of diagnostic layers e.g. <i>plinthite</i> , <i>fragipan</i> , <i>duripan</i> .
SUBGROUP:	Central concept taxa* for greatgroups and properties indicating intergradations to other greatgroups, suborders and orders. The concept of “ <i>Typic</i> ” and “ <i>Non-typic</i> ” subgroups is introduced here. At this level one intends to separate the <i>Typic</i> subgroups (those in which the key properties defining the greatgroups i.e. the central concept) are there, and the non-typic ones (those with properties inter-gradating to other greatgroups, suborders, orders, or those extragradating to non-existent soils -nonsoils) *Taxon: a class at any categorical level in the US Soil Classification System.
FAMILY:	Properties important for plant root growth; broad soil textural classes; mineralogical classes; soil temperature classes etc.
SERIES:	Kind and arrangement of horizons, colour, texture, structure, consistence, and reaction of horizons, chemical and mineralogical properties of the horizons.

Principles of nomenclature (see Table 6 p.84, Soil Taxonomy)

ORDER

The name of each order ends in *sol* (L. *solum*. soil) with the connecting vowel *o* for Greek roots and connecting vowel *i* for other roots. For example Alf*is*ol, Arid*is*ol, Ent*is*ol, Histosol, Incept*is*ol, Mollisol, Ox*is*ol, Ult*is*ol, Vert*is*ol, And*is*ol. Prior to 1990 only the first 10 orders were recognised. The order Andisol was introduced afterwards, and the number of soil orders became 11. More recently another order Gelisol representing soils with permafrost has been introduced (Soil Survey Staff, 1999). So the current number of

soil orders is 12.

Formative elements (used as endings for names at the other levels of the classification)

Each name of order contains a formative element that begins with the vowel next preceding the connecting vowel, and ends with the last consonant preceding the connecting vowel. Consider as an example the order **ENTISOL**: -the connecting vowel is *i*; the vowel next preceding the connecting vowel is *e*; the last consonant preceding the connecting vowel *i* is *t*. Hence the formative element is *-ent*. Table 1 presents the formative elements for the different soil ORDERS.

Table 1. Formative elements in the names of orders (table 8 p. 87, Soil Taxonomy)

Name of order	Formative element	Derivation of formative element
Alfisol	Alf	Meaningless syllable
Aridisol	Id	L. aridus, dry
Entisol	Ent	Meaningless syllable
Histosol	Ist	Gr. histos, tissue
Inceptisol	Ept	L. inceptum, beginning
Mollisol	Oll	L. mollis, soft
Oxisol	Ox	F. oxide, oxide
Spodosol	Od	Gr. spodos, wood ash
Ultisol	Ult	L. ultimus, last
Vertisol	Ert	L. verito, turn
Andisol	And	J. an, dark; do, soil
Gelisol	El	L. gelare, to freeze

SUBORDER

Names have exactly two syllables, the first syllable connotes something of the diagnostic properties of the soil, and the second syllable is the formative element derived from the order name. Example: *Aquent*, *Aquod*, *Fluvent*, *Perox*. These formative elements are used with the other formative elements derived from order names to make names of suborders. Table 2 presents the formative elements used in the names of suborders.

Table 2. Formative elements in names of suborders (derived from table 9, p. 88 Soil Taxonomy)

Formative element	Derivation	Connotation
Alb	L. albus, white	Presence of albic horizon
Aqu	L. aqua, water	Aquic moisture regime
Ar	L. arare to plow	Mixed horizons
Arg	L. argilla, white clay	Presence of argillic horizon
Bor	Gr. boreas, northern	Cool
Cry	Gr. kryos, icy cold	Cold

Ferr	L. ferrum, iron	Presence of iron
Fibr	L. fibra, fibres	Least decomposed stage
Fluv	L. fluvius, river	Floodplain
Fol	L. folia, leaves	Mass of leaves
Hem	Gr. hemi, half	Intermediate stage of decomposition
Hum	L. humus, earth	Presence of organic matter
Ochr	Gr. Ochros, pale	Presence of ochric epipedon
Orth	Gr. orthos, true	The common ones
*Plagg	Ger. plaggen, sod	Presence of plaggen epipedon
Psamm	Gr. psammos, sand	Sand texture
Rend	Modified from rendzina	High carbonate content
Sapr	Gr. sapos, rotten	Most decomposed stage
Torr	L. torridus, hot and dry	Torric moisture regime
Ud	L. udus, humid	Udic moisture regime
Umbr	L. umbra, shade	Presence of umbric epipedon
Ust	L. ustus, burnt	Ustic moisture regime
Vitr	L. vitrum, glass	Presence of glassy or vitric material
Xer	Gr. xeros, dry	Xeric moisture regime

*plaggen = sod = upper layer of grassland including grass with its roots and earth

GREATGROUP

The name of a greatgroup consists of a name of a suborder and a *prefix* that consists of one or two formative elements suggesting something of the diagnostic properties of the soil. Thus its name is of three or four syllables and ends with the name of the suborder. For example *Cryofluvent*, *Sombriperox*. Table 3 gives the formative elements used for names of greatgroups.

SUBGROUP

Subgroup consists of a name of greatgroup modified by one or more adjectives. Different types of subgroups are recognised:

1. **Typic subgroups:** The adjective *Typic* is used for subgroup that has typical properties (central concept) defining the greatgroup. For example *Typic Cryofluvent*, *Typic Torrifuvent*.
2. **Intergrade subgroups:** These belong to one greatgroup but have some properties of another order, suborder or greatgroup. They are named by using appropriate modifier in the form of adjectival names. Example: *Vertic Torrifuvents* have some of the properties of Vertisols superimposed on the complete set of diagnostic properties of Torrifuvents

Table 3. Formative elements used in the names of greatgroups ((Table 10, p.89, Soil Taxonomy)

Formative element	Derivation	Connotation
Acr	Gr. Akros, at the end	Extreme weathering
Agr	L. ager, field	Presence of an agric horizon
Alb	L. albus, white	Presence of an albic horizon
And	J. an, dark; do, soil	Soils rich in volcanic material with dark surface soil
Arg	L. argilla, white clay	Presence of argillic horizon
Bor	Gr. boreas, northern	Cool
Calc	L. calcis, lime	Presence of calcic horizon
Camb	L. cambiare, to change	Presence of cambic horizon
Chrom	Gr. chromos, colour	High chroma (bright colours)
Cry	Gr. kryos, icy cold	Cold
Dur	L. durus, hard	Presence of a duripan
Dystr	Gr. dys, ill, dystrophic, infertile	Low base saturation
Eutr	Gr.eu, good, eutrophic, fertile	High base saturation
Ferr	L. ferrum, iron	Presence of iron
Fluv	L. fluvius, river	Floodplain
Frag	L. fragilis, brittle	Presence of a fragipan
Fragloss	Compound of fra(g) and gloss	See formative elements frag and gloss
Fulv	-----	Used to separate some Andisols
Gel	L. gelu, frost	Permafrost
Gibbs	Modified from gibbsite	Presence of gibbsite
Gyps	L. gypsum, gypsum	Presence of gypsic horizon
Gloss	L. glossa, tongue	Tongued
Hal	Gr. hals, salt	Salty
Hapl	Gr. haplous, simple	Minimum horizon
Hum	L. humus, earth	Presence of humus
Hydr	Gr. hydor, water	Presence of water
Luv	Gr. louo, to wash	Illuvial
Med	L. media, middle	Of temperate climate (mid-latitudes)
Melan	Gr. melas-anos, black	Presence of melanic epipedon
Nadur	Compound of na(tr) and dur	See formative elements natr and dur
Natr	L. natrium, sodium	Presence of a natric horizon
Ochr	Gr. ochros, pale	Presence of ochric epipedon
Pale	Gr. paleos, old	Excessive development
Pell	Gr. pellos, dusky	Low chroma (dark colours)
Plac	Gr. plax, flat stone	Presence of a thin pan
Plagg	Ger. plaggen, sod*	Presence of plaggen epipedon
Plinth	Gr. plinthos, brick	Presence of plinthite
Psamm	Gr. psammos, sand	Sandy texture
Quartz	Germ. quarz, quartz	High quartz content
Rhod	Gr. rhodon, rose	Dark red colour
Sal	L. sal, salt	Presence of salic horizon
Sider	Gr. sideros, iron	Presence of free iron oxides
Sombr	Fr. sombre, dark	Presence of dark horizon
Sphagn	Gr. sphagnos, bog	Presence of sphagnum
Sulf	L. sulfur, sulphur	Presence of sulphides or their oxidation products
Torr	L. torridus, hot and dry	Torric soil moisture regime
Trop	Gr. tropikos, tropical	Humid and continually warm
Ud	L.udus, humid	Udic soil moisture regime
Umbr	L. umbra, shade	Presence of umbric epipedon
Ust	L. ustus, burnt	Ustic soil moisture regime
Verm	Gr. vermos, worm	Wormy, or mixed by animals
Vitr	L. vitrum, glass	Presence of glassy or vitric material
Xer	Gr. xeros, dry	Xeric soil moisture regime

*sod = upper layer of grassland including the grass with its roots and earth

1. Extragrade subgroups: These have important properties not representative of the greatgroup, but that do not indicate transition to any other known kind of soil. They are named by modifying the greatgroup name with an adjective that connotes something of the aberrant properties. For example *Lithic Haploxerults* are Haploxerults that have a shallow lithic contact.

It is possible to have a subgroup with several modifiers arranged alphabetically e.g. *Cumulic Glossic Natraqualfs* are Natraqualfs with thickened epipedon and tongued boundaries. Table 4 gives the adjectives used in the names of extragrades and their meaning.

Table 4. Adjectives in names of extragrades and their meaning (derived from Table 11, p.90, Soil Taxonomy)

Adjective	Derivation	Connotation
Abruptic	L. abruptum, torn off	Abrupt textural change
Anthropic	Gr. anthropos, man	Presence of an anthropic epipedon
Arenic	L.arena, sand	Sandy epipedon between 50 and 100 cm
Cumulic	L. cumulus. Heap	Thickened epipedon
Glossic	Gr. glossa, tongue	Tongued horizon boundaries
Grossarenic	L.grossus, thick and L. arena, sand	Thick sandy epipedon >1 m thick
Hydric	Gr. hydor, water	Presence of water
Leptic	Gr. leptos, thin	A thin soil
Limnic	Gr. limn, lake	Presence of limnic layer
Lithic	Gr. lithos, stone	Presence of a shallow lithic contact
Pachic	Gr. pachys, thick	A thick epipedon
Paralithic	Gr. para, besides, and lithic	Presence of shallow paralithic (lithic-like) contact
Pergelic	L.per, throughout & L.gelare to freeze	Permanently frozen, having permafrost
Petrocalcic	Gr. petra, rock & L. calcis, lime	Presence of petrocalcic horizon
Petroferric	Gr. petra, rock & L. ferrum, iron	Presence of petroferric horizon (ironstone)
Plinthic	Gr. plinthos, brick	Presence of plinthite
Ruptic	L. ruptum, broken	Broken horizons
Terric	L. terra, earth	A mineral substratum
Thapto	Gr. thapto, buried	Buried soil

FAMILY

The names at family level are polynomial consisting of the name of a subgroup and adjectives, generally three or more to indicate:

1. particle size class
2. mineralogy
3. calcareousness
4. reaction
5. depth
6. consistence
7. slope
8. temperature regime

For example, *coarse-loamy, mixed, acid, Typic Cryorthent, clayey over loamy, mixed, calcareous, hyperthermic, Vertic Torrifluent*.

SERIES

Names of the series, as a rule are abstract place names. The name usually is taken from a place near the one where the series was first recognised. For example *Mgeta series*,

Morogoro series.

Meaning of soil names

The name of a soil up to family level indicates its properties, as formative elements are indicative of properties. Hence it is possible to tell the properties of a soil by systematically breaking the soil name into its component formative elements.

DIAGNOSTIC HORIZONS AND FEATURES USED IN THE SOIL TAXONOMY

The US system of classification relies on the identification of diagnostic horizons and features in the surface and subsurface. Diagnostic horizons are soil horizons that represent a set of features used for soil identification. Since the characteristics of soil horizons are produced by soil forming processes, the use of diagnostic horizons for separating soils relates soil classification to general principles of soil genesis. Epipedons are simply the uppermost soil horizons. Epipedon is not synonymous with A horizon and may be thinner than the A horizon or may include some of the B horizons.

DIAGNOSTIC EPIPEDONS

Originally only 6 diagnostic epipedons were recognised in the Soil Taxonomy. In 1990, a new epipedon i.e. *melanic* was introduced to bring the number of diagnostic epipedons to 7. Their definitions are summarised below. The reader is referred to their full definitions in The Soil Taxonomy Handbook and the Keys to Soil Taxonomy (Soil Survey Staff, 1990).

1. MOLLIC EPIPEDON

This is a thick dark coloured surface horizon which meets the following requirements:

- i. structure is sufficiently strong that the horizon is not both massive and hard or very hard when dry.
- ii. has colours with a chroma of less than 3.5 when moist, and a value darker than 3.5 when moist and 5.5 when dry.
- iii. base saturation (by 1M NH₄ OAc at pH 7.0) is 50 percent or more.
- iv. organic carbon content is at least 0.6 percent
- v. thickness = or > 10 cm if resting directly on hard rock, or petrocalcic horizon, petrogypsic horizon, or duripan; where the solum < 75 cm thick, thickness of horizon = or > 18 cm and > 1/3 of the thickness of the solum; and where the solum = or > 75 cm thick must be more than 25 cm
- vi. content of P₂O₅ soluble in 1 percent citric acid is less than 250 mg/kg soil.
- vii. n value is < 0.7.
- viii. horizon not naturally dry for > 3 months per year.

2. UMBRIC EPIPEDON

This horizon meets all the requirements of mollic epipedon in terms of colour, organic carbon and phosphorus content, consistence, structure and thickness except that it has a base saturation (by 1M NH₄OAc at pH 7.0) of less than 50 percent.

3. ANTHROPIC EPIPEDON

- i. this is a man-made surface layer = or > 50 cm thick which has been produced by long continued fertilization particularly with phosphatic fertilizers.
- ii. it commonly contains artifacts such as bits of bricks and pottery throughout its depth.

iii. meets all requirements of mollic epihedon except that the content of P_2O_5 soluble in 1 percent citric acid is 250 mg/kg soil or more.

4. HISTIC EPIPEDON

- i. this is an organic horizon having its upper boundary within 40 cm of the surface and is > 20 cm but < 40 cm thick.
- ii. it can be > 40 cm but < 60 cm thick if it consists of 75% or > by volume of sphagnum fibers or has a BD when moist of < 0.1 Mg/m³.
- iii. it has 18% or > OC if mineral fraction contains > 60% clay, or 8% or > OC if mineral fraction contains no clay, or intermediate contents of OC for intermediate contents of clay.
- iv. it is water-saturated for 30 or > consecutive days per year.

5. PLAGGEN EPIPEDON

- i. this is a man-made surface horizon that is 50 cm or > thick, created by many years of manure addition
- ii. it commonly contains artifacts such as bits of bricks and pottery, spade marks etc. throughout its depth.

6. MELANIC EPIPEDON

- i. this is a thick black horizon containing high concentration of OC.
- ii. it has its upper boundary at or within 30 cm of the soil.
- iii. has andic* properties.
- iv. has moist colour value and chroma of 2 or <
- v. has OC of 6% or >.

**Andic properties:*

- a. Acid-oxalate extractable Al + $\frac{1}{2}$ acid-oxalate extractable Fe = or >2.0 in fine earth fraction
- b. BD of the fine earth = or < 0.9 g/cc
- c. phosphate retention capacity of the fine earth = or > 85%

7. OCHRIC EPIPEDON

This is a surface horizon that is too light in colour, has too high a chroma, too little OC or is too thin to be mollic, anthropic, umbric, histic, plaggen or melanic, or that is both hard and massive when dry.

SUBSURFACE DIAGNOSTIC HORIZONS

1. ARGILLIC HORIZON

- i. this is a B horizon that is clay-enriched i.e. contains more clay than the overlying eluvial horizon. The textural differentiation may be due to illuvial accumulation of clay or to destruction of clay in the surface horizon, or to selective surface erosion of clay, or to biological activity, or to a combination of two or more of these different processes.
- ii. has texture that is sandy loam or finer and has at least 8 percent clay in the fine earth fraction.
- iii. lacks the set of properties which characterize the oxic horizon.
- iv. contains more total clay than an overlying coarser-textured horizon:
 - a. if the overlying horizon has <15 % total clay in the fine earth fraction, the argillic horizon must contain at least 3% more clay.
 - b. if the overlying horizon has 15 % or > but < 40 % total clay in the fine earth fraction, the ratio of clay in the horizon to that in the overlying horizon must be 1.2 or more.

- c. if the overlying horizon has 40 % or > total clay in the fine earth fraction, the argillic B-horizon must contain at least 8% more clay.
- v. the argillic horizon must be at least one tenth of the thickness of the sum of all overlying horizons.
- vi. presence of clay skins (cutans)

2. NATRIC HORIZON

- i. this horizon meets all the requirements of the argillic horizon.
- ii. moreover it has a prismatic or columnar structure and ESP = or > 15 % .

