THE WORLD REFERENCE BASE FOR SOIL RESOURCES

An Introduction with Special Reference to

Soils of Tropical Forest Ecosystems

Otto C. Spaargaren
Jozef Deckers

1995

INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE
THE WORLD REFERENCE BASE FOR SOIL RESOURCES

An introduction with special reference to soils of tropical forest ecosystems

Otto C. Spaargaren¹ and Jozef Deckers²

Abstract. The World Reference Base for Soil Resources (WRB) is the successor to the International Reference Base for Soil Classification (IRB). Its task is to apply the IRB principles of definitions and linkages to the existing classes of the Revised FAO-Unesco Soil Map of the World Legend (FAO, 1988). The main objective is to provide scientific depth and background, and to ensure that the latest knowledge relating to global soil resources and interrelationships is incorporated in a world-wide soil reference system.

At present, it is proposed that WRB comprises 29 major soil groups. Three new major soil groups, i.e. Cryosols, Stagnosols and Umbrisols, are introduced compared with the Revised Legend, Greyzems are deleted, Acrisols and Lixisols are amalgamated and named Lixisols, and Podzoluvisols renamed Glossisols. The concept and terminology of diagnostic horizons and properties is retained and expanded. In addition, diagnostic soil materials are defined. In the description and definition of the WRB diagnostic horizons, properties and materials emphasis is placed on field identification. Analytical criteria are given to help the

¹ International Soil Reference and Information Centre, P.O. Box 353, 6700 AJ Wageningen, The Netherlands. Tel: +31-(0)317-471711; fax: +31-(0)317-471700; E-mail: ISRIC@RCL.WAU.NL

² Institute for Land and Water Management, Catholic University of Leuven, Vital Decosterstraat 102, B-3000 Leuven, Belgium. Tel: +32-(0)16-231381; fax: +32-(0)16-230607; E-mail: SEPPE.DECKERS@AGR.KULEUVEN.AC.BE
identification. Some modifications are proposed to diagnostic horizons, properties and materials as defined in the Revised Legend and a number of new ones are formulated. The basic philosophy of WRB is that the soil groups must represent a minimal geographical coverage and are the result of a major pedogenetic process. Soils are characterized by their morphological expression rather than by analytical data. In a number of proposed major soil groups this has led to divisions and in others to amalgamation.

Ferralsols, Lixisols (Acrisols and Lixisols in the FAO-Unesco Revised Legend), Alisols and Nitisols are the main major soil groups in tropical forest ecosystems occupying well drained upland positions. Other soil groups of local or regional importance are Andosols, Podzols, Umbrisols and Arenosols. The main soils occupying poorly drained positions in the tropics are Histosols, Fluvisols, Plinthosols, Gleysols and Glossisols, and, to a lesser extent, Planosols and Stagnosols.

On one hand, the World Reference Base for Soil Resources, like the FAO-Unesco Legend, continues to build up on existing soil classification systems. Examples are the description, definition and subdivision of Anthrosols and Andosols. On the other hand, some proposals result from new ideas which are not yet reflected in published classification systems.

The final aim is a well described and defined World Reference Base for Soil Resources that is internationally accepted by the community of soil scientists. It also intends to facilitate the international use of pedological data, not only by soil scientists, but also by other users of soil and land.
1. INTRODUCTION

It is a matter of great concern that after some hundred years of modern soil science one system of soil classification has not yet been adopted universally (Dudal, 1990a). This situation arises partly from the fact that soils constitute a continuum which, unlike individual plants and animals, needs to be subdivided into classes by convention. To remedy this situation work has been going on during the past 15 years to arrive at what now is known as a *World Reference Base for Soil Resources*.

**History.** The World Reference Base for Soil Resources (WRB) is the successor to the International Reference Base for Soil Classification (IRB), an initiative of the International Society of Soil Science (ISSS). The intention of the IRB project was to arrive at a framework through which existing soil classification systems could be correlated and ongoing soil classification work harmonized. The objective was to reach an international agreement on major soil groupings to be recognized at a global scale and on the criteria and methodology to be applied for defining and separating them. Such an agreement was meant to facilitate the exchange of information and experience, to provide a common scientific language, to strengthen the applications of soil science, and to enhance the communication with other disciplines.