1. SPODIC HORIZON

- i. this is subsurface horizon with illuvial accumulation of OM with Fe and /or Al.
- ii. it has a subhorizon > 2.5 cm thick that is continuously cemented by some combinations of OM, Al, Fe
- iii. there are many specific limitations dealing with Al, Fe, OM and clay ratios.
- iv. its particle size class is sandy or coarse loamy

2. AGRIC HORIZON

- i. this horizon is formed directly under the plow layer.
- ii. it has illuvial clay, silt and humus accumulated in worm channels, root channels or ped surfaces as in-fillings or as thick, dark lamellae to the extent that they occupy at least 15% of the soil volume.
- iii. the in-fillings or lamellae are always with colour values and chromas lower than those of the soil matrix.

5. CAMBIC HORIZON

- i. this is an altered horizon lacking properties that meet the requirements of an argillic, natric or spodic horizon, having the following properties:
- ii. has a texture of sandy loam or finer and has at least 8 % clay in the fine earth fraction.
- iii. it is at least 15 thick.
- iv. soil structure is only moderately developed
- v. shows evidence of alteration in one of the following forms:
 - stronger (=higher) chroma, redder hue, or higher clay content than the underlying horizon,
 - evidence of removal of carbonates.

3. KANDIC HORIZON

- i. this is a subsurface horizon enriched with clay just like the argillic horizon.
- ii. it is rich in kandite group of clay minerals e.g. kaolinite.
- iii. it has a CEC = 16 or < cmol(+)/kg clay or an effective cation exchange capacity ECEC) = 12 or < cmol(+)/kg clay (ECEC= sum of bases extracted with 1N NH₄OAc pH 7 + 1N KCl extractable Al).
- iv. it is at least 30 cm thick.
- v. it has a texture of loamy very fine sand or finer.
- vi. it underlies a coarser textured surface horizon.
- vii. clay skins may or may not be present.

7. OXIC HORIZON

This is a subsurface horizon that has the following properties:

- i. has a texture that is sandy loam or finer and has at least 8 % clay in the fine earth fraction.
- ii. it is at least 30 cm thick.

- iii. it is highly weathered and dominated by 1:1 silicate clay minerals and sesquioxides.
- iv. has a CEC of the fine earth fraction = or < 16 cmol(+)/kg clay, or has an effective cation exchange capacity (ECEC) of the fine earth fraction = or < 12 cmol(+)/kg clay.
- v. has < 10 % weatherable minerals in the 50-200 µm fraction.
- vi. has < 10 % water-dispersible clay
- vii. has a silt-clay ratio which is = or < 0.2.
- viii. has < 5 % by volume showing rock structure.

8. ALBIC HORIZON

- i. this is typically an eluvial horizon, with certain colour limitations; colour values = 5 or > dry, or = 4 or > moist.
- ii. it is generally white due to loss of clay, OM and free Fe oxides.
- iii. it is normally underlain by a spodic, argillic or natric horizon.

9. FRAGIPAN

- i. this is a subsoil layer of high bulk density, brittle when moist, and very hard when dry.
- ii. it is very low in organic matter content.
- iii. the texture is commonly loamy.

1. CALCIC HORIZON

- i. this is a layer of secondary accumulations of carbonates, usually of Ca and Mg, having 15% or > CaCO₃ equivalent.
- ii. it contains at least 5% more carbonate than an underlying layer.
- iii. it is 15 cm or > thick.

2. GYPSIC HORIZON

- i. this is a horizon of calcium sulphate (gypsum) enrichment.
- ii. it contains at least 5% more calcium sulphate than underlying material.
- iii. it is 15 cm or > thick.
- iv. the product of thickness in cm and % gypsum = 150 or >.

12. PETROCALCIC HORIZON

- i. this is an indurated calcic horizon.
- ii. it has a hardness of 3 or > (Mohs' scale of hardness).
- iii. at least half of it breaks in acid, but does not break in water.

13. PETROGYPSIC HORIZON

- i. this is an indurated gypsic horizon.
- ii. it is hard to the extent that dry fragments do not slake in water and roots cannot enter.

14. PLINTHITE

- i. this is a sesquioxide-rich, humus-poor horizon which hardens irreversibly to ironstone hardpan or aggregates with repeated wetting and drying.
- ii. it commonly occurs as dark red mottles.
- iii. it generally forms in areas which are saturated with water at some season.

15. DURIPAN

- i. this is a silica-cemented subsurface horizon.
- ii. cementation is strong enough that dry fragments do not slake in water.
- iii. has coatings of silica which are insoluble in 1N HCl even after prolonged soaking, but soluble in hot concentrated KOH.

16. SALIC HORIZON

- i. this is a horizon of secondary accumulation of soluble salts (salts more soluble in cold water than gypsum).
- ii. it is 15 cm or > thick.
- iii. it contains at least 2% salt.
- iv. the product of its thickness in cm and salt % by weight = 60 or >.

17. SOMBRIC HORIZON

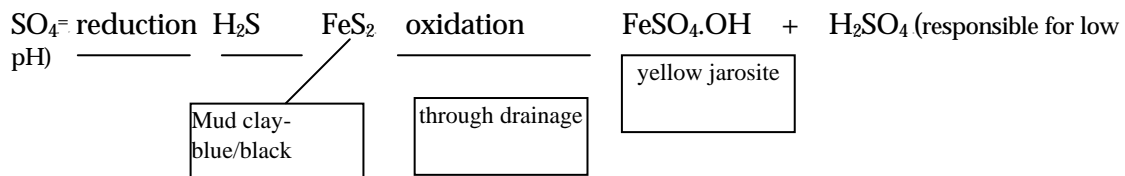
- i. this is a subsurface horizon of mineral soils formed under free drainage.
- ii. it contains illuvial humus that is neither associated with Al as the humus in the spodic horizon, nor dispersed by sodium as is common in the natric horizon.
- iii. does not have the high CEC of a spodic horizon relative to clay, and does not have the high BS of a natric horizon.
- iv. it does not underlie an albic horizon.

18. PLACIC HORIZON

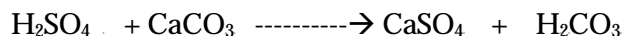
- i. this is a thin cemented pan.
- ii. it is cemented by iron, or by iron and manganese, or by an iron-OM complex.
- iii. it has black to dark reddish colour.
- iv. its thickness generally ranges from 2 to 10 mm.
- v. it is a barrier to water and roots.

19. SULFURIC HORIZON

- i. this is a horizon composed either of mineral or organic material that has both a pH < 3.5 (ratio 1:1 in water) and jarosite mottles the colour of which has a hue of 2.5Y or yellower and chroma = 6 or >.
- ii. it forms as a result of artificial drainage and oxidation of sulfide-rich mineral or organic material as shown below:



- iii. the sulfuric acid so produced brings down the pH to values of less than 3.5, which makes the horizon highly toxic to plants and free of living roots. If CaCO_3 is present in the soil (or is added), this neutralises to some degree the H_2SO_4 so that the pH is not too acidic.



OTHER DIAGNOSTIC SOIL CHARACTERISTICS

1. ABRUPT TEXTURAL CHANGE

- i. this is a change from an ochric epipedon or an albic horizon to an argillic horizon.
- ii. there is in the zone of contact, a very appreciable increase in clay content within a very short distance in depth as follows:
 - if % clay in the ochric/albic horizon is < 20, then it should double in the argillic.
 - if % clay in the ochric/albic horizon = 20 or >, the increase in clay content should be at least 20%, for example from 22 to 42%.

2. DURINODES

- i. these are weakly cemented to indurated nodules whose main cement is SiO₂ presumably opal and microcrystalline forms of silica.
- ii. it breaks down in hot concentrated KOH after treatment with HCl to remove carbonates, but it does not break down in hot concentrated HCl alone.

3. GILGAI

- i. this is the microrelief that is typical of clayey soils that have a high coefficient of expansion with changes in moisture content and also have distinct seasonal changes in moisture content.
- ii. the microrelief consists of a succession of enclosed microbasins and microknolls in nearly level areas, or of microvalleys and microridges that run up and down the slope.
- iii. the height of the microridges commonly ranges from a few centimeters to 1 metre.

4. COEFFICIENT OF LINEAR EXTENSIBILITY (COLE)

- i. this is ratio of the difference between the moist length and dry length of a clod* to its dry length.
- ii. it can be presented as: $COLE = (L_m - L_d) / L_d$ where L_m is the length at 1/3 bar tension, and L_d the length when dry.
- iii. when $COLE > 0.09$, significant swell-shrink activity can be expected; when $COLE > 0.03$, significant amount of montmorillonitic clay is expected.

*clod: is a compact, coherent mass of soil produced artificially by man through plowing or digging, especially when these operations are done on soils that are too wet or too dry for normal tillage operations.

5. POTENTIAL LINEAR EXTENSIBILITY

This characteristic is the sum of the products, for each horizon, of the thickness of the horizon in centimeters and the COLE of the horizon over a specified soil profile depth.

6. SLICKENSIDES

- i. these are polished and grooved surfaces that are produced by one soil mass moving past another.
- ii. slickesides are very common in soils rich in swelling clays.

7. n-VALUE

- i. this refers to the relationship between the percentage of water under field conditions and the percentage of clay and humus.
- ii. it can be presented as: $n\text{-value} = (A - 0.2R) / (L + 3H)$ where A is the % water in the soil under field conditions calculated on a dry soil basis; R is the % silt plus sand; L is the % clay and H is the % OM.
- iii. the value is helpful in predicting whether the soil may be grazed by livestock or will support other loads, and the degree of subsidence that would occur after drainage.
- iv. the critical value is $n\text{-value} = 0.7$; greater values imply problems (low/poor carrying capacity).

8. SOFT POWDERY LIME

- i. soft powdery lime is used in the definition of a number of taxa.
- ii. it refers to translocated lime, which is soft enough to be cut readily with fingernail, that was precipitated in place from soil solution rather than inherited from soil parent material.

9. LITHIC CONTACT

This is a boundary between soil and continuous coherent material, with a hardness = 3 or > (Mohs' scale).

10. PARALITHIC (lithic-like) CONTACT

This is a boundary between soil and continuous coherent material, with a hardness < 3 (Mohs' scale).

11. PERMAFROST

This is a continuously frozen layer.

12. LIMNIC MATERIALS

- i. these are organic or inorganic materials deposited in water by the action of aquatic organisms or derived from underwater and floating organisms.
- ii. marl (soft loose CaCO_3 usually mixed with clay and other impurities) and sedimentary peat are limnic materials.

13. PETROFERRIC CONTACT

This is a boundary between soil and a continuous layer of indurated material in which iron in an important cement and organic matter is absent or is present only in traces.

14. SOIL MOISTURE REGIMES

The soil moisture regime as the term is used here, refers to the presence or absence either of ground water or of water held at a tension < 1500 kPa in the soil or in specific horizons. Using climatic data on rainfall, it is possible to estimate the soil moisture regime (SMR). However, careful field and laboratory experimentation during different seasons may be necessary. The following classes of soil moisture regimes are recognised in the Soil Taxonomy:

(a) *Aquic SMR*: The soil must be partly or wholly saturated with water for at least some days during a year. This implies a reducing regime that is virtually free of dissolved oxygen.

(b) *Aridic and torric SMRs*: In most years the soil is dry in all parts more than half the time (cumulative) when the soil temperature at a depth of 50 cm is > 5°C; the soil is never moist in some or all parts for as long as 90 consecutive days when the soil temperature at a depth of 50 cm is above 8°C. Soils with aridic or torric SMR are normally found in arid climates. A few are in semi-arid climates. There is little or no leaching in these moisture regimes.

(c) *Udic SMR*: The soil is not dry in any part for as long as 90 cumulative days. Extreme wet regime is called *perudic*.

(d) *Ustic SMR*: This moisture regime is intermediate between the aridic and udic regime. It describes a condition of limited water, but soil water is present at a time when conditions are suitable for plant growth.

(e) *Xeric SMR*: This is typical of Mediterranean climates, where winters are moist and cool and summers are dry and warm. The soil is dry in all parts for 45 or more consecutive days within the 4 months that follow the *summer solstice (i.e. July, August, September, October). It is moist in all parts for 45 or more consecutive days within the 4 months that follow the *winter solstice (i.e. January, February, March, April).

**Summer solstice*: the time when the sun is farthest N of the Equator. This is on 21st June.

**Winter solstice*: the time when the sun is farthest S of the Equator. This is on 22nd December.

15. SOIL TEMPERATURE REGIMES

Soil temperature regimes are also used to classify soils. Mean atmospheric temperatures are obtained to estimate the soil temperature regime (STR). Mean annual air temperature, mean summer and mean winter temperatures have to be determined; and these are ultimately used to estimate the mean annual soil temperature (MAST). The following classes of soil temperature regimes are recognised in the Soil Taxonomy:

- (a) *Pergelic STR*: (Meaning permanent frost). MAST < 0°C.
- (b) *Cryic STR*: (Meaning very cold soils). MAST > 0°C < 8°C.
- (c) *Frigid STR*: The soil is warmer in summer than one in the cryic regime, but its MAST < 8°C.
- (d) *Mesic STR*: The MAST =or> 8°C but < 15°C.
- (e) *Thermic STR*: MAST =or> 15°C but < 22°C
- (f) *Hyperthermic STR*: MAST =or> 22°C

If the name of a soil temperature regime has a prefix "*iso*" e.g. isomesic, isothermic etc. the mean summer and winter temperatures differ by < 5°C at a depth of 50 cm or at a lithic or paralithic contact, whichever is shallower.

16. WEATHERABLE MINERALS

Minerals that are included in the meaning of weatherable minerals are the following:

- i. clay minerals: all 2:1 lattice clays except Al-interlayered chlorite. Sepiolite, talc and glauconite are also included in the meaning of this group of weatherable minerals, although they are not everywhere of clay size.
- ii. Silt- and sand-size minerals (0.02 – 0.2 mm in diameter): feldspars, ferromagnesian minerals, micas and apatite are examples.

17. TONGUING OF ALBIC MATERIALS

Tongues of albic materials consist of penetrations of bleached material that has the colour of an albic horizon into an argillic horizon or a natric horizon, along ped surfaces if peds are present. The orientation of the tongues is vertical only.

18. INTERFINGERING OF ALBIC MATERIALS

Consist of penetrations of albic materials into underlying argillic horizon or a natric horizon, along ped faces, primarily in vertical sense but to a lesser degree along horizontal faces

DIAGNOSTIC FEATURES OF ORGANIC SOILS

The definitions of these features are based on the degree of decomposition of the organic material as measured by organic fibre content and colour of Na-pyrophosphate extracts. The fibre content decreases with increased degree of decomposition. The organic matter – Na-pyrophosphate extracts become darker with increased degree of decomposition.

On the basis of fibre content and colour of Na-pyrophosphate extracts, three types of organic materials are recognised:

i. FIBRIC MATERIALS

In rubbed condition, fibres compose $\frac{3}{4}$ or more of the soil volume, or the fibre content in a rubbed condition is $\frac{2}{5}$ or more of soil volume and the material yields almost clear solution when extracted in Na-pyrophosphate. This situation represents least degree of decomposition. Fibric materials were formerly called peat.

ii. SAPRIC MATERIALS

In a rubbed condition, the fibre content is less than $\frac{1}{6}$ of the soil volume and the material yields Na-pyrophosphate extracts with colours lower in value and higher in chroma than 10YR 7/3. They have the smallest amount of plant fibre, the highest BD and the lowest water content (on dry weight basis). Sapric materials were formerly called muck.

iii. HEMIC MATERIALS

These materials represent intermediate degree of decomposition between the less decomposed fibric stage and the more decomposed sapric stage. They have morphological features that give intermediate values between the fibric and sapric materials. Hemic materials were formerly called peaty muck or mucky peat.