The IRB proposed during the 14th International Congress of Soil Science in Kyoto, Japan, some 20 major soil groupings (Dudal, 1990b). Some of these groupings, however, were so broad that it proved difficult to prepare consistent definitions. As a result these major soil groupings had to be split in order to obtain a meaningful subdivision. When comparing the
20 IRB units and the 28 major soil groupings which were defined in Revised Legend of the Soil Map of the World (FAO, 1988), the question arose if it was justified to develop the two systems side by side. If one were to take into account the need for a further split of some IRB units the result would be an almost identical list of units. Moreover, since both the IRB and the Soil Map of the World were co-sponsored by the ISSS, it was felt inappropriate to pursue two programmes simultaneously, which essentially had the same goal, namely to support the inventory of global soil resources.

It was therefore decided that the IRB should adopt the Revised Legend as the frame for its further work. It would become IRB’s task to apply its principles of definitions and linkages to the existing soil units to give them more depth and validation. The merger of the two efforts was launched under the name: ‘World Reference Base for Soil Resources’, an ISSS/FAO/Unesco/ISRIC undertaking. During the 15th World Congress of Soil Science in Acapulco, Mexico, a Draft World Reference Base for Soil Resources (Spaargaren, 1994) was presented for further comments and scrutiny.

**Objectives and principles.** The main objective of the World Reference Base for Soil Resources is to provide scientific depth and background to the Revised Legend, so that it incorporates the latest knowledge relating to global soil resources and interrelationships. More specifically, the objectives are:

- to develop an internationally acceptable framework for delineating soil resources to which national classification systems can be related and through which the national systems can be linked, using the Revised Legend as a guideline;
- to provide this framework with a sound scientific basis so that it facilitates the 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, architects, etc.;
- to acknowledge in the framework important lateral relationships of soils and soil horizons as characterized by topo- and chronosequences; and
- to emphasize the morphological characterization of soils rather than to follow an approach purely based upon laboratory analyses.

Consequently, the basic framework of the FAO-Unesco Legend, with its two categoric levels and guidelines for developing classes at a third level (Nachtergaele et al., 1994), was adopted. The principles that govern this class differentiation and which are also applied in the WRB, are:

- At the first categoric level classes are differentiated mainly according to the primary pedogenetic process which has produced the characteristic soil features. In certain cases it appears that soil parent materials have overriding importance, such as in Vertisols, Andosols and Arenosols.

- At the second categoric level classes are differentiated according to important aspects affecting soil use and management, such as gleyic or stagnic properties, eutric/dystric characteristics, etc., as well as any predominant secondary soil forming process that has significantly affected the primary soil features.
Elements of the World Reference Base for Soil Resources. For describing and defining
the major soil groups and soil units of the WRB, use is made of soil characteristics,
properties and horizons, which in combination will define soils and their interrelationships.

Soil characteristics are single parameters which are observable or measurable in the field,
in the laboratory, or can be analyzed by using microscope techniques. They include
characteristics such as colour, texture and structure of the soil, features of biological
activity, arrangement of voids and pedogenetic concentrations (mottles, cutans, nodules, ....)
as well as analytical determinations (soil reaction, particle-size distribution, cation exchange
capacity, exchangeable cations, amount and nature of soluble salts, ...).

Soil properties are combinations ("assemblages") of soil characteristics which are known
to occur in soils and which are considered to be indicative of present or past soil-forming
processes (e.g. vertic properties are a combination of heavy texture, smectitic mineralogy,
gilgai, slickensides, hard consistence when dry, sticky consistence when wet, shrinking
when dry and swelling when wet).

Soil horizons are three-dimensional pedological bodies which are more or less parallel to
the earth's surface. Each horizon is characterized by one or more properties, occurring over
a certain depth, with a certain degree of expression. The thickness varies from a few
centimetres to several metres; most commonly it is about a few decimeters. The upper and
lower limits ("boundaries") are diffuse, gradual, clear or abrupt. Laterally, the extension of
a soil horizon varies greatly, from a metre to several kilometres. However, a soil horizon
is never infinite. Laterally, it disappears or grades into another horizon.
Major soil groups are defined by a vertical combination of horizons within a defined depth, and by the lateral organization of these horizons, or by the lack of them.

Soil horizons and properties are intended to reflect the expression of genetic processes which are widely recognized as occurring in soils. They can therefore be used to describe and define soil classes. They are considered to be "diagnostic" when they reach a minimum degree of expression, which is determined by visibility, prominence, measurability, importance and relevance for soil formation and soil use, and quantitative criteria. To be considered diagnostic, soil horizons also require a minimum thickness, which must be appraised in relation to bioclimatic factors (e.g. a podzolic B horizon in boreal regions is expected to be less thick than one in the tropics).

Table 1 illustrates the interrelationships between soil characteristics, diagnostic properties, diagnostic horizons and major soil groups, with Ferralsols as an example.

It is recognized that a number of the major soil groups may occur under different climatic conditions. It was decided, however, not to introduce separations on account of climatic characteristics in order to keep the units within manageable limits and in order not to subordinate the classification of soils to the availability of climatic data.
Table 1. Relationships for Ferralsols and ferralic soil units between soil characteristics, diagnostic properties, thickness, diagnostic horizons and major soil groups.

<table>
<thead>
<tr>
<th>Soil characteristic</th>
<th>Limiting value</th>
<th>Diagnostic property</th>
<th>Thickness</th>
<th>Diagnostic horizon</th>
<th>Major soil group</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC</td>
<td>≤24 cmol$_e$ kg$^{-1}$ clay</td>
<td>Ferralic (protic)</td>
<td>(≥15 cm)</td>
<td>(Cambic)</td>
<td>Ferralic Cambisols</td>
</tr>
<tr>
<td></td>
<td>≤16 cmol$_e$ kg$^{-1}$ clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ECEC*</td>
<td>&lt;12 cmol$_e$ kg$^{-1}$ clay</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>&lt;1.5 cmol$_e$ kg$^{-1}$ clay</td>
<td>Geric</td>
<td>(≥30 cm$^*$)</td>
<td>Ferralic</td>
<td>Geric Ferralsols</td>
</tr>
<tr>
<td>Soil reaction</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH$<em>{KCl}$ - pH$</em>{water}$ ≥0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water-dispersible clay</td>
<td>&lt;10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gravel content**</td>
<td>&lt;90%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weatherable minerals*</td>
<td>&lt;10%</td>
<td>Ferralic (orthic)</td>
<td>(≥30 cm$^*$)</td>
<td>Ferralic</td>
<td>Other Ferralsols</td>
</tr>
<tr>
<td>Texture***</td>
<td>sandy loam or finer</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Structure</td>
<td>weak to moderate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Failing one or more of these the soil classifies as Ferralic Cambisol. ** Failing this the soil classifies as Leptosol. *** Failing this the soil classifies as Ferralic Arenosol.
2. THE MAJOR SOIL GROUPS IN THE WRB

The WRB major soil groups. The 29 major soil groups presently proposed are Histosols, Anthrosols, Leptosols, Cryosols, Vertisols, Fluvisols, Solonchaks, Gleysols, Andosols, Podzols, Plinthosols, Ferralsols, Planosols, Solonetz, Chernozems, Kastanozems, Phaeozems, Gypsisols, Calcisols, Glossisols, Stagnosols, Alisols, Nitisols, Lixisols, Luvisols, Umbrisols, Cambisols, Arenosols and Regosols.

New groups and shifts at the highest level. The newly introduced major soil groups are Cryosols, Stagnosols and Umbrisols. 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.

Stagnosols combine a variety of soils which are influenced by surface water, unlike the Gleysols which are conditioned by groundwater. They show a typical stagnic colour pattern resulting from temporary reducing conditions in the upper 50 cm of the soil, on top of an oxidized subsoil.