SIMPLIFIED KEY TO SOIL ORDERS (USDA SOIL TAXONOMY)

1. Soils containing high OC content (at least 12% OC or 18% OC depending on clay content) and do not have andic properties in layers 35 cm or more thick within 60 cm from the surface

HISTOSOLS

2. Other soils developed in volcanic ejecta having a melanic epipedon; or having andic properties throughout subhorizons which have a cumulative thickness of 35 cm or more within 60 cm from the surface

ANDISOLS

3. Other soils that have either a spodic horizon whose upper boundary is within 200 cm from the surface or a placic horizon that meets all requirements of spodic horizon except thickness and index of accumulation of amorphous material

SPODOSOLS

4. Other soils that have an oxic horizon with its upper boundary within 150 cm from the soil surface and do not have properties characteristic of kandic horizon within a depth of 150 cm

OXISOLS

5. Other soils that do not have lithic or paralithic contact, petrocalcic horizon or duripan within 50 cm from the surface; having 30% clay or more in all subhorizons to a depth of 50 cm or more and having at some time in most years open cracks (at least 1 cm wide) at 50 cm that extend upward to the surface and having one or more of the following: gilgai microrelief, slickensides, or wedge-shaped aggregates

VERTISOLS

6. Other soils that are dry more than 50% of the year (aridic SMR) and have an ochric or an anthropic epipedon and either have salic horizon whose upper boundary is within 75 cm from the surface; or have one or more of the following horizons whose upper boundary is within 100 cm from the surface: calcic, petrocalcic, gypsic, petrogypsic, cambic or duripan

ARIDISOLS

7. Other soils that have a mesic, isomesic or warmer STR and have one of the following combinations of characteristics:

- . have an argillic or kandic horizon but not a fragipan and have a BS by sum of cations (pH 8.2) of < 35%
- . have a fragipan that meets all requirements of an argillic or kandic horizon and a BS by sum of cations (pH 8.2) of < 35%

ULTISOLS

8. Other soils that have a mollic epipedon or a surface horizon that meets all requirements of mollic except thickness, and have a BS (NH₄OAc pH 7.0) of 50% or more

MOLLISOLS

9. Other soils that have either an argillic, kandic or natric horizon but no fragipan or have fragipan that meets all requirements of argillic or kandic or has clay skins more than 1 mm thick in some part

ALFISOLS

10. Other soils that have no sulfidic materials within 50 cm from the surface, and have one or more of the following: an umbric, mollic or plaggen epipedon or a cambic horizon or SAR of 13 or more

INCEPTISOLS

11. Other soils that have either a permafrost within 100 cm of the soil surface ; or gelic materials within 100 cm of the soil surface and a permafrost within 200 cm of the soil surface

GELISOLS

Other soils

ENTISOLS

----- **SUBORDERS OF THE USDA SOIL TAXONOMY**

There are 56 suborders according to the USDA Soil Taxonomy. A brief description of the taxa is given below.

<u>ORDER</u>	<u>SUBORDERS</u>
Entisols	<p><u>Aquents</u>: with aquic soil moisture regime (SMR); permanently or seasonally wet and even if artificially drained, they display bluish gray (gleyed) or very mottled horizons.</p> <p><u>Arents</u>: exhibit fragments of diagnostic horizons below the Ap horizon due to deep plowing.</p> <p><u>Fluvents</u>: alluvial soils with very simple profiles having irregular change of OM content with depth, and stratification is common.</p> <p><u>Psamments</u>: have textures of loamy fine sand or coarser.</p> <p><u>Orthents</u>: loamy and clayey Entisols with regular decrease in OM with depth.</p>
Vertisols	<p><u>Torrerts</u>: with torric SMR; usually dry in all parts of the solum and the cracks are open the whole year to the surface in most years unless irrigated; or they are closed for less than 60 consecutive days.</p> <p><u>Usterts</u>: with ustic SMR, the cracks open and close more than once a year but remain open for a total of 90 or more days a year.</p> <p><u>Xererts</u>: with xeric SMR; the cracks open and close once a year and remain open for 60 or more consecutive days a year.</p> <p><u>Uderts</u>: with udic SMR; usually moist, but cracks open at some time during the year but do not remain open for as long as 90 cumulative days.</p>

Inceptisols	<p><u>Aquepts</u>: with aquic SMR; saturated with water at some period in the year unless artificially drained.</p> <p><u>Plaggepts</u>: have plaggen epipedon.</p> <p><u>Tropepts</u>: Inceptisols of the tropical regions. They have isomesic or warmer iso- temperature regime.</p> <p><u>Ochrepts</u>: with ochric epipedon; or with umbric or mollic epipedon that is less than 25 cm thick and have mesic or warmer STR.</p> <p><u>Umbrepts</u>: other Inceptisols.</p>
Aridisols	<p><u>Argids</u>: with argillic horizon.</p> <p><u>Orthids</u>: without argillic horizon.</p>
Mollisols	<p><u>Albolls</u>: have albic horizon under the mollic; may have argillic or natric horizon.</p> <p><u>Aquolls</u>: with aquic SMR; show characteristics of wetness.</p> <p><u>Borolls</u>: have mean annual soil temperature (MAST) of less than 8°C.</p> <p><u>Rendolls</u>: have epipedons that are less than 50 cm thick and overly coarse fragments of calcareous rocks and stones.</p> <p><u>Udolls</u>: with udic SMR; not dry for as long as 90 cumulative day per year or 60 consecutive days per year.</p> <p><u>Ustolls</u>: with ustic SMR; are dry for more than 90 cumulative days per year, but not as long as 60 consecutive days per year.</p> <p><u>Xerolls</u>: with xeric SMR; are dry for more than 60 consecutive days per year in most years.</p>
Spodosols	<p><u>Aquods</u>: with aquic SMR; commonly saturated with water, or if artificially drained, display evidences of former wetness.</p> <p><u>Ferrod</u>: have more than six times as much Fe as C in the spodic horizon.</p> <p><u>Humods</u>: have spodic horizon containing dispersed OM and Al but little Fe (less than 0.5% of the fine earth).</p> <p><u>Orthods</u>: have in the spodic horizon a content of Fe not more than six times that of C.</p>
Alfisols	<p><u>Aqualfs</u>: with aquic SMR; are seasonally water saturated, or if artificially drained, display evidence of former wetness such as mottles, low chromas and Fe-Mn concretions.</p> <p><u>Boralfs</u>: are cool with MAST of less than 8°C (and commonly exhibit an albic horizon that tongues into the argillic or natric horizon).</p> <p><u>Udalfs</u>: have a udic SMR and mesic or warmer soil temperature regime (STR).</p> <p><u>Ustalfs</u>: have ustic SMR; are dry for less than 60 consecutive days per year, and commonly have a carbonate accumulation at the base of the solum.</p> <p><u>Xeralfs</u>: have xeric SMR; are dry for more than 60 consecutive days per year.</p>
Ultisols	<p><u>Aquults</u>: with aquic SMR; are either saturated with water at some period of the year or are artificially drained and display evidence of former wetness as shown by presence of mottles, Fe-Mn concretions or low chromas.</p> <p><u>Ustults</u>: with ustic SMR; are dry for 90 or more cumulative days per year in most years.</p> <p><u>Xerults</u>: with xeric SMR; are in areas of prolonged dry season, MAST is</p>

less than 22°C. OM content is low and the soils are dry for 60 or more consecutive days per year.

Humults: have high OM content. By definition they contain more than 0.9% OC in the upper 15 cm of the argillic horizon or have over 12 kg of OM in a cubic metre of the upper 1 metre of the soil excluding an O horizon.

Udults: have udic SMR; are of humid regions where dry periods are of short duration; OM content is low.

- Oxisols** Aquox: with aquic SMR; are either saturated with water during some period of the year, or are artificially drained and have an oxic horizon with characteristics associated with wetness.
Torrox: with torric/aridic SMR.
Ustox: have ustic SMR.
Perox: have perudic SMR.
Udox: other Oxisols (with udic SMR).
- Histosols** Folists: with accumulation of organic soil materials mainly as forest litter.
Fibrists: have fibric material dominant.
Hemists: have hemic material dominant.
Saprists: have sapric material dominant.
- Andisols** Aquands: with aquic SMR
Cryands: with cryic or pergelic STR.
Torrands: with torric/aridic SMR.
Xerands: with xeric SMR.
Vitrands: dominated by vitric (glassy/amorphous) materials.
Ustands: with ustic SMR.
Udands: with udic SMR.
- Gelisols** Histels: with large amounts of OC that accumulates under anaerobic conditions
Turbels: with one or more horizons showing cryoturbation in the form of irregular, broken or distorted horizon boundaries
Orthels: other Gelisols

THE FAO-UNESCO SOIL CLASSIFICATION SYSTEM

This system of classification was established to assist in the preparation of the Soil Map of the World at a scale of 1:5 000 000. The first version of the classification was published in 1974 (FAO-UNESCO, 1974) and a revised edition was produced in 1988 (FAO UNESCO, 1988). The two versions are slightly different in that some names of the old system have been dropped and some new ones have been introduced in the new version. The objectives of preparing the Soil Map of the World were to:

- i. make a first appraisal of the world's soil resources,
- ii. supply a scientific basis for the transfer of experience between areas with similar environments,
- iii. promote the establishment of a generally accepted soil classification and nomenclature,
- iv. establish a common framework for more detailed investigations in developing areas,

- v. serve as a basic document for educational, research, and development activities, and
- vi. strengthen international contacts in the field of soil science.

The FAO-Unesco classification system is basically a bi-categorical system i.e. with two levels of classification. The two levels are level-1 soil names, and level-2 soil names. Like in the USDA Soil Taxonomy, this system of classification makes use of diagnostic horizons and properties to give names to soils. Apparently most of the diagnostic features used in this system are derived from those of the USDA and have been modified and simplified to suit the purposes of the classification scheme. The salic, the sombric, and the agric horizons of the USDA Soil Taxonomy have not been used as diagnostic horizons. The duripan, fragipan and the placic horizon are used as phases. Most soil names end with *-sol(s)* and this is connected with formative elements which indicate some properties of the soils.

According to the revised edition of the legend of the Soil Map of the World (FAO, 1988) there are now 28 level-1 soil units and 153 level-2 soil units. Phases are also used in this classification to include features of the land which are significant to its use and management. Phases usually cut across soil boundaries and hence have not been used to define individual soil units. 16 phases are recognized in the FAO (1988) version.

SUMMARY OF DIAGNOSTIC HORIZONS (see FAO-UNESCO Classification Handbook and USDA Soil Taxonomy for full definitions)

<u>DIAGNOSTIC HORIZONS</u>	<u>MOST PROMINENT FEATURES</u>
histic H - horizon	peaty surface soil of 20 to 40 cm depth; in some cases till 60 cm.
mollic A - horizon	surface horizon with dark colour due to organic matter; base saturation = or >50%.
umbric A - horizon	similar to a mollic A - horizon but base saturation < 50%.
fimic A - horizon	man-made surface layer, 50 cm or more thick, produced by long-continued manuring.
ochric A - horizon	surface horizon without stratification and lacking the characteristics of a histic H - horizon, or a mollic, umbric or fimic A - horizon.
albic E - horizon	bleached eluviation horizon with the colour of uncoated primary soil material, usually overlying an illuviation horizon.
argic B - horizon	clay accumulation horizon lacking properties of a natric B - horizon and/or a ferralic B - horizon.
natric B - horizon	clay accumulation horizon with more than 15 percent exchangeable sodium, usually with a columnar or prismatic structure.
spodic B - horizon	horizon with illuviation of organic matter with iron or aluminium or with both.
ferralic B - horizon	highly weathered horizon, at least 30 cm thick, with a cation exchange capacity = or < 16 cmol(+)/kg clay.
cambic B - horizon	genetically young B - horizon (therefore not meeting the criteria for argic, natric, spodic or ferralic B - horizons) showing evidence of alteration: modified colour, removal of carbonates or presence of soil

calcic horizon	structure. horizon with distinct calcium carbonate enrichment.
gypsic horizon	horizon with distinct calcium sulphate enrichment.
petrocalcic horizon	a continuous cemented or indurated calcic horizon.
petrogypsic horizon	a gypsic horizon hardened to the extent that dry fragments do not slake in water and roots cannot enter.
sulfuric horizon	horizon of at least 15 cm thick, having jarosite mottles and $\text{pH}(\text{H}_2\text{O}, 1: 1) < 3.5$.

OTHER DIAGNOSTIC PROPERTIES AND FEATUTES (see FAO-UNESCO Classification Handbook and USDA Soil Taxonomy for full definitions)

<u>DIAGNOSTIC PROPERTIES</u>	<u>MOST PROMINENT FEATURES</u>
andic properties	refer to largely volcanic material; normally high in extractable aluminium.
ferralic properties	mark a cation exchange capacity (by 1M NH_4OAc at pH 7.0) of $< 24 \text{ cmol}(+)/\text{kg}$ clay in Cambisols and Arenosols.
ferric properties	mark the presence of Fe - enriched mottles or nodules in Alisols, Lixisols and Acrisols.
fluvic properties	mark ongoing sedimentation or stratification or an irregular organic carbon profile in recent alluvial deposits.
geric properties	mark soil materials having $1.5 \text{ cmol}(+)/\text{kg}$ soil or $<$ of extractable bases plus aluminium and a $\text{pH}(1\text{M KCl}) =$ or > 5.0 ; or having a delta-pH (pH KCl minus $\text{pH H}_2\text{O}$) of $+0.1$ or more.
gleytic and stagnic properties	present visible evidence of prolonged waterlogging either by shallow groundwater (gleytic properties) or by a perched water table (stagnic properties).
nitic properties	mark a moderate to strong angular blocky elements, showing shiny ped faces.
salic properties	mark an electrical conductivity of the saturation extract of more than $15 \text{ dS}/\text{m}$, or of more than $4 \text{ dS}/\text{m}$ if the $\text{pH}(\text{H}_2\text{O}, 1:1)$ exceeds 8.5.
sodic properties	mark high saturation of the exchange complex by sodium (15 percent or more).
vertic properties	mark cracks, slickensides, wedge - shaped structural aggregates that are not in a combination, or are not sufficiently expressed for the soil to qualify as a Vertisol.
abrupt textural	mark a doubling of the clay content or an increase of the clay content by 20 percent, over a short distance in a soil profile.
calcareous	refers to soil material which shows strong effervescence in contact with HCl and/or having more than 2 percent of CaCO_3 - equivalent.
continuous hard rock	material which is sufficiently coherent and hard when moist to make digging with a spade impracticable.
interfingering	narrow penetrations of an albic E - horizon into an

	underlying argic or natric B- horizon along mainly vertical ped faces and to some extent in horizontal direction.
gypsiferous	Refers to soil material which contains 5% or more gypsum.
organic soil materials	water-saturated soil materials (unless drained) having 18% or > organic carbon if having 60% or > clay, or having 12% or > organic carbon if without clay; or having a proportional carbon content if the clay content is between 0 and 60%percent; or soil materials that are never saturated for more than a few days having 20% or > organic carbon.
permafrost	the condition of soil temperatures being perennially at or below °C.
plinthite	an iron - rich, humus - poor mixture of clay and quartz that hardens irreversibly on drying.
slickensides	polished and grooved surfaces that are produced by one soil mass sliding past another.
smearly consistence	a consistence which changes under pressure and returns to the original state after the pressure is released ('thixotropic' materials in Andosols).
soft powdery lime	calcium carbonate which changes under precipitated in situ and soft enough to be cut with a finger nail.
strongly humic	refers to soil materials having more than 1.4 % organic carbon as a weighted average over a depth of 100 cm from the surface.
sulfidic materials	waterlogged mineral or organic soil material containing 0.75% or > sulfur and less than three times as much carbonates as sulfur.
tonguing	relatively wide penetrations of an albic E - horizon into an underlying argic or natric B - horizon along vertical ped faces.
Weatherable minerals	minerals that release plant nutrients and iron or aluminium by weathering

FORMATIVE ELEMENTS USED FOR NAMING MAJOR SOIL GROUPINGS (LEVEL-1)

There are 28 level-1 soil names:

ACRISOLS: from L. *acer*, *acetum*, strong acid; connotative of soils with low base saturation.

ALISOLS: from L. *alumer*; connotative of soils with high aluminum content.

ANDOSOLS: from Japanese *an*, dark, *do*, soil; connotative of soils formed from materials rich in volcanic glass, commonly having a dark surface horizon.

ANTHROSOLS: from Gr. *anthropos*, man; connotative of soils formed from human activities.

ARENOSOLS: from L. *arena*, sand; connotative of weakly developed coarse textured soils.

CALCISOLS: from L. *calcis*, lime; connotative of soils with accumulation of calcium carbonate.

CAMBISOLS: from L. *cambiare*, to change; connotative of soils showing some pedogenic development as evidenced from changes in colour, structure and consistence.

CHERNOZEMS: from Russian, *chern*, black and *zemlja*, earth; connotative of soils rich in organic matter having a black colour.

FERRALSOLS: from L. *ferrum*, iron, *alumen*, aluminium; connotative of soils rich in sesquioxides.

FLUVISOLS: from L. *fluvius*, river; connotative of soils formed from alluvial deposits.

GLEYSOLS: from Russian *gley*, mucky soil mass; connotative of soils with an excess of water.

GREYZEMS: from English *grey*, and Russian *zemlja*, earth; connotative of soils with with

uncoated silt and quartz grains which are present in layers rich in organic matter.

GYPSISOLS: from L. *gypsum*, gypsum; connotative of soils with accumulation of calcium sulphate.

HISTOSOLS: from Gr. *histos*, tissue; connotative of soils with fresh or partly decomposed organic material.

KASTANOZEMS: from L. *castanea*, chestnut, and from Russian *zemlja*, earth, land; connotative of soils rich in organic matter having a brown or chestnut colour.

LEPTOSOLS: from Gr. *leptos*, thin; connotative of weakly developed shallow soils.

LIXISOLS: from L. *lixivia*, washing; connotative of soils with accumulation of clay and strong weathering.

LUVISOLS: from L. *luere*, to wash; connotative of soils with accumulation of clay.

NITISOLS: from L. *nitidus*, shiny; connotative of soils with shiny ped faces.

PHAEZEMS: from Gr. *phaios*, dusky and Russian *zemlja*, earth, land; connotative of soils rich in organic matter having a dark colour.