Umbrisols are proposed to cover the soils which have an umbric horizon. They are a logical counterpart of the Chernozems, Kastanozems and Phaeozems.

Acrisols and Lixisols are amalgamated (and named Lixisols) as their difference is solely based on base saturation which is to be reflected at a second level. The amalgamation does
not affect the geographical coherence as both soils occur in tropical/subtropical regions, Acrisols towards the wetter parts and Lixisols in the drier areas.

The Podzoluvisols as known in the FAO-Unesco Revised Legend have been renamed Glossisols in the WRB. The name Podzoluvisol 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 (resulting in ‘albeluvic tonguing’). The name Glossisols, which was already considered during the development of the Legend of the Soil Map of the World (FAO-Unesco, 1974), is therefore thought to be more appropriate.

For the World Reference Base it was decided to exclude from the Leptosols soils which have pedogenetic horizons such as indurated calcic or gypsic horizons or hardened plinthite. This necessitated inclusion of these soils in the appropriate major soil group. Included in the Plinthosols, Gypsisols and Calcisols are soils which have a petroplinthic, petrogypsic or petrocalcic layer at shallow depth. In the Revised Legend the latter soils belong to the Leptosols.

Although it is realized that soils with shallow petroplinthic layers and soils having plinthite usually occupy different positions in the landscape, it was felt appropriate to group them together as they are genetically related.
3. WELL DRAINED SOILS OF TROPICAL FOREST ECOSYSTEMS

Four major soil groups constitute the main soils in well drained upland positions in the tropics, viz. Ferralsols, Lixisols (including the Acrisols of the FAO-Unesco Revised Legend), Alisols and Nitisols. Diagnostic for these soil groups are the presence of a ferralic horizon, an argic horizon dominated by low activity clays, alic properties, and a nitic horizon, respectively. Other soil groups of local or regional importance are Andosols (Southeast Asia, Central America), Podzols (South America, Southeast Asia), Umbrisols (tropical highlands) and Arenosols (South America, Africa, Southeast Asia).

The main characteristic of Ferralsols is the dominance of low activity clays (mainly kaolinite) resulting from strong weathering and mineral alteration. They can usually be recognized by their rather uniform appearance, their weak to moderately developed macrostructure and friable consistence, and gradual to diffuse horizon boundaries. Microstructure, however, is normally strongly developed, resulting in "pseudosand" or "pseudosilt" structures. The dominance of low activity clays is expressed by a low CEC, in Ferralsols of 16 cmolₖg⁻¹ clay or less (corrected for organic matter). In addition, they have a low content of water-dispersible clay. Some Ferralsols exhibit a significant clay increase somewhere in the solum, but this is not considered as an argic horizon if the water-dispersible clay content is low (less than 10%). These characteristics form together the requirements for the ferralic horizon, which is diagnostic for the Ferralsols.

Ferralsols have low nutrient reserves and available aluminium and manganese may reach toxic levels. Phosphate fixing capacity is usually high, more than 85%. The available water content is low (normally less than 100 mm per meter soil). The favourable physical
properties ensure that these soils are easy to work and hardly prone to erosion. However, the surface is liable to compaction and crusting if heavy machinery is used to clear forest. Ferralsols occur mainly in South America and Central Africa, and to a lesser extent in South and East Asia.

Lixisols are characterized by having an increase in clay content sufficient to meet the requirements for an argic horizon and by a rather advanced stage of weathering reflected in a CEC of less than 24 cmol_\(e\) kg\(^{-1}\) clay. They often show a clearly developed horizonation, particularly in the upper part of the soil. Many Lixisols have topsoils of sandy loam or sand clay loam textures with clear boundaries to an argic horizon having a sandy clay or clay texture. Soil structure is normally only weakly developed, although Lixisols with a high base saturation (the proper Lixisols in the Revised Legend) tend to have a somewhat better developed soil structure. Surface horizons of Lixisols are generally thin, with a low amount of organic matter, especially in regions with pronounced dry seasons. Only in tropical highlands, under fairly humid conditions and/or low temperatures, organic matter accumulation may be considerable.

Lixisols have poor chemical and physical properties. Adverse characteristics are the low nutrient retention capacity and nutrient reserves, the high aluminium saturation in many Lixisols, and a low structural stability of the topsoil. They are easily erodible. Careful soil management, including use of adapted varieties, is required to make these soils productive. Amongst the measures to be taken are minimum tillage (to prevent slaking and caking), preservation of the topsoil and its organic matter status, erosion control, split application of fertilizers and minimal disturbance when clearing the land.

Main Lixisol areas in the world are Southeast Asia, West Africa and Latin America.
Alisols form a relatively new group in the system. The name Alisols was coined in the Revised Legend for soils having an argic B horizon, a CEC of 24 cmol$_e$ kg$^{-1}$ clay or more and a base saturation (by $IM$ NH$_4$OAc) of less than 50%. This group of soils were separated from the Acrisols as originally defined in the 1974 FAO-Unesco Legend because they generally have a high total exchangeable aluminium content (FAO, 1988).

Conceptually, Alisols are soils with 2:1 clays (chlorite, smectite, vermiculite) in which a process of mineral alteration is taking place in silica and base depleted environment. This group of soils is characterized by an intermediate to advanced weathering stage, dominated by high activity clays, from which most primary minerals have disappeared. Through weathering of the secondary 2:1 clay minerals, large amounts of aluminium and magnesium are released, giving rise to the strongly acid conditions. The total reserve of bases (i.e. the content of total basic cations (Ca, Mg, K and Na), including both exchangeable and non-exchangeable pools, and expressed in cmol$_e$ kg$^{-1}$ soil) is concentrated mainly in the clay fraction and constitutes usually 80% or more of the total reserve of bases in the fine earth fraction. These characteristics define *alic properties* which are diagnostic for Alisols.

In the field, many Alisols have a dark coloured surface horizon with massive or weakly developed structures. Subsurface horizons normally have angular blocky or prismatic structures and develop cracks upon drying, unlike Lixisols and Ferralsols. They usually have a medium to high clay content, a low content in silt (silt-clay ratio less than 0.6) and are often derived from, or associated with, basic rocks.

Besides the specific chemical problems, Alisols have unfavourable physical properties in the surface horizon(s). The low structural stability of the surface horizon results in slaking and a reduced permeability and internal drainage (FAO, 1991). Alisols are known to be erosion-prone.
The importance of recognizing Alisols a major soil group is that these soils with high activity clay soils have a very high aluminium saturation, which is toxic to most plants. However, unlike the Lixisols, these soils may be made very productive after heavy fertilization and liming. Minimum tillage is recommended to preserve the surface soil. The extent of Alisols is not precisely known, but major occurrences are recorded from Southeast USA, Latin America, West Indies, West and East Africa, Indonesia and China.

Throughout the tropics and subtropics well drained soils occur which consist of dusky red to dark brown clays with a moderately strong to strong angular blocky structure. The peds are "polyhedral or nutty" elements and have shiny faces resulting from thin clay and/or manganese coatings or pressure faces. These soils, called Nitisols, have a high aggregate stability, friable consistence, high porosity, fair to good moisture storage capacity and an easy rooting. Horizon boundaries between the surface layer(s) and the underlying horizons are usually gradual to diffuse. The upper horizons contain variable amounts of organic matter and may be acid or neutral in reaction. They have in common that they are predominantly composed of low activity clay minerals. P-adsorption capacity is high but this does not, however, result in acute P deficiencies. Characteristic for the Nitisols is the occurrence of a nitic horizon. Besides the typical structure, nitic horizons have a clayey texture although in the field the material feels loamy. Most Nitisols show a gradual clay increase in the subsoil. Silt content is low (silt-clay ratios of 0.20-0.35) as is the water-dispersible clay content (less than 10% of the total clay). Usually no gravel or stone sized concretions are present, but some fine Fe/Mn concretions (’shot’) may occur.
The CEC (by \( IM \text{NH}_4\text{OAc} \)) in humus-poor nitic layers is between 8 and 24 cmol, kg\(^{-1}\) clay, sometimes higher. These values can increase substantially with an increase in organic matter. ECEC is about half of the CEC. This points to a predominance of 1:1 lattice type clay minerals (kaolinite, halloysite).