PLANOSOLS: from L. *planus*, flat, level; connotative of soils generally developed in level or depressed relief with seasonal surface waterlogging.

PLINTHOSOLS: from Gr. *plinthos*, brick; connotative of soils with mottled clayey materials which harden upon exposure.

PODZOLS: from Russian *pod*, under, and *zola*, ash; connotative of soils with strongly bleached horizon.

PODZOLUVISOLS: from Podzols and Luvisols.

REGOSOLS: from Gr. *rhegos*, blanket; connotative of soils with a mantle of loose material overlying the hard core of the earth.

OLONCHAKS: from Russian *sol*, salt, *chak*, area; connotative of salty area.

OLONETZ: from Russian *sol*, salt, and *etz*, strongly expressed; connotative of salty soils (with high exchangeable sodium percent).

VERTISOLS: from L. *vertere*, to turn; connotative of soils with swelling clays in which there is turnover of surface materials.

SIMPLIFIED KEY TO THE MAJOR SOIL GROUPINGS (FAO-UNESCO)

Soils having an H-horizon, or an O-horizon of 40 cm or more (60 cm or more if the organic material consists mainly of sphagnum or moss or has a bulk density of less than 0.1 Mg/m³); the thickness of the H- or O-horizon may be less if it rests on rocks or on fragmented material of which the interstices are filled with organic matter:

HISTOSOLS (HS)

Other soils in which human activities resulted in profound modification of the original soil characteristics:

ANTHROSOLS (AT)

Other soils which are limited in depth by continuous hard rock or highly calcareous materials or a continuous cemented layer within 30 cm of the surface; having no diagnostic horizons other than a mollic, umbric, or ochric A- horizon with or without a cambic B-horizon:

LEPTOSOLS (LP)

Other soils having, after the upper 20 cm have been mixed, 30 percent or more clay in all

horizons to a depth of at least 50 cm; developing cracks from the soil surface downward which at some period in most years (unless the soil is irrigated) are at least 1 cm wide to a depth of 50 cm; having one or more of the following: intersecting slickensides or wedge-shaped or paralleliped structural aggregates at some depth between 25 and 100 cm from the surface:

VERTISOLS (VR)

Other soils showing fluvic properties and having no diagnostic horizons other than an ochric, a mollic, or an umbric A-horizon, or a histic H-horizon, or a sulfuric horizon, or sulfidic material within 125 cm of the surface:

FLUVISOLS (FL)

Other soils showing salic properties and having no diagnostic horizons other than an A-horizon, a histic H-horizon, a cambic B-horizon, a calcic or a gypsic horizon:

SOLONCHAKS (SC)

Other soils showing gleyic properties within 50 cm of the surface; having no diagnostic horizons other than an A-horizon, a histic H-horizon, a cambic B-horizon, a calcic or a gypsic horizon; lacking plinthite within 125 cm of the surface:

GLEYSOLS (GL)

Other soils showing andic properties to a depth of 35 cm or more from the surface and having a mollic or an umbric A-horizon possibly overlying a cambic B-horizon, or an ochric A-horizon and a cambic B-horizon; having no other diagnostic horizons:

ANDOSOLS (AN)

Other soils which are coarser than sandy loam to a depth of at least 100 cm from the surface, having no diagnostic horizons other than an ochric A-horizon or an albic E-horizon:

ARENOSOLS (AR)

Other soils having no diagnostic horizons other than an ochric or umbric A-horizon:

REGOSOLS (RG)

Other soils having a spodic B-horizon:

PODZOLS (PZ)

Other soils having 25 percent or more plinthite by volume in a horizon which is at least 15 cm thick within 50 cm of the surface or within a depth of 125 cm if underlying an albic E-horizon:

PLINTHOSOLS (PT)

Other soils having a ferralic B-horizon:

FERRALSOLS (FR)

Other soils having an E-horizon showing stagnic properties at least in part of the horizon and abruptly overlying a slowly permeable horizon within 125 cm of the surface, exclusive of a natric or a spodic B-horizon:

PLANOSOLS (PL)

Other soils having a natric B-horizon:

SOLONETZ (SN)

Other soils having a mollic A-horizon with a moist chroma of 2 or less to a depth of at least 15 cm, showing uncoated silt and quartz grains on structural ped surfaces; having an argic B-horizon:

GREYZEMS (GR)

Other soils having mollic A-horizon with a moist chroma of 2 or less to a depth of at least 15 cm; having a calcic horizon, or concentrations of soft powdery lime within 125 cm of the surface, or both:

CHERNOZEMS (CH)

Other soils having a mollic A-horizon with a moist chroma of more than 2 to a depth of at least 15 cm; having one or more of the following; a calcic or gypsic horizon, or concentrations of soft powdery lime within 125 cm of the surface:

KASTANOZEMS (KS)

Other soils having a mollic A-horizon: having a base saturation (by 1M NH₄OAc method at pH 7.0) of 50 percent or more throughout the upper 125 cm of the soils:

PHAEZEMS (PH)

Other soils having an argic B-horizon showing an irregular or broken upper boundary resulting from deep tonguing of the E-horizon into the B-horizon:

PODZOLUVISOLS (PD)

Other soils having a gypsic or a petrogypsic horizon within 125 cm of the surface: having no diagnostic horizons other than an ochric A-horizon, a cambic B-horizon or an argic B-horizon invaded by gypsum or calcium carbonate, a calcic or a petrocalcic horizon:

GYPSISOLS (GY)

Other soils having a calcic or a petrocalcic horizon, or a concentration of soft powdery lime, within 125 cm of the surface; having no diagnostic horizons other than an ochric A-horizon, a cambic B-horizon or an argic B-horizon invaded by calcium carbonate:

CALCISOLS (CL)

Other soils having an argic B-horizon with a clay distribution which does not show a relative decrease from its maximum of more than 20 percent within 150 cm of the surface; showing gradual to diffuse horizon boundaries between A- and B- horizons; having nitic properties in some subhorizon within 125 cm of the surface:

NITISOLS (NT)

Other soils having an argic B-horizon which has a cation exchange capacity equal to or more than 24 cmol(+)/kg clay and a base saturation (by 1M NH₄OAc method at pH 7.0) of less than 50 percent at least in some part of the B-horizon within 125 cm of the surface:

ALISOLS (AL)

Other soils having an argic B-horizon which has a cation exchange capacity of less than 24 cmol(+)/kg clay and a base saturation (by 1M NH₄OAc method at pH 7.0) of less than 50 percent in at least some part of the B-horizon within 125 cm of the surface:

ACRISOLS (AC)

Other soils having an argic B-horizon which has a cation exchange capacity equal to or more than 24 cmol(+)/kg clay and a base saturation (by 1M NH₄OAc method at pH 7.0) of 50 percent or more throughout the B-horizon to a depth of 125 cm:

LUVISOLS (LV)

Other soils having an argic B-horizon which has a cation exchange capacity of less than 24 cmol(+)/kg clay and a base saturation (by 1M NH₄OAc method at pH 7.0) of 50 percent or more throughout the B-horizon to a depth of 125 cm:

LIXISOLS (LX)

Other soils with cambic B-horizon

CAMBISOLS (CM)

FORMATIVE ELEMENTS USED FOR NAMING LEVEL 2 SOIL UNITS

ALBIC:	from L. albus, white, connotative of strong bleaching.
ANDIC:	from Japanese an, dark and do, soil; connotative of Andosols.
ARIC:	from L, arare, to plough; connotative of plough layer.
CALCARIC:	from L. calcarius, calcareous; connotative of the presence of calcareous material.
CALCIC:	from L. calcis, lime, connotative of accumulation of calcium carbonate
CAMBIC:	from L. cambiare, to change; connotative of change in colour, structure or consistence.
CARBIC:	from L, carbo, charcoal; connotative of high organic carbon content in spodic B horizons.
CHROMIC:	from Gr. chromos, colour, connotative of soils with bright colours.
CUMULIC:	from L. cumulare, to accumulate; connotative of accumulation of sediments.
DYSTRIC:	from Gr. dys, ill, dystrophic, infertile; connotative of low base saturation.
EUTRIC:	from Gr. eu, good, eutrophic, fertile; connotative of high base saturation.
FERRALIC:	from L. ferrum and alumen; connotative of a high content of sesquioxides.
FERRIC:	from L. ferrum, iron; connotative of ferruginous mottling or an accumulation of iron
FIBRIC:	from L. fibra, fibre; connotative of weakly decomposed organic material.
FIMIC:	from L. fimum, manure, slurry, mud; connotative of a horizon formed by long continued manuring.
FOLIC:	from L. folium, leaf; connotative of undecomposed organic material.

GELIC:	from L. gelu, frost; connotative of permafrost.
GERIC:	from Gr. geraios, old; connotative of strong weathering
GLEYIC	from Russian local name gley, mucky soil mass.
GLOSSIC:	from Gr. glossa, tongue; connotative of tonguing of a horizon into the underlying layers.
GYPsic:	from L. gypsum; connotative of an accumulation of gypsum
HAPLIC:	from Gr. haplos, simple; connotative of soils with a simple, normal horizon sequence.
HUMIC:	from L. humus, earth; rich in organic matter.
LITHIC:	from Gr. lithos, rock; connotative of very thin soils.
LUVIC:	from L. luere, to wash, 'lessiver', connotative of accumulation of clay.
MOLLIC:	from L. mollis, soft; connotative of good surface structure.
PETRIC:	from L. petra, stone; connotative of the presence of an indurated layer at shallow depth.
PLINTHIC:	from Gr. plinthos, brick; connotative of mottled clay materials which harden irreversibly upon exposure.
RENDZIC	from Polish colloquial rzedzic, connotative of noise made by plough over shallow stony soil.
RHODIC:	from Gr. rhodon, rose; connotative of red coloured soils.
SALIC:	from L. sal, salt; connotative of high salinity.
SODIC:	from L. sodium connotative of high content of exchangeable sodium.
STAGNIC:	from L. stagnare, to flood; connotative of surface waterlogging.
TERRIC:	from L. terra, earth; connotative of well decomposed and humified organic materials.
THIONIC:	from Gr. theion, sulfur, denoting the presence of sulfidic materials.
UMBRIC:	from L. umbra, shade; denoting the presence of an umbric A horizon.
URBIC:	from L. urbis, town; connotative of disposal of wastes.
VERTIC:	from L. vertere, to turn; connotative of turnover over of surface soil.
VITRIC:	from L. vitrum, glass; connotative of soils rich in vitric material.
XANTHIC:	from Gr. xanthos, yellow; connotative of yellow coloured soils.

SUMMARY OF LEVEL-1 AND LEVEL-2 SOIL UNITS

Histosols

Gelic
Thionic
Folic
Fibric
Terric

Solonchaks

Gelic
Gleyic
Mollic
Gypsic
Calcic
Sodic
Haplic

Podzols

Gelic
Gleyic
Carbic
Ferric
Cambic
Haplic

Anthrosols

Aric
Fimic
Cumulic
Urbic

Gleysols

Gelic
Thionic
Andic
Mollic
Umbric
Calcic
Dystric
Eutric

Plinthosols

Albic
Humic
Dystric
Eutric

Leptosols

Lithic
Gelic

Andosols

Gelic
Gleyic

Ferralsols

Plinthic
Geric

Rendzic
Mollic
Umbric
Dystric
Eutric

Vertisols

Gypsic
Calcic
Dystric
Eutric

Fluvisols

Thionic
Mollic
Calcaric
Umbric
Dystric
Salic
Eutric

Solonetz

Gleyic
Stagnic
Mollic
Gypsic
Calcic
Haplic

Greyzems

Gleyic
Haplic

Chernozems

Gleyic
Luvic
Glossic
Calcic
Haplic

Vitric
Mollic
Umbric
Haplic

Arenosols

Gleyic
Albic
Calcaric
Luvic
Ferralic
Cambic
Haplic

Regosols

Gelic
Umbric
Gypsic
Calcaric
Dystric
Eutric

Gypsisols

Petric
Calcic
Luvic
Haplic

Cambisols

Gelic
Gleyic
Vertic
Humic
Calcaric
Ferralic
Dystric
Chromic
Eutric

Nitisols

Humic
Rhodic
Haplic

Humic
Rhodic
Xanthic
Haplic

Planosols

Gelic
Mollic
Umbric
Dystric
Eutric

Lixisols

Plinthic
Gleyic
Stagnic
Albic
Ferric
Haplic

Calcisols

Petric
Luvic
Haplic

Kastanozems

Gypsic
Luvic
Calcic
Haplic

Alisols

Plinthic
Gleyic
Stagnic
Humic
Ferric
Haplic

Phaeozems

Gleyic
Stagnic
Luvic
Calcic
Haplic

Acrisols

Plinthic
Gleyic
Humic
Ferric
Haplic

Podzoluvisols

Gelic
Gleyic
Stagnic
Dystric
Eutric

Luvisols

Gleyic
Stagnic
Albic
Vertic
Calcic
Ferric
Chromic
Haplic

PHASES

Phases are limiting factors related to surface or subsurface features of the land. They are not necessarily related to soil formation and generally cut across the boundaries of different soil units. These features may form a constraint to the use of the land. The phases recognized here are: *anthraquic*, *duripan fragipan*, *gelundic*, *gilgai*, *inundic*, *lithic*, *petroferric*, *phreatic*, *placic*, *rudic*, *salic*, *skeletal*, *sodic*, *takyric* and *yermic*.

The definitions of the petrocalcic and petrogypsic horizons, the petroferric phase (contact), the fragipan and the duripan are those formulated in the Soil Taxonomy of the U.S. Soil Conservation Service (1975). It is to be noted that in Soil Taxonomy the petrocalcic and petrogypsic horizons and the fragipan and duripan are diagnostic for separating different categories of soils. Since the occurrence of these horizons has not been systematically recorded in a number of countries, they are shown as phases on the FAO-UNESCO Soil map of the World where they have been observed.

1. ANTHRAQUIC PHASE

The anthraquic phase marks soils showing stagnic properties within 50 cm of the surface due to surface waterlogging associated with long continued irrigation, particularly of rice.

2. DURIPAN PHASE

A duripan is a subsurface horizon that is cemented by silica so that dry fragments do not slake during prolonged soaking in water or in hydrochloric acid. The duripan phase marks soils in which the upper level of a duripan occurs within 100 cm of the surface. Duripans vary in the degree of cementation by silica and, in addition, they commonly contain accessory cements, mainly iron oxides and calcium carbonate. As a result, duripans vary in appearance but all of them have a very firm or extremely firm moist

consistency, and they are always brittle even after prolonged wetting.

3. FRAGIPAN PHASE

A fragipan is a loamy (uncommonly a sandy) subsurface horizon which has a high bulk density relative to the horizons above it, is hard or very hard and seemingly cemented when dry, is weakly to moderately brittle when moist; when pressure is applied peds or clods tend to rupture suddenly rather than to undergo slow deformation. Dry fragments slake or fracture when placed in water. The fragipan phase marks soils which have the upper level of the fragipan occurring within 100 cm of the surface.

A fragipan is low in organic matter, slowly or very slowly permeable and often shows bleached fracture planes that are faces of coarse or very coarse polyhedrons or prisms. clay skins may occur as patches or discontinuous streaks both on the faces and in the interiors of the prisms. A fragipan commonly, but not necessarily, underlines a B horizon. It may be from 15 to 200 cm thick with commonly an abrupt or clear upper boundary, while the lower boundary is mostly gradual or diffuse.

4. GELUNDIC PHASE

The gelundic phase marks soils showing formation of polygons on their surface due to frost heaving.

5. GILGAI PHASE

Gilgai is the microrelief typical of clayey soils, mainly Vertisols, that have a high coefficient of expansion with distinct seasonal changes in moisture content. This microrelief consists of either a succession of enclosed microbasins and microknolls in nearly level areas, or of microvalleys and microridges that run up and the slope. The height of the microridges commonly ranges from a few cm to 100 cm. Rarely does the height attain 200 cm.

6. INUNDIC PHASE

The inundic phase is used when standing or flowing water is present on the soil surface for more than 10 days during the growing period.

7. LITHIC PHASE

The lithic phase is used when continuous hard rock occurs within 50 cm of the surface.

8. PETROFERRIC PHASE

The petroferric phase refers to the occurrence of a continuous layer of indurated material, in which iron is an important cement and in which organic matter is absent, or present only in traces. The petroferric layer differs from a thin iron pan and from an indurated spodic B horizon in containing little or no organic matter. The petroferric phase marks soils in which the upper part of the indurated layer occurs within 100 cm of the surface.

9. PHREATIC PHASE

The phreatic phase refers to the occurrence of a groundwater table within 5 m from the surface, the presence of which is not reflected in the morphology of the soil. therefore the phreatic phase is not shown, for instance, with Fluvisols or Gleysols. Its presence is important especially in arid areas where, with irrigation, special attention should be paid to effective water use and

drainage in order to avoid salinization as a result of rising groundwater.

10. PLACIC PHASE

The placic phase refers to the presence of a thin iron pan, a black to dark reddish layer cemented by iron, by iron and manganese, or by an iron-organic matter complex, the thickness of which ranges generally from 2 mm to 10 mm. In spots it may be as thin as 1 mm or as thick as 20 to 40 mm, but this is rare. It may, but not necessarily, be associated with stratification in parent materials. It is in the solum, roughly parallel to the soil surface, and is commonly within the upper 50 cm of the mineral soil. The placic phase marks soils that have a thin iron pan within 100 cm of the surface.

11. RUDIC PHASE

The rudic phase marks areas where the presence of gravel, stones, boulders or rock outcrops in the surface layers or at the surface makes the use of mechanized agricultural equipment impracticable. Hand tools can normally be used and also simple mechanical equipment if other conditions are particularly favourable. Fragments with a diameter up to 7.5 cm are considered as gravel; larger fragments are called stones or boulders.

12. SALIC PHASE

The salic phase marks soils which, in some horizons within 100 cm of the surface, show electric conductivity values of the saturation extract higher than 4 dS/m at 25°C. The salic phase is not shown for Solonchaks because their definition implies a high salt content. Salinity in a soil may show seasonal variations or may fluctuate as a result of irrigation practice. Though the salic phase indicates present or potential salinization, it should be realized that the effect of salinity varies greatly with the type of salts present, the permeability of the soil, the climatic conditions, and the kind of crops grown.

13. SKELETIC PHASE

The skeletal phase refers to soil materials that consist of 40 percent or more, by volume, of coarse fragments of oxidic concretions or of hardened plinthite, ironstone or other hard materials, with a thickness of at least 25 cm, the upper part of which occurs within 50 cm of the surface. The difference from the petroferric phase is that the concretionary layer of the skeletal phase is not continuously cemented.

14. SODIC PHASE

The sodic phase marks soils that have more than 6 percent saturation with exchangeable sodium at least in some horizons within 100 cm of the surface. The sodic phase is not shown for soil units which have a natric B horizon or which have sodic properties since a high percentage of sodium saturation is already implied in their definition.

15. TAKYRIC PHASE

The takyric phase applies to heavy textured soils that crack into polygonal elements when dry and form a platy or massive surface crust.

16. YERMIC PHASE

The yermic phase applies to soils which have less than 0.6 percent organic carbon in the surface 18 cm when mixed, or less than 0.20 percent organic carbon if the texture is coarser than sandy loam, and which show one or more

of the following features connotative of arid conditions:

- i. presence in the surface horizon of gravels or stones shaped by the wind.
- ii. presence of 2 percent or more palygorskite in the clay fraction in at least some subhorizon within 50 cm of the surface.
- iii. surface cracks filled with in-blown sand or silt.
- iv. accumulation of blown sand on a stable surface.

HORIZON SEQUENCES FOR THE DIFFERENT SOIL UNITS- LEVEL 1 (FAO UNESCO CLASSIFICATION SYSTEM)

Histosols: Mostly H or HCr profile

Anthrosols: Very variable; human influence mostly restricted to the surface horizon(s); a buried soil can still be intact at some depth.

Leptosols: Mostly A(B)R or A(B)C profiles. Leptosols in calcareous weathering material have commonly a mollic A-horizon with high degree of biological activity.

Vertisols: A(B)C profiles. Presence of deep wide cracks; slickensides and wedge-shaped aggregates present in the subsoil.

Fluvisols: AC profiles; a distinct Ah may be present. Lower horizons have stratification and have no or only a weak structure. Gley is common in the lower part of profile.

Solonchaks: Mostly AC or ABC profiles; salt accumulation.

Gleysols: Mostly A(Bg)Cr or H(Bg)Cr profiles. Evidence of reduction within 50 cm of the surface.

Andosols: AC or ABC profiles.

Arenosols: Mostly AC profiles. In dry areas, an ochric A-horizon is the only diagnostic horizon.

Regosols: AC profiles, with no other diagnostic horizons than an ochric or umbric A-horizon. Profile development is minimal.

Podzols: Mostly AhEBhC profiles. The eluvial albic E-horizon is evidently bleached.

Plinthosols: Mostly ABC or AEBC profiles. The B could be qualified as Bsq.

Ferralsols: ABC profiles. Deep and intensive weathering evident in the ferralic B-horizon.

Planosols: Mostly AEBC profiles. Impeded downward movement of water is evident.

Solonetz: Mostly ABtnC profiles with a black or brown A-horizon over a natric B-horizon.

Greyzems: Mostly AhBtC profiles with mollic A-horizon over an argic B-horizon.

Chernozems: AhBC profiles with dark brown to black mollic A-horizon over a cambic or argic B-horizon.

Kastanozems: Mostly AhBC profiles with a brown Ah-horizon of medium depth over a brown cambic or argic B-horizon.

Phaeozems: Mostly AhBC profiles with a mollic A-horizon over a cambic or argic B-horizon.

Podzoluvisols: Mostly AEBtC profiles with a dark but thin ochric A-horizon over an albic E-horizon that tongues into a brown argic B-horizon.

Gypsisols: ABC profiles with a yellowish brown ochric A-horizon over a cambic or argic B-horizon. Accumulation of calcium sulphate is concentrated in and below the B-horizon.

Calcisols: ABC profiles with a pale brown ochric A-horizon over a cambic or argic B-horizon. Accumulation of carbonates at some depth below the surface.

Nitisols: ABtC profiles. Reddish brown clayey soils with a deeply developed clay

illuviation horizon of high structural stability.

Alisols: Mostly ABtC profiles.

Acrisols: Mostly ABtC profiles.

Luvisols: Mostly ABtC profiles.

Lixisols: Mostly ABtC profiles.

Cambisols: ABwC profiles.

PRACTICAL EXERCISES ON SOIL CLASSIFICATION- USDA SOIL TAXONOMY

Name:

1. You are provided with both field morphological data and analytical data of a soil profile. Using the data make an inventory of the diagnostic horizons and features of the profile and tabulate the information as follows:

Diagnostic epipedons/ surface horizon(s)	Diagnostic subsurface horizon(s)	Any other diagnostic features/materials
USDA Soil Taxonomy	USDA Soil Taxonomy	USDA Soil Taxonomy

2. Classify the profile up to Family level (USDA Soil Taxonomy) and tabulate your results as follows:

USDA Soil Taxonomy (Soil Survey Staff, 1990)				
<i>Order</i>	<i>Suborder</i>	<i>Greatgroup</i>	<i>Subgroup</i>	<i>Family</i>

3. Comment on the potentials and constraints of the soil

Name:

Profile number : MIK-P1 Mapping unit: Agro-ecol. zone:
 Region : Morogoro District : Morogoro
 Map sheet no. : 183/2 & 4
 Coordinates : 37° 56' 8.5" E / 6° 45' 33.8" S
 Location : Mikese farm STR: isohyperthermic SMR: ustic
 Elevation : m asl. Parent material: alluvio-colluvium derived from metamorphic rocks
 gneisses). Landform: in-filled valleys (depressions).
 Slope: 2 %; concave Surface characteristics : Erosion: none or slight. Deposition:
 evident. Natural drainage class : well drained. Vegetation: Miombo savannah with *Brachystegia*
spp., *Combretum sp.*, *Acacia spp.*, *Pterocarpus angolensis* etc. Land use: forest / woodland.
 Described by B.M. Msanya and D.N. Kimaro on 28/11/98

Ah 0 - 18/33 cm: black (7.5YR2.5/1) moist; sandy clay loam; friable moist, slightly sticky
 and slightly plastic wet; moderate medium and coarse subangular blocks; many fine and very
 fine pores, few medium pores; few coarse and many fine roots; clear wavy boundary to

Bw 18/33 - 40/51 cm: dark brown (7.5YR3/2) moist; sandy clay loam; friable moist, sticky
 and plastic wet; weak fine and medium subangular blocks; many fine and very fine pores, few
 medium pores; frequent small spherical hard nodules; few coarse and fine roots; clear wavy
 boundary to

Ab 40/51 - 82/94 cm: very dark grey (7.5YR3/1) moist; sandy clay loam; friable moist,
 sticky and plastic wet; weak fine subangular blocks and medium subangular blocks; many fine
 and very fine pores, few medium pores; frequent small spherical hard nodules; fine and very
 few very fine roots; clear wavy boundary to

Bwb 82/94 - 150 cm: dark reddish brown (5YR3/2) moist; sandy clay; friable moist, sticky
 and plastic wet; moderate fine and medium subangular blocks; many fine and very fine pores,
 few medium pores; frequent small spherical hard nodules; few fine and very fine roots

Mineralogy: kaolinite (30%), smectite (40%); illite (20%), others (10%)

SOIL CLASSIFICATION:

USDA Soil Taxonomy:

ANALYTICAL DATA FOR PROFILE MIK-P1

Horizon	Ah	Bw	Ab	Bwb
Depth (cm)	0-18/33	18/33-	40/51-	82/94-
		40/51	82/94	150+
Clay %	25	29	32	42
Silt %	10	6	2	6
Sand %	65	65	66	52
Texture class	SCL	SCL	SCL	SC
pH H ₂ O 1:2.5	6.6	6.2	6.1	6.3
pH KCl 1:2.5	5.5	4.8	4.8	4.9
EC mS/cm	0.08	0.04	0.03	0.05
Organic C %	3.04	2.83	1.41	1.13
Total N %	0.24	0.19	0.17	0.16
C/N	13	15	8	7
Avail. P Bray mg/kg	5.46	1.03	0.70	0.32
CEC soil cmol(+)/kg	7.22	8.31	10.38	13.35
Ca cmol(+)/kg	2.9	5.0	4.3	6.5
Mg cmol(+)/kg	2.3	2.8	2.9	3.7
K cmol(+)/kg	1.10	0.30	0.19	0.13
Na cmol(+)/kg	0.05	0.05	0.08	0.11
TEB cmol(+)/kg	6.35	8.15	7.49	10.44
Base sat. %	88	98	72	78
ECe mS/cm	0.31	0.16	0.13	0.19
CEC clay cmol(+)/kg	28.9	28.7	32.3	31.8

Name:

Profile number : SUAP-1 Mapping unit: 24C1(ET) Agro-ecol. zone:
 Region : Morogoro District : Morogoro
 Map sheet no. : 183/3 Coordinates : 37° 38' 50.3" E/ 6° 50' 34.4" S
 Location : SUA Botanical Garden, 450 west of Morogoro-Mzinga Road
 Elevation : 630 m asl. Parent material: colluvium derived from mafic metamorphic rocks (hornblende pyroxene granulites) of the Uluguru mountains. Landform: plain; flat or almost flat. Slope: 0.5 %; straight Surface characteristics : Erosion: slight sheet erosion. Deposition: none. Natural drainage class : well drained
 Described by B.M. Msanya and S. Maliondo on 13/07/98

Ah 0 - 16 cm: dark reddish brown (2.5YR3/4) dry, dark reddish brown (2.5YR3/3) moist; clay; slightly hard dry, friable moist, slightly sticky and slightly plastic wet; moderate fine subangular blocks; common coarse and few medium pores; many fine and few coarse roots; clear wavy boundary to
 Bs1 16 - 40 cm: red (2.5YR4/8) dry, dark red (2.5YR3/6) moist; clay; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; weak fine and medium subangular blocks; common fine and many very fine pores; many fine and few coarse roots; few crotovinas present; gradual smooth boundary to
 Bs2 40 - 75 cm: red (2.5YR4/8) dry, dark red (2.5YR3/6) moist; clay; soft dry, very friable moist, slightly sticky and slightly plastic wet; weak fine and medium subangular blocks; common medium and many very fine pores; few medium spherical soft nodules; common fine and few coarse roots; few crotovinas present; diffuse smooth boundary to
 Bs3 75 - 130 cm: dark red (2.5YR3/6) moist; clay; very friable moist, slightly sticky and slightly plastic wet; weak fine subangular blocks; many very fine and few fine pores; frequent medium irregular soft nodules; few fine and coarse roots; diffuse smooth boundary to
 Bs4 130 - 205 cm: dark red (2.5YR3/6) moist; clay; very friable moist, slightly sticky and slightly plastic wet; weak fine subangular blocks; many very fine and few fine pores; frequent medium irregular soft nodules; few fine roots

Mineralogy: kaolinite (95%), sesquioxides (5%)

SOIL CLASSIFICATION:
 USDA Soil Taxonomy:

ANALYTICAL DATA FOR PROFILE SUAP-1

Horizon	Ah	Bs1	Bs2	Bs3	Bs4	Composite
Depth (cm)	0 -16	16 - 40	40 - 75	75- 130	130 - 205	0 - 30
Clay %	58	62	64	65	62	52
Silt %	10	9	9	10	10	11
Sand %	32	29	27	25	28	37
Texture class	C	C	C	C	C	C
Silt/clay ratio	0.17	0.15	0.14	0.15	0.16	0.21
Bulk density g/cc	1.12	nd	1.13	1.22	nd	nd
pH H ₂ O	5.83	5.13	5.51	5.51	5.95	5.9
pH KCl	4.47	4.00	4.02	4.08	4.01	4.44
Organic C %	1.32	0.64	0.42	0.30	0.20	1.24
Total N %	0.10	0.05	0.04	0.06	0.03	0.11
C/N	13	13	11	5	7	11
Avail. P mg/kg	2.11	1.05	0.53	0.46	0.46	1.54
CEC NH ₄ OAc cmol(+)/kg	9.20	9.80	6.40	6.20	6.00	8.40
Exch. Ca cmol(+)/kg	2.23	0.61	0.61	0.32	0.51	1.99
Exch. Mg cmol(+)/kg	2.46	1.49	2.05	1.88	1.53	2.03
Exch. K cmol(+)/kg	0.46	0.29	0.16	0.14	0.14	0.40
Exch. Na cmol(+)/kg	0.28	0.26	0.21	0.19	0.19	0.30
TEB cmol(+)/kg	5.43	2.65	3.03	2.53	2.37	4.72
Base saturation %	59	27	47	41	40	56
CEC clay cmol(+)/kg	15.9	15.8	10	9.5	9.7	16.2

Name:

Profile number : SUA-P2 Mapping unit: 14B1(HT) Agro-ecol. zone:
 Region : Morogoro District : Morogoro
 Map sheet no. : 183/3 Coordinates : 37° 38' 35.5" E/ 6° 50' 58.9" S
 Location : SUA- Magadu Farm, 300 m west of Morogoro-Mzinga Road
 Elevation : 623 m asl. Parent material: colluvium derived from mafic metamorphic rocks
 (hornblende pyroxene granulites) of the Uluguru mountains. Landform: plain; very gently undulating.
 Slope: 2 %; straight Surface characteristics : Erosion: slight sheet erosion. Deposition:
 none.

Natural drainage class : well drained SMR: ustic STR: isohyperthermic

Described by S. Maliondo and B.M. Msanya on 27/07/98

Ah 0 - 16 cm: dark brown (7.5YR3/4) dry, very dark brown (7.5YR2.5/3) moist; clay; hard dry, firm moist, sticky and plastic wet; weak fine subangular blocks falling into moderate fine subangular blocks; common fine and few medium pores; common medium and many fine roots; abrupt wavy boundary to

Bt1 16 - 36 cm: strong brown (7.5YR4/6) dry, brown (7.5YR4/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium subangular blocks; patchy thin clay cutans; many fine and few medium pores; many fine and common medium roots; few ant nests present; clear smooth boundary to

Bt2 36 - 71 cm: strong brown (7.5YR5/6) dry, strong brown (7.5YR4/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; broken thin clay cutans; many fine and very fine pores; few small irregular slightly weathered quartz fragments; common fine and few medium roots; common ant nests present; clear smooth boundary to

Bt3 71 - 132 cm: strong brown (7.5YR5/6) dry, strong brown (7.5YR4/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; broken thin clay cutans; many very fine and few medium pores; few small irregular weathered quartz fragments; frequent medium irregular soft nodules; few fine roots; clear smooth boundary to

Bt4 132 - 192 cm: strong brown (7.5YR4/6) dry, brown (7.5YR4/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; strong fine and medium angular blocks; broken thin clay cutans; many very fine and common medium pores; few small irregular weathered quartz fragments; frequent small spherical soft manganese nodules

Mineralogy: kaolinite (85%), illite (10%), goethite (5%)

SOIL CLASSIFICATION:

USDA Soil Taxonomy:

ANALYTICAL DATA FOR PROFILE SUAP-2

Horizon	Ah	Bt1	Bt2	Bt3	Bt4	Composite
Depth (cm)	0 - 16/18	16 - 36	36 - 71	71 - 132	132 - 192	0 - 30
Clay %	46	54	53	55	54	49
Silt %	15	12	12	13	13	12
Sand %	39	34	35	32	33	39
Texture class	C	C	C	C	C	C
Silt/clay ratio	0.32	0.22	0.23	0.24	0.24	0.24
Bulk density g/cc	1.53	nd	1.26	1.32	nd	nd
pH H ₂ O	6.78	5.99	6.36	5.92	6.50	6.72
pH KCl	4.97	4.49	4.86	4.81	5.02	5.08
Organic C %	1.30	1.06	0.44	0.30	0.20	1.20
Total N %	0.11	0.08	0.06	0.05	0.03	0.12
C/N	12	13	7	6	7	10
Avail. P mg/kg	1.42	1.12	0.53	0.38	0.53	1.89
CEC NH ₄ OAc cmol(+)/kg	11.40	10.00	10.20	10.31	12.52	11.00
Exch. Ca cmol(+)/kg	4.40	3.74	3.27	2.96	3.53	3.23
Exch. Mg cmol(+)/kg	1.56	1.44	1.95	1.82	2.45	1.65
Exch. K cmol(+)/kg	1.21	0.56	0.36	0.35	0.30	1.24
Exch. Na cmol(+)/kg	0.27	0.25	0.20	0.21	0.22	0.24
TEB cmol(+)/kg	7.44	5.99	5.78	5.34	6.50	6.36
Base saturation %	65.3	55.9	56.7	51.8	53.5	57.8
CEC clay cmol(+)/kg	24.8	18.5	19.2	18.7	22.5	22.4

PRACTICAL EXERCISES ON SOIL CLASSIFICATION- FAO-UNESCO SYSTEM

Name:

1. You are provided with both field morphological data and analytical data of a soil profile. Using the data make an inventory of the diagnostic horizons and features of the profile and tabulate the information as follows:

Diagnostic horizon(s)	Any other diagnostic features/materials
FAO-UNESCO Soil Classification (FAO, 1988)	FAO-UNESCO Soil Classification

2. Classify the profile up to level-2 soil unit name and tabulate your results as follows:

<i>Level-1 soil name</i>	<i>Level-2 soil name</i>	<i>Phase ?</i>

Name:

Profile number : MIK-P1 Mapping unit: Agro-ecol. zone:
 Region : Morogoro District : Morogoro
 Map sheet no. : 183/2 & 4
 Coordinates : 37° 56' 8.5" E / 6° 45' 33.8" S
 Location : Mikese farm STR: isohyperthermic SMR: ustic
 Elevation : m asl. Parent material: alluvio-colluvium derived from metamorphic rocks
 gneisses). Landform: in-filled valleys (depressions).
 Slope: 2 %; concave Surface characteristics : Erosion: none or slight. Deposition:
 evident. Natural drainage class : well drained. Vegetation: Miombo savannah with
Brachystegia spp., Combretum sp., Acacia spp., Pterocarpus angolensis etc. Land use:
 forest / woodland.
 Described by B.M. Msanya and D.N. Kimaro on 28/11/98

Ah 0 - 18/33 cm: black (7.5YR2.5/1) moist; sandy clay loam; friable moist, slightly sticky
 and slightly plastic wet; moderate medium and coarse subangular blocks; many fine and very
 fine pores, few medium pores; few coarse and many fine roots; clear wavy boundary to

Bw 18/33 - 40/51 cm: dark brown (7.5YR3/2) moist; sandy clay loam; friable moist, sticky
 and plastic wet; weak fine and medium subangular blocks; many fine and very fine pores, few
 medium pores; frequent small spherical hard nodules; few coarse and fine roots; clear wavy
 boundary to

Ab 40/51 - 82/94 cm: very dark grey (7.5YR3/1) moist; sandy clay loam; friable moist,
 sticky and plastic wet; weak fine subangular blocks and medium subangular blocks; many fine
 and very fine pores, few medium pores; frequent small spherical hard nodules; fine and very
 few very fine roots; clear wavy boundary to

Bwb 82/94 - 150 cm: dark reddish brown (5YR3/2) moist; sandy clay; friable moist, sticky
 and plastic wet; moderate fine and medium subangular blocks; many fine and very fine pores,
 few medium pores; frequent small spherical hard nodules; few fine and very fine roots

Mineralogy: kaolinite (30%), smectite (40%); illite (20%), others (10%)

SOIL CLASSIFICATION:

USDA Soil Taxonomy:

ANALYTICAL DATA FOR PROFILE MIK-P1

Horizon	Ah	Bw	Ab	Bwb
Depth (cm)	0-18/33	18/33- 40/51	40/51- 82/94	82/94- 150+
Clay %	25	29	32	42
Silt %	10	6	2	6
Sand %	65	65	66	52
Texture class	SCL	SCL	SCL	SC
pH H ₂ O 1:2.5	6.6	6.2	6.1	6.3
pH KCl 1:2.5	5.5	4.8	4.8	4.9
EC mS/cm	0.08	0.04	0.03	0.05
Organic C %	3.04	2.83	1.41	1.13
Total N %	0.24	0.19	0.17	0.16
C/N	13	15	8	7
Avail. P Bray mg/kg	5.46	1.03	0.70	0.32
CEC soil cmol(+)/kg	7.22	8.31	10.38	13.35
Ca cmol(+)/kg	2.9	5.0	4.3	6.5
Mg cmol(+)/kg	2.3	2.8	2.9	3.7
K cmol(+)/kg	1.10	0.30	0.19	0.13
Na cmol(+)/kg	0.05	0.05	0.08	0.11
TEB cmol(+)/kg	6.35	8.15	7.49	10.44
Base sat. %	88	98	72	78
ECe mS/cm	0.31	0.16	0.13	0.19
CEC clay cmol(+)/kg	28.9	28.7	32.3	31.8

Name:

Profile number : SUAP-1 Mapping unit: 24C1(ET) Agro-ecol. zone:
 Region : Morogoro District : Morogoro
 Map sheet no. : 183/3 Coordinates : 37° 38' 50.3" E/ 6° 50' 34.4" S
 Location : SUA Botanical Garden, 450 west of Morogoro-Mzinga Road
 Elevation : 630 m asl. Parent material: colluvium derived from mafic metamorphic
 rocks (hornblende pyroxene granulites) of the Uluguru mountains. Landform: plain; flat or
 almost flat. Slope: 0.5 %; straight Surface characteristics : Erosion: slight
 sheet erosion. Deposition: none. Natural drainage class : well drained
 Described by B.M. Msanya and S. Maliondo on 13/07/98

Ah 0 - 16 cm: dark reddish brown (2.5YR3/4) dry, dark reddish brown (2.5YR3/3)
 moist; clay; slightly hard dry, friable moist, slightly sticky and slightly plastic wet;
 moderate fine subangular blocks; common coarse and few medium pores; many fine and
 few coarse roots; clear wavy boundary to
 Bs1 16 - 40 cm: red (2.5YR4/8) dry, dark red (2.5YR3/6) moist; clay; slightly hard
 dry, very friable moist, slightly sticky and slightly plastic wet; weak fine and medium
 subangular blocks; common fine and many very fine pores; many fine and few coarse
 roots; few crotovinas present; gradual smooth boundary to
 Bs2 40 - 75 cm: red (2.5YR4/8) dry, dark red (2.5YR3/6) moist; clay; soft dry, very
 friable moist, slightly sticky and slightly plastic wet; weak fine and medium subangular
 blocks; common medium and many very fine pores; few medium spherical soft nodules;
 common fine and few coarse roots; few crotovinas present; diffuse smooth boundary to
 Bs3 75 - 130 cm: dark red (2.5YR3/6) moist; clay; very friable moist, slightly sticky and
 slightly plastic wet; weak fine subangular blocks; many very fine and few fine pores;
 frequent medium irregular soft nodules; few fine and coarse roots; diffuse smooth
 boundary to
 Bs4 130 - 205 cm: dark red (2.5YR3/6) moist; clay; very friable moist, slightly sticky
 and slightly plastic wet; weak fine subangular blocks; many very fine and few fine pores;
 frequent medium irregular soft nodules; few fine roots

Mineralogy: kaolinite (95%), sesquioxides (5%)

SOIL CLASSIFICATION:
 USDA Soil Taxonomy:

ANALYTICAL DATA FOR PROFILE SUAP-1

Horizon	Ah	Bs1	Bs2	Bs3	Bs4	Composite
Depth (cm)	0 -16	16 - 40	40 - 75	75- 130	130 - 205	0 - 30
Clay %	58	62	64	65	62	52
Silt %	10	9	9	10	10	11
Sand %	32	29	27	25	28	37
Texture class	C	C	C	C	C	C
Silt/clay ratio	0.17	0.15	0.14	0.15	0.16	0.21
Bulk density g/cc	1.12	nd	1.13	1.22	nd	nd
pH H ₂ O	5.83	5.13	5.51	5.51	5.95	5.9
pH KCl	4.47	4.00	4.02	4.08	4.01	4.44
Organic C %	1.32	0.64	0.42	0.30	0.20	1.24
Total N %	0.10	0.05	0.04	0.06	0.03	0.11
C/N	13	13	11	5	7	11
Avail. P mg/kg	2.11	1.05	0.53	0.46	0.46	1.54
CEC NH ₄ OAc cmol(+)/kg	9.20	9.80	6.40	6.20	6.00	8.40
Exch. Ca cmol(+)/kg	2.23	0.61	0.61	0.32	0.51	1.99
Exch. Mg cmol(+)/kg	2.46	1.49	2.05	1.88	1.53	2.03
Exch. K cmol(+)/kg	0.46	0.29	0.16	0.14	0.14	0.40
Exch. Na cmol(+)/kg	0.28	0.26	0.21	0.19	0.19	0.30
TEB cmol(+)/kg	5.43	2.65	3.03	2.53	2.37	4.72
Base saturation %	59	27	47	41	40	56
CEC clay cmol(+)/kg	15.9	15.8	10	9.5	9.7	16.2

Name:

Profile number : SUA-P2 Mapping unit: 14B1(HT) Agro-ecol. zone:
 Region : Morogoro District : Morogoro
 Map sheet no. : 183/3 Coordinates : 37° 38' 35.5" E/ 6° 50' 58.9" S
 Location : SUA- Magadu Farm, 300 m west of Morogoro-Mzinga Road
 Elevation : 623 m asl. Parent material: colluvium derived from mafic metamorphic rocks (hornblende pyroxene granulites) of the Uluguru mountains. Landform: plain; very gently undulating. Slope: 2 %; straight Surface characteristics :
 Erosion: slight sheet erosion. Deposition: none.
 Natural drainage class : well drained SMR: ustic STR: isohyperthermic
 Described by S. Maliondo and B.M. Msanya on 27/07/98
 Ah 0 - 16 cm: dark brown (7.5YR3/4) dry, very dark brown (7.5YR2.5/3) moist; clay; hard dry, firm moist, sticky and plastic wet; weak fine subangular blocks falling into moderate fine subangular blocks; common fine and few medium pores; common medium and many fine roots; abrupt wavy boundary to
 Bt1 16 - 36 cm: strong brown (7.5YR4/6) dry, brown (7.5YR4/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium subangular blocks; patchy thin clay cutans; many fine and few medium pores; many fine and common medium roots; few ant nests present; clear smooth boundary to
 Bt2 36 - 71 cm: strong brown (7.5YR5/6) dry, strong brown (7.5YR4/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; broken thin clay cutans; many fine and very fine pores; few small irregular slightly weathered quartz fragments; common fine and few medium roots; common ant nests present; clear smooth boundary to
 Bt3 71 - 132 cm: strong brown (7.5YR5/6) dry, strong brown (7.5YR4/6) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; moderate medium and fine subangular blocks; broken thin clay cutans; many very fine and few medium pores; few small irregular weathered quartz fragments; frequent medium irregular soft nodules; few fine roots; clear smooth boundary to
 Bt4 132 - 192 cm: strong brown (7.5YR4/6) dry, brown (7.5YR4/4) moist; clay; slightly hard dry, friable moist, sticky and plastic wet; strong fine and medium angular blocks; broken thin clay cutans; many very fine and common medium pores; few small irregular weathered quartz fragments; frequent small spherical soft manganese nodules

Mineralogy: kaolinite (85%), illite (10%), goethite (5%)

SOIL CLASSIFICATION: USDA Soil Taxonomy:

ANALYTICAL DATA FOR PROFILE SUAP-2

Horizon	Ah	Bt1	Bt2	Bt3	Bt4	Composite
Depth (cm)	0 - 16/18	16 - 36	36 - 71	71 - 132	132 - 192	0 - 30
Clay %	46	54	53	55	54	49
Silt %	15	12	12	13	13	12
Sand %	39	34	35	32	33	39
Texture class	C	C	C	C	C	C
Silt/clay ratio	0.32	0.22	0.23	0.24	0.24	0.24
Bulk density g/cc	1.53	nd	1.26	1.32	nd	nd
pH H ₂ O	6.78	5.99	6.36	5.92	6.50	6.72
pH KCl	4.97	4.49	4.86	4.81	5.02	5.08
Organic C %	1.30	1.06	0.44	0.30	0.20	1.20
Total N %	0.11	0.08	0.06	0.05	0.03	0.12
C/N	12	13	7	6	7	10
Avail. P mg/kg	1.42	1.12	0.53	0.38	0.53	1.89
CEC NH ₄ OAc cmol(+)/kg	11.40	10.00	10.20	10.31	12.52	11.00
Exch. Ca cmol(+)/kg	4.40	3.74	3.27	2.96	3.53	3.23
Exch. Mg cmol(+)/kg	1.56	1.44	1.95	1.82	2.45	1.65
Exch. K cmol(+)/kg	1.21	0.56	0.36	0.35	0.30	1.24
Exch. Na cmol(+)/kg	0.27	0.25	0.20	0.21	0.22	0.24
TEB cmol(+)/kg	7.44	5.99	5.78	5.34	6.50	6.36
Base saturation %	65.3	55.9	56.7	51.8	53.5	57.8
CEC clay cmol(+)/kg	24.8	18.5	19.2	18.7	22.5	22.4

INTRODUCTION TO THE WORLD REFERENCE BASE (WRB) FOR SOIL RESOURCES (FAO *et al.*, 1998)

The WRB system of soil classification is an improvement over the FAO-UNESCO 1974, 1988 legends for the soil map of the world.

Objectives of establishing the WRB

The main objective of the *World Reference Base for Soil Resources* was to provide scientific depth and background to the 1988 FAO Revised Legend, incorporating the latest knowledge relating to global soil resources and their interrelationships. To include some of the most recent pedological studies and to expand use of the system from an agricultural base to a broader environmental one. It was recognized that a limited number of important changes to the 1988 Legend were becoming necessary.

More specifically, the objectives were:

1. to develop an internationally acceptable system for delineating soil resources to which national classifications can be attached and related, using FAO's Revised Legend as a framework;
2. to provide this framework with a sound scientific basis so that it can also serve different applications in related fields such as agriculture, geology, hydrology and ecology;
3. to recognize within the framework important spatial relationships of soils and soil horizons as characterized by topo- and chronosequences; and
4. to emphasize the morphological characterization of soils rather than to follow a purely laboratory-based analytical approach.

WRB is designed as **an easy means of communication amongst scientists** to identify, characterize and name major types of soils. It is not meant to replace national soil classification systems, but be a tool for better **correlation between national systems**. It aims to act as a common denominator through which national systems can be compared. WRB also serves as a common ground among people with an interest in land and natural resources. WRB is also a tool for **identifying pedological structures** and their significance. It serves as a **basic language in soil science** to facilitate:

- scientific communication;
- implementation of soil inventories and transfer of pedological data, elaboration of different systems of classification having a common base, interpretation of maps;
- acknowledgement of relationships between soils and soil horizon distribution as characterized by topo- and chronosequences;
- international use of pedological data, not only by soil scientists but also by other users of soil and land, such as geologists, botanists, agronomists, hydrologists, ecologists, farmers, foresters, civil engineers and architects, with as a particular objective to improve upon:
 - the use of soil data for the benefit of other sciences;

- the evaluation of soil resources and the potential use of different types of soil cover;
- the monitoring of soils, particularly soil development which is dependent on the way soils are used by the human community;
- the validation of experimental methods of soil use for sustainable development, which maintain and, if possible, improve the soil's potential;
- transfer of soil use technologies from one region to another.

Principles

The general principles of the WRB can be summarized as follows:

- the classification of soils is based on soil properties defined in terms of diagnostic horizons and characteristics, which to the greatest extent possible should be measurable and observable in the field;
- the selection of diagnostic horizons and characteristics takes into account their relationship with soil forming processes. It is recognized that an understanding of soil forming processes contributes to a better characterization of soils but that they should not, as such, be used as differentiating criteria;
- to the extent possible at a high level of generalization it is attempted to select diagnostic features which are of significance for management purposes;
- climatic parameters are not applied in the classification of soils. It is fully realized that they should be used for interpretation purposes, in dynamic combination with soil properties, but they should not be part of soil definitions;
- WRB is meant to be a comprehensive classification system which enables people to accommodate their own national classification system. It comprises two tiers of categorical detail:
 1. the "Reference base" which is limited to the first level only, having 30 reference soil groups; and
 2. the "WRB Classification System" consisting of combinations of a set of prefixes as unique qualifiers (or modifiers) added to the reference soil groups, allowing very precise characterization and classification of individual soil profiles;
- the reference soil units in WRB should be representative of major soil regions so as to provide a comprehensive overview of the world's soil cover;
- the reference base is not meant to substitute for national soil classification systems but rather to serve as a common denominator for communication at an international level. This implies that lower-level categories, possibly a third category of the WRB, could accommodate local diversity at country

level. Concurrently the lower levels could emphasize soil features which are important for land use and soil management;

- the Revised Legend of FAO/UNESCO Soil Map of the World has been used as a basis for the development of the WRB in order to take advantage of the international soil correlation work which has already been conducted through this project;
- definitions and descriptions of soil units are to reflect variations in soil characteristics both vertically and laterally so as to account for spatial linkages within the landscape;
- the term 'Reference Base' is connotative of the common denominator function which the WRB will assume. Its units should have sufficient width to stimulate harmonization and correlation of existing national systems;
- in addition to serving as a link between existing classification systems the WRB may also serve as a consistent communication tool for compiling global soil databases and for the inventory and monitoring of the world's soil resources.
- the nomenclature used to distinguish soil groups will retain terms which have been traditionally used or which can easily be introduced in current language. These terms are precisely defined in order to avoid the confusion which occurs when names are used with different connotations.

Although the basic framework of the FAO Legend, with its two categoric levels and guidelines for developing classes at a third level, was adopted, it has been decided to merge the lower levels. Each reference soil group of WRB is provided with a listing of possible qualifiers in a priority sequence, from which the user can construct the various lower-level units. The broad principles which govern the WRB class differentiation are:

- at the **higher categoric level** classes are differentiated mainly according to the primary pedogenetic process that has produced the characteristic soil features, except where 'special' soil parent materials are of overriding importance; and
- at the **lower categoric levels** classes are differentiated according to any predominant secondary soil forming process that has significantly affected the primary soil features. In certain cases, soil characteristics that have a significant effect on use may be taken into account.

It is recognized that a number of reference soil groups may occur under different climatic conditions. It was decided, however, not to introduce separations on account of climatic characteristics so that the classification of soils is not subordinated to the availability of climatic data.

Elements of the world reference base for soil resources

The WRB reference soil groups

After reviewing FAO's Revised Legend, 30 reference soil groups were identified to constitute the World Reference Base for Soil Resources. Three new reference soil groups are included: the *Cryosols*, *Durisols*, and *Umbrisols*. The *Greyzems* have been merged with the *Phaeozems*, and the *Podzoluisols* are renamed *Albeluvisols*.

The 30 major soil groups of the WRB are *Acrisols*, *Albeluvisols*, *Alisols*, *Andosols*, *Anthrosols*, *Arenosols*, *Calcisols*, *Cambisols*, *Chernozems*, *Cryosols*, *Durisols*, *Ferralsols*, *Fluvisols*, *Gleysols*, *Gypsisols*, *Histosols*, *Kastanozems*, *Leptosols*, *Lixisols*, *Luvisols*, *Nitisols*,

Phaeozems, Planosols, Plinthosols, Podzols, Regosols, Solonchaks, Solonetz, Umbrisols, and Vertisols.

Cryosols are introduced at the highest level to identify a group of soils which occur under the unique environmental conditions of alternating thawing and freezing. These soils have permafrost within 100 cm of the soil surface and are saturated with water during the period of thaw. In addition, they show evidence of cryoturbation. **Durisols** comprise the soils in semi-arid environments which have an accumulation of secondary silica, either in the form of nodules, or as a massive, indurated layer. **Umbrisols** cover the soils which have either an umbric horizon, or have a mollic horizon and a base saturation of less than 50% in some parts within the upper 125 cm of the soil surface. They are a logical counterpart of the *Chernozems, Kastanozems* and *Phaeozems*.

Plinthosols bring together the *Plinthosols* of the Revised Legend and the soils which have a petroplinthic layer at shallow depth. In the Revised Legend the latter soils belong to the *Leptosols*. For the WRB it was decided to exclude from the *Leptosols* soils with pedogenetic horizons such as indurated calcic or gypsic horizons or hardened plinthite. This necessitated the definition of a reference soil group which included these soils. Although it is realized that soils with shallow petroplinthic layers and soils having plinthite normally occupy different positions in the landscape, it was felt appropriate to group them together as they are genetically related.

Podzoluvisols are renamed **Albeluvisols**. The name *Podzoluvisols* suggests that in these soils both the processes of cheluviation (leading to *Podzols*) and subsurface accumulation of clay (resulting in *Luvisols*) take place, while in fact the dominant process consists of removal of clay and iron/manganese along preferential zones (ped faces, cracks) in the argic horizon. The name *Albeluvisols* is therefore thought to be more appropriate, expressing the presence of a bleached eluvial horizon ("*albic horizon*"), a clay-enriched horizon ("*argic horizon*") and the occurrence of "*albeluvisol tonguing*".

WRB diagnostic horizons, properties and materials

Earlier it was agreed that the soil groups should be defined in terms of a specific combination of soil horizons, called '*reference horizons*' rather than '*diagnostic horizons*'. Reference horizons were intended to reflect genetic horizons which are widely recognized as occurring in soils. Unfortunately, the distinction between reference and diagnostic horizons created confusion and it was agreed to retain the FAO terminology of diagnostic horizons as well as the diagnostic properties. Additionally it appeared necessary to define diagnostic soil materials. This together resulted in a comprehensive list of WRB diagnostic horizons, properties and materials, defined in terms of morphological characteristics and/or analytical criteria. In line with the WRB objectives, attributes are described as much as possible to help field identification.

Modifications to definitions of FAO's diagnostic horizons and properties

Of the 16 diagnostic horizons of the Revised Legend only the *fimic A horizon* has not been retained. It covers too wide a range of human-made surface layers and is replaced in the WRB by the hortic, plaggic and ferric horizons.

For the WRB, the definition of the *histic horizon* was broadened by reducing its minimum thickness to 10 cm and removing the maximum thickness. This is because of a second use of the definition. In the Revised Legend the histic H horizon is used to distinguish soils at second level to identify histic soil units; in the WRB it is used

also at the highest level to define *Histosols*. It was agreed that *Histosols* over continuous hard rock should have a minimum thickness of 10 cm in order to avoid very thin organic layers over rock being classified as *Histosols*.

The P₂O₅ content requirement for FAO's mollic and umbric A horizons has been deleted from the WRB definition of *mollic* and *umbric horizons*. This requirement cannot be considered diagnostic since thick, dark coloured, human-made horizons in, for instance, China, also have low amounts of phosphate. Other criteria have to be found to separate mollic and umbric horizons from anthropogenic horizons.

A *chernic horizon* is defined as a special kind of mollic horizon. The present definition of the mollic horizon was felt to be too broad to reflect properly the unique characteristics of the deep, blackish, porous surface horizons which are so typical for *Chernozems*.

The definition of the *ochric horizon* is similar to the ochric A horizon. The colour requirement for the *albic horizon* has been slightly changed compared to FAO's albic E horizon, to suit albic horizons which show a considerable shift in chroma upon moistening. Such conditions are frequently found in soils of the southern hemisphere.

The *argic horizon* definition differs from that of the argic B horizon of the Revised Legend in that the percentage clay skins on both horizontal and vertical ped faces and in pores has been increased from one to five percent. This is expected to provide a better correlation with the earlier requirement of at least one percent oriented clay in thin sections.

Guidelines to recognize a lithological discontinuity, if not clear from the field observation, were added to the description of the argic horizon. It can be identified by the percentage of coarse sand, fine sand and silt, calculated on a clay-free basis (international particle size distribution or using the additional groupings of the United States Department of Agriculture (USDA) system or other), or by changes in the content of gravel and coarser fractions. A relative change of at least 20 percent in any of the major particle size fractions is regarded as diagnostic for a lithological discontinuity. However, it should only be taken into account if it is located in the section of the solum where the clay increase occurs and if there is evidence that the overlying layer was coarser textured.

The adjustments made in the description of the argic horizon also apply to the *natric horizon*.

The definition of FAO's cambic B horizon has been slightly amended by deleting the requirement '*....and has at least eight percent clay*'. This requirement forces some soils, which have a well-developed structural-B horizon and silt loam or silt textures with a low clay content, as found, for instance, in fluvio-glacial deposits of the nordic countries, into the *Regosols* rather than in the *Cambisols*. Because there is also no need for this requirement to separate *Cambisols* from *Arenosols* (defined in the WRB as soils having a loamy sand or coarser texture) it has not been used in the definition proposed for the WRB *cambic horizon*.

Major alterations are made in the definition of the *spodic horizon*. It has been brought into line with the recent modifications in soil taxonomy (Soil Survey Staff, 1996) regarding the definition of spodic materials. Colour requirements were added, a limit of 0.5 or more in percentage oxalate extractable aluminium plus half that of iron is used, and a value for the optical density of oxalate extract (ODOE) of 0.25 or more is introduced. Moreover, the upper limit of spodic horizons has been set at 10 cm depth.

The silt-clay ratio of 0.2 or less has been deleted from the definition of the *ferrallic horizon*. This criterion was felt to be too strict; the silt particle size fraction has been increased from 2-50 to 2-63 µm (FAO, 1990). Other values have been proposed (silt-

clay ratio of 0.7 or less; fine silt-clay ratio of 0.2 or less) but, as yet, no consensus has been reached.

Some alterations are made in the definitions of the *calcic* and *gypsic horizons*. For WRB purposes they are split into calcic/gypsic and *hypercalcic/hypergypsic horizons*. These latter horizons have a calcium carbonate equivalent and gypsum content of 50 and 60 percent, respectively, but are not cemented.

The definition for the *sulfuric horizon* remains the same as in the Revised Legend.

In addition to these diagnostic horizons, 19 new ones are proposed. Some are adopted from FAO's diagnostic properties, others are newly formulated. Together they bring the total of diagnostic horizons recognized in the WRB to 34. The newly defined diagnostic horizons are the *andic, anthropedogenic, chernic, cryic, duric, ferric, folic, fragic, fulvic, glacic, melanic, nitic, petroduric, petroplinthic, plinthic, salic, takyric, vertic, vitric* and *vermic horizons*.

A combination of an *anthraquic horizon* at the surface with an underlying *hydragic horizon*, totalling together a thickness of at least 50 cm, defines certain *Anthrosols* which show evidence of alteration through wet-cultivation practices. It comprises a puddled layer, a plough pan and an illuvial subsurface horizon. This combination is characteristic for soils which have been used for long-term paddy rice cultivation.

Newly defined diagnostic properties and materials are *albeluvic tonguing, alic* and *aridic properties*, and *anthropogeomorphic, calcaric, fluvic, gypsiric, organic, sulfidic* and *tephric soil material*.

Gleyic and *stagnic properties* have been reformulated. Slight changes are made in FAO's definitions of *abrupt textural change* and *geric properites*, while the definitions of *permafrost* and soft powdery lime, renamed *secondary carbonates*, have been adopted without change.

In the description of the *gleyic* and *stagnic properties* the occurrence of 'gleyic' and 'stagnic colour patterns' is introduced. These terms apply to the specific distribution pattern of Fe/Mn (hydr)oxides caused by saturation with groundwater or stagnating surface water. A gleyic colour pattern has 'oximorphic' features on the outside of structural elements, along root channels and pores, or as a gradient upwards in the soil. A stagnic colour pattern on the other hand shows these features in the centre of peas or as a gradient downwards resulting from impedance of the water flow.

The slight changes in the descriptions of *abrupt textural change* and *geric properties* refer to a different depth in which the change in texture must occur and another way of calculating the effective cation exchange capacity (ECEC)¹, respectively.

¹ ECEC: effective cation exchange capacity (sum of exchangeable bases plus extractable acidity).

Key to the reference soil groups of the world reference base for soil resources

Soils having a *histic* or *folic* horizon,

1. *either* a. 10 cm or more thick from the soil surface to a lithic or paralithic contact;
or b. 40 cm or more thick and starting within 30 cm from the soil surface;
and
2. lacking an *andic* or *vitric* horizon starting within 30 cm from the soil surface.

HISTOSOLS (HS)

Other soils having one or more *cryic* horizons within 100 cm from the soil surface.

CRYOSOLS (CR)

Other soils having *either*

1. a *hortic*, *irragric*, *plaggic* or *terric* horizon 50 cm or more thick; *or*
2. an *anthraquic* horizon and an underlying *hydragric* horizon with a combined thickness of 50 cm or more.

ANTHROSOLS (AT)

Other soils, which are *either*

1. Imitated in depth by *continuous hard rock* within 25 cm from the soil surface; *or*
2. overlying material with a calcium carbonate equivalent of more than 40 percent within 25 cm from the soil surface; *or*
3. containing less than 10 percent (by weight) fine earth to a depth of 75 cm or more from the soil surface; *and*
4. having no diagnostic horizons other than a *mollic*, *ochric*, *umbric*, *yermic* or *vertic* horizon.

LEPTOSOLS (LP)

Other soils having

1. a *vertic* horizon within 100 cm from the soil surface; *and*
2. after the upper 20 cm have been mixed, 30 percent or more clay in all horizons to a depth of 100 cm or more, or to a contrasting layer (lithic or paralithic contact, *petrocalcic*, *petroduric* or *petrogypsic* horizons, sedimentary discontinuity, etc.) between 50 and 100 cm; *and*
3. cracks² which open and close periodically.

² A crack is a separation between gross polyhedrons. If the surface is strongly self-mulching, i.e. a mass of granules ("*grumic*"), or if the soil is cultivated while cracks are open, the cracks may be filled mainly by granular materials from the soil surface but they are open in the sense that the polyhedrons are separated. A crack is regarded as open if it controls the infiltration and percolation of water in dry, clayey soil (Soil Survey Staff, 1996). If the soil is irrigated the upper 50 cm has a coefficient of linear extensibility (COLE) of 0.06 or more throughout.

VERTISOLS (VR)

Other soils having

1. *fluvic* soil material starting within 25 cm from the soil surface and continuing to a depth of at least 50 cm from the soil surface; *and*
2. no diagnostic horizons other than a *histic*, *mollic*, *ochric*, *takyric*, *umbric*, *yermic*, *salic* or *sulfuric* horizon.

FLUVISOLS (FL)

Other soils having

1. a *salic* horizon starting within 50 cm from the soil surface; **and**
2. no diagnostic horizons other than a *histic*, *mollic*, *ochric*, *takyric*, *yermic*, *calcic*, *cambic*, *duric*, *gypsic* or *vertic* horizon.

SOLONCHAKS (SC)

Other soils having

1. *gleyic* properties within 50 cm from the soil surface; **and**
2. no diagnostic horizons other than a anthraquic, *histic*, *mollic*, *ochric*, *takyric*, *umbric*, *andic*, *calcic*, *cambic*, *gypsic*, *plinthic*, *salic*, *sulfuric* or *vitric* horizon within 100 cm from the soil surface.

GLEYSOLS (GL)

Other soils having

1. **either** a *vitric* **or** an *andic* horizon starting within 25 cm from the soil surface; **and**
2. having no diagnostic horizons (unless buried deeper than 50 cm) other than a *histic*, *fulvic*, *melanic*, *mollic*, *umbric*, *ochric*, *duric* or *cambic* horizon.

ANDOSOLS (AN)

Other soils having a *spodic* horizon starting within 200 cm from the soil surface, underlying an *albic*, *histic*, *umbric* or *ochric* horizon, or an *anthropedogenic* horizon less than 50 cm thick.

PODZOLS (PZ)

Other soils having **either**

1. a *petroplinthic* horizon starting within 50 cm from the soil surface; **or**
2. a *plinthic* horizon starting within 50 cm from the soil surface; **or**
3. a *plinthic* horizon starting within 100 cm from the soil surface when underlying either an *albic* horizon or a horizon with *stagnic* properties.

PLINTHOSOLS (PT)

Other soils

1. having a *ferralic* horizon at some depth between 25 and 200 cm from the soil surface; **and**
2. lacking a *nitic* horizon within 100 cm from the soil surface; **and**
3. lacking a layer which fulfils the requirements of an *argic* horizon and which has in the upper 30 cm, 10 percent or more water-dispersible clay (unless the soil material has *geric* properties or more than 1.4 percent organic carbon).

FERRALSOLS (FR)

Other soils having a *natric* horizon within 100 cm from the soil surface.

SOLONETZ (SN)

Other soils having

1. an eluvial horizon, the lower boundary of which is marked, within 100 cm from the soil surface, by an *abrupt textural change* associated with *stagnic* properties above that boundary; **and**

2. no *albeluvic tonguing*.

PLANOSOLS (PL)

Other soils having

1. a *mollic* horizon with a moist chrome of 2 or less if the texture is finer than sandy loam, or less than 3.5 if the texture is sandy loam or coarser, both to a depth of at least 20 cm, or having these chromes directly below any plough layer; **and**

2. concentrations of *secondary carbonates* starting within 50 cm of the lower limit of the Ah horizon but within 200 cm from the soil surface; **and**

3. no *petrocalcic* horizon between 25 and 100 cm from the soil surface; **and**

4. no secondary gypsum; **and**

5. no uncoated silt and sand grains on structural ped surfaces.

CHERNOZEMS (CH)

Other soils having

1. a *mollic* horizon with a moist chrome of more than 2 to a depth of at least 20 cm, or having this chrome directly below any plough layer; **and**

2. concentrations of *secondary carbonates* within 100 cm from the soil surface; **and**

3. no diagnostic horizons other than an *argic*, *calcic*, *cambic*, *gypsic* or *vertic* horizon.

KASTANOZEMS (KS)

Other soils having

1. a *mollic* horizon; **and**

2. a base saturation (by 1 M NH₄OAc) of 50 percent or more and a calcium carbonate-free soil matrix at least to a depth of 100 cm from the soil surface, or to a contrasting layer (lithic or paralithic contact, *petrocalcic* horizon) between 25 and 100 cm; **and**

3. no diagnostic horizons other than an *albic*, *argic*, *cambic* or *vertic* horizon, or a *petrocalcic* horizon³ in the substratum.

³ A *petrocalcic* horizon may be present locally (e.g. tile "Tosca" in Argentina). Such *petrocalcic horizons are considered to be polygenetic and may best be handled for classification purposes at phase level (e.g. Luvic Phaeozem, Tosca phase)*.

PHAEZEMS (PH)

Other soils having

1. **either** a *gypsic* or *petrogypsic* horizon within 100 cm from the soil surface, **or** 15 percent (by volume) or more gypsum, which has accumulated under hydromorphic conditions, averaged over a depth of 100 cm; **and**

2. no diagnostic horizons other than an *ochric* or *cambic* horizon, an *argic* horizon permeated with gypsum or calcium carbonate, a *vertic* horizon, or a *calcic* or *petrocalcic* horizon underlying the *gypsic* horizon.

GYPSISOLS (GY)

Other soils having a *duric* or *petroduric* horizon within 100 cm from the soil surface.

DURISOLS (DU)

Other soils having

1. a *calcic* or *petrocalcic* horizon within 100 cm of the surface; **and**

2. no diagnostic horizons other than an *ochric* or *cambic* horizon, an *argic* horizon which is calcareous, a *vertic* horizon, or a *gypsic* horizon underlying a *petrocalcic* horizon.

CALCISOLS (CL)

Other soils having an *argic* horizon within 100 cm from the soil surface with an irregular upper boundary resulting from *albeluvic tonguing* into the *argic* horizon.

ALBELUVISOLS (AB)

Other soils having

1. an *argic* horizon, which has a cation exchange capacity (by 1 M NH₄OAc) of 24 cmol_c kg⁻¹ clay or more, either starting within 100 cm from the soil surface, or within 200 cm from the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout; **and**

2. *alic* properties in the major part between 25 and 100 cm from the soil surface; **and**

3. no diagnostic horizons other than an *ochric*, *umbric*, *albic*, *andic*, *ferric*, *nitic*, *plinthic* or *vertic* horizon.

ALISOLS (AL)

Other soils having

1. a *nitic* horizon starting within 100 cm from the soil surface; **and**

2. gradual to diffuse horizon boundaries between the surface and the underlying horizons; **and**

3. no *ferric*, *plinthic* or *vertic* horizon within 100 cm from the soil surface.

NITISOLS (NT)

Other soils having

1. an *argic* horizon, which has a cation exchange capacity (by 1 M NH₄OAc) of less than 24 cmol_c kg⁻¹ clay in some part, either starting within 100 cm from the soil surface, or within 200 cm from the soil surface if the *argic* horizon is overlain by loamy sand or coarser textures throughout, **and**

2. a base saturation (by 1M NH₄OAc) of less than 50 percent in the major part between 25 and 100 cm.

ACRISOLS (AC)

Other soils having an argic horizon with a cation exchange capacity (by 1 M NH₄OAc) equal to or more than 24 cmol_c kg⁻¹ clay throughout.

LUVISOLS (LV)

Other soils having an *argic* horizon.

LIXISOLS (LX)

Other soils having

1. an *umbric* horizon; **and**
2. no diagnostic horizons other than an *anthropedogenic* horizon less than 50 cm thick, or an *albic* or *cambic* horizon.

UMBRISOLS (UM)

Other soils having **either**

1. a *cambic* horizon; **or**
2. a *mollic* horizon overlying a subsoil which has a base saturation (by 1 M NH₄OAc) of less than 50 percent in some part within 100 cm from the soil surface; **or**
3. one of the following diagnostic horizons within the specified depth from the soil surface:
 - a. an *andic*, *vertic* or *vitric* horizon starting between 25 and 100 cm;
 - b. a *plinthic*, *petroplinthic* or *salic* horizon starting between 50 and 100 cm, in the absence of loamy sand or coarser textures above these horizons.

CAMBISOLS (CM)

Other soils having

1. a texture which is loamy sand or coarser **either** to a depth of at least 100 cm from the soil surface, **or** to a *plinthic*, *petroplinthic* or *salic* horizon between 50 and 100 cm from the soil surface; **and**
2. less than 35 percent (by volume) of rock fragments or other coarse fragments within 100 cm from the soil surface; **and**
3. no diagnostic horizons other than an *ochric*, *yermic* or *albic* horizon, or a *plinthic*, *petroplinthic* or *salic* horizon below 50 cm from the soil surface, or an *argic* or *spodic* horizon below 200 cm depth.

ARENOSOLS (AR)

Other soils.

REGOSOLS (RG)

INDIGENOUS KNOWLEDGE ON SOIL CLASSIFICATION

Concepts on “Indigenous Knowledge”

Indigenous knowledge (IK) is defined as '... the unique, traditional, local knowledge existing within and developed around the specific conditions of women and men indigenous to a particular geographic area (Grenier, 1998; Larson, 1998). Indigenous knowledge, which is also referred to as 'traditional' or 'local' knowledge, is embedded in the community and is unique to a given culture, location or society. The term refers to the large body of knowledge and skills (Indigenous Knowledge Systems and Practices/IKSP, Indigenous Technological Knowledge/ITK) that has been developed and evolved outside the formal educational system, and that enables communities to survive.

The domination of the western knowledge system has led to the prevailing situation whereby indigenous knowledge is ignored and neglected. It is thus easy to forget that, over many years, human beings have been producing knowledge and strategies enabling them to survive in a balanced relation with their natural and social environment. As IK is closely related to survival and subsistence, it provides a basis for local-level decision making in food security, human and animal health, education, natural resource management and various other community-based activities.

IK is dynamic and is a result of a continuous process of experimentation, innovation, and adaptation. It has the capacity to blend with knowledge based on science and technology, and should therefore be considered complementary to scientific and technological efforts to solve problems in social and economic development. IK has the disadvantage of not having been captured and stored in a systematic way. The main reason for this constraint is that it is mostly handed down orally from generation to generation. This creates a danger that IKSP may become extinct.

The salient characteristics of Indigenous Knowledge:

- IK is generated within communities
- IK is location and culture specific
- IK is the basis for decision making and survival strategies
- IK is not systematically documented
- IK concerns critical issues of human and animal life: primary production, human and animal life, natural resource management
- IK is dynamic and based on innovation, adaptation, and experimentation
- IK is oral and rural in nature

The role of indigenous knowledge in development

In recent years there has been a remarkable increase in interest in the role that indigenous knowledge (IK) can play in truly participatory approaches to sustainable development. Indigenous knowledge systems contain a wealth of local ecological knowledge and are a key to understanding the sociocultural context of rural producers, thus representing a way to address problems that have plagued agricultural development programs for a long time (Ettema, 1994). The growing interest in IK is reflected in the numerous activities generated within communities, which are recording their knowledge for use in their school systems and for planning

purposes; within national institutions, where indigenous knowledge systems are now being regarded as an invaluable national resource; and within the development community, where IK provides opportunities for designing development projects that emerge from priority problems identified within a community, and which build upon and strengthen community-level knowledge systems and organizations.

It may not be accidental that the growing interest in the potential contribution of indigenous knowledge to development is becoming manifest at a time when current development models have proven not too successful. Today, hundreds of millions of marginalized people all over the world are still being excluded from the mainstream of development. These people have not benefited from development efforts which have mostly been based on a top-down development model, with the maximization of productivity as its major target. The agricultural sector provides a prime example. The objective of the Green Revolution was to maximize yields through the introduction of new crops. These crops depended on the optimal availability of fertilizers and water to achieve high yields. From a production point of view the Green Revolution was a success, but its potential could only be fully realized in areas with good soil and a secure water supply, and by farmers with access to financial inputs. However, for people without good land, no adequate access to irrigation facilities and a lack of financial means, the results have been of little use.

Many case studies and research projects have shown that there are no simple technical Western solutions that can be easily diffused and adopted by people on the margins. New insights reveal that development interventions have failed to induce people to participate because of the absence of instruments and mechanisms that enable them to use their own knowledge. Recent research has given valuable insights into how people use their own locally generated knowledge to change and to improve, for example, natural resource management. Greater efforts therefore should be undertaken to strengthen the capacity of local people to develop their own knowledge base and to develop methodologies to promote activities at the interface of scientific disciplines and indigenous knowledge.

Indigenous soil classification systems

A growing number of field studies have focused on the importance and usefulness of indigenous soil taxonomies as they relate to agricultural production. Indigenous soil classification systems are found in many parts of the world: Africa, Latin America, Southeast Asia (Table 5). They form the basis for decisions on land use practices including cropping systems and soil conservation techniques. The indigenous soil taxonomy is not only useful to the farmer but also could serve as a guiding complementary tool to scientifically based systems. However, many soil surveys have ignored the indigenous soil classification (Tabor, 1990). But evidence indicates that the soil scientist may gain time and insights if he/she knows the local indigenous soil classification system. For instance, based on investigations in Tabora region (Tanzania), Acres (1984) indicates that the results of systematic soil survey can be related to the soil *nomenclature* used by local farmers and their assessment of soil suitability for cultivation. In addition, the use of local names helps to alleviate the language barriers between administrators, planners, soil specialists, extensionists/agriculturalists and farmers.

Table 5. Records on some existing indigenous soil classification systems

Source	People (from)
Bellon and Taylor, 1993	Chiapas, South Mexico
William and Ortiz-Solorio, 1981	Tepetlaozoc, East Mexico
Carter, 1969	Kekchi people, Gutemala
Furbee, 1989; Guillet, 1992	Lari people, Guatemala
Msanya <i>et al.</i> ,1998; 2000	Iraqw people Mbulu and Karatu ~ Tanzania
Hatibu <i>et al.</i> , 2000	Sukuma people of Lake Zone ~ Tanzania
Behrens, 1989	Shipibo people, Peru
Stacishin de Queroz & Norton, 1992	Coatinga region, Brazil
Posey, 1989	Mebengokre people, Brazil
Zimmerer, 1994	Cochabamba, Bolivia
Knapp, 1991	Andes, Equador
Ollier <i>et al.</i> , 1971	Baruya people, New Guinea
Conklin, cited in Marten & Vityakon, 1986	Hanunoo people, Phillipines
Marten & Vityakon 1986	Java, Indonesia
Marten & Vityakon 1986	Thailand
Acres, 1984	Tabora region, Tanzania
Drovak, 1988	India
Kerven & Sikana, 1988	Northern Province, Zambia
Malinowski, cited in Weinstock, 1984	Trobriand Islands, Melanesia
Weinstock, 1984	Malaysia
Taylor-Powell <i>et al.</i> , 1991	Hamdallaye, Niger
Osunade, 1988	Yoruba people, Nigeria
Dialla, 1993	Mossi people, Burkina Faso
Malcolm, cited in Weinstock, 1984	Sukuma people, Tanzania
Arntzen, cited in Reijntjes <i>et al.</i> , 1992	Gaborone, Botswana
Dolva <i>et al.</i> , 1988	Northern Province, Zambia
Improved from Ettema, 1994	

Comparing Indigenous and “Western” Soil Classifications

According to indigenous soil classification systems (unlike the Western Classification Systems which use a multitude of attributes) normally use very few attributes in recognizing soil types, in particular soil color and texture. Other physical characteristics are recognized but are not used formally in these classifications.

Indigenous soil classification systems are based more on surface characteristics unlike the Western Classifications which focus on the whole soil to a depth of close to two metres (if there is no limiting layer) and apply the concepts of soil profile and pedon characteristics (Ettema, (1994; Msanya *et al.*, 2000). The main diagnostic features that differentiate western soil taxa are the character and sequence of soil horizons of a soil profile.

While indigenous soil classification systems are primarily functional in orientation (Furbee, 1989), common western soil classifications divide their soils primarily based on knowledge about pedogenesis.

Extract from “The IRAQW Soil Classification System, Tanzania” (An example of Indigenous Soil Taxonomy) (Msanya *et al.*, 2000)

Preamble

The Department of Soil Science at Sokoine University of Agriculture in Morogoro, Tanzania, conducted research on the indigenous knowledge of soils in selected villages in the Mbulu and Karatu districts of the Arusha region of Tanzania. The study focused on the local soil classification system used by the *Iraqw* people in these districts and attempted to identify the local diagnostic criteria for differentiating soil types as well as to explain how indigenous knowledge of soils has been applied to land use. Data were collected using participatory rural appraisal (PRA) techniques with men and women farmers. These included group discussions, interviews, direct field walks and observations.

The *Iraqw* live in the Mbulu, Karatu, Hanang and Babati districts of the Arusha region in Tanzania. They migrated from Kondoa-Irangi in the central region of Tanzania in search of more land to accommodate their fast-growing population. In the research area, the Mbulu and Karatu districts, the *Iraqw* now make up 65 per cent of the population. Being traditional agro-pastoralists, the *Iraqw* operate a production system whereby manure produced by livestock is put on the fields, while the livestock are fed on crop residues. The main crops include maize, wheat, barley, beans, sorghum, sweet potato, Irish potato, and peas. The main livestock are cattle, goats, sheep and pigs. The high livestock densities typical in many areas of the districts have resulted in serious land degradation problems, particularly soil erosion, which is quite rampant.

Results

Detailed information was produced and can be used for further ethno-taxonomical research at Sokoine University of Agriculture. What is important to report here is the system by which *Iraqw* farmers classify soil and use the land.

The *Iraqw* soil classification system is based largely on surface characteristics, unlike the more technological classification systems, which focus on the whole soil to a depth of close to two metres (if there is no limiting layer) and which apply the concepts of soil profile and pedon characteristics. These well established systems of soil classification - such as the FAO-UNESCO and USDA Soil Taxonomy systems - have good reasons for using these concepts since plants depend not only on the surface soil for their growth, but also on the subsoil. Yet if we are serious about integrating local knowledge into development efforts, it is essential to start from an understanding of the ethno-taxonomy of soils.

Interviews and discussions with local people in Mbulu and Karatu revealed clearly that when they talk of a particular soil type they are referring to the soil as seen in terms of its surface characteristics. There are two basic principles behind the framework of the *Iraqw* classification:

1. Most soil names start with the formative element '*Hhaper*' which literally means soil.
2. *Hhaper* is then followed by one or more adjectives which describe the type of soil in terms of the properties of its top layer. Examples of such properties include:

Soil colour. A typically red soil would be called *Hhaper daäten*, which simply means red soil (*Daäten* means red). Likewise, *Hhaper bo'o* means dark or black soil and *Hhaper Sir-daäten* means reddish brown soil.

Soil texture. A clayey soil would be called *Hhaper tlei* (*tlei* means clay). *Hhaper sasagwan* is typically a coarsely textured soil.

Soil workability (consistency). The soil type known as *Hhaper bulgar bo'o* is named for its hard consistency and difficult workability (*bulgar*). In the research area, *Hhaper bulgar bo'o* is associated with other characteristics as well, notably deep and wide cracking, which

starts at the surface and extends to depths of more than 50 cm.

Presence of salts. The soil type *Hhaper Hharki* is a salty soil (*Hharki* means salt).

Water-logged conditions. *Hhaper naari* is a soil saturated with water (*Naari* means water-logged).

Other qualifiers:

Position in the landscape. Soils on valley floors and floodplains, for example, are generally called *Hhaper baraduxa* (*Baraduxa* means river valley or floodplain).

Occasionally subsoil characteristics are used. For example the soil type *Hhaper baraduxa* (valley-floor soil) is characterized by stratification which can be seen only when the soil is exposed. Another example is *Hhaper busli Awak*, which forms deep and wide gullies that expose saprolite, a rock that weathers to a whitish colour.

Based on their knowledge of soil types, farmers decide the use to which a particular piece of land can best be put. For example, they attribute a high fertility status to *Hhaper bo'o* because it has a dark colour, feels humid because of its high organic content, and is easy to work with. Thus they use it for beans, sweet potatoes, bananas, maize, pigeon peas, wheat, sorghum, barley, wheat, sunflower, sugarcane, vegetables and all other crops. Another example is *Hhaper bulgar bo'o*. The Iraqw observe that this type of soil expands when wet, shrinks and cracks upon drying, is very sticky and difficult to till, and contains salts. They thus know that it is best suited for grazing. The farmers put soils which they judge to be unfit for agricultural production to other uses. For example, the coarsely textured soils are used for road construction, and the fine, sticky and powdery soils are used for plastering walls and making pots and bricks.

Conclusion and recommendation

The study revealed that farmers are familiar with the various soils in their localities. This confirms findings among farmers in other countries. Soil scientists and the managers of land resources should recognize the existence of local knowledge pertaining to local soils, and should incorporate this into their professional assessments of the suitability of soil and land. This would facilitate communication between the two parties for the purpose of developing plans for sustainable land use.

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