Typical for nitic horizons is the high amount of sesquioxidic minerals in the clay fraction, especially those of iron (total iron content may be as high as 15 percent). Hematite, goethite and gibbsite are the most common. Magnetite and maghemite are present in smaller but not insignificant amounts, making the soil material magnetic in dry conditions. Also crystalline titanium- and manganese oxides are present.

Main regions with Nitisols are East Africa, South Brazil, Central America and Southeast Asia (Java, Philippines).

Nitisols are much sought after for sustained smallholders’ farming and plantation crops such as cocoa and coffee, despite the low CEC and frequently low base saturation. The fact that these soils are less prone to erosion than most other upland soils in the (sub)tropics, their good tilth, easy workability and other favourable physical attributes have contributed to the success of sustainable low-input agriculture on these soils.

An important change in the concept of Alisols and Nitisols with respect to the Revised Legend is that these soils are not necessarily characterized by the presence of an argic horizon. Moreover, to separate Ferralsols from Nitisols in which all requirements for a ferralic horizon are met, Ferralsols are not permitted to have a nitic horizon.
The relationships between Ferralsols, Lixisols, Alisols and Nitisols, as well as with Vertisols\(^1\), based on pH, cation exchange capacity of the clay fraction, total reserve of bases and texture, is shown in Figure 1.

Figure 1. General scheme illustrating the conceptual linkages of some major soil groups and soil units in intertropical regions according to the CEC\(_{\text{clay}}\), TRB (total reserve of bases), texture and soil acidity (pH\(_{\text{KCl}}\)) in B horizons (modified after Delvaux & Herbillon, 1993).

\(^1\) Vertisols are clayey soils also dominated by 2:1 clays. However, these soils are less acid than Alisols and usually occur under less freely drained conditions in climates with a pronounced dry season.
4. POORLY DRAINED SOILS OF TROPICAL FOREST ECOSYSTEMS

Five major soil groups constitute the main soils in poorly drained positions in the tropics, viz. Histosols, Fluvisols, Plinthosols, Gleysols and Glossisols. Diagnostic for these soil groups are the presence of a thick *histic* horizon, *fluvic* properties, a *plinthic* or *petroplinthic* horizon, *glevic* properties and an *argic* horizon with an irregular upper boundary resulting from *albeluvic tonguing*, respectively. Soils of less importance in tropical forest ecosystems are Planosols, Stagnosols and gleyic or stagnic soil units of other major soil groups.

**Histosols** differ from other soils in that they are formed of 'organic soil material' with physical, chemical and mechanical properties that are very different from those of mineral soil materials. They develop in conditions where organic material is produced by an adapted (climax) vegetation, and where biochemical decomposition of plant debris is retarded by low temperatures, persistent waterlogging, extreme acidity, oligotrophy and/or the presence of high levels of electrolytes or organic toxins.

**Fluvisols** occur on materials deposited in aqueous sedimentary environments. Driessen and Dudal (1991) suggest that there are three situations where fresh material is continually added by sedimentation from water. These are (1) the inland fluvial and lacustrine fresh-water environments, (2) the marine environment and (3) the coastal salty or brackish marsh environment, of which deltas are a special case.
The concept of **Plinthosols** is one of soils affected, at present or in the past, by groundwater or stagnating surface water in which iron has been segregated to such an extent that a humus-poor, mottled layer has been formed, which irreversibly hardens when exposed to the air and sunshine. Included in the concept are those soils that have such a hardened layer at shallow depth.

**Gleysols** are soils influenced by groundwater, unlike Stagnosols, which are conditioned by stagnating surface water. The subsoil of Gleysols is permanently wet and reduced (unless drained), contains free Fe$^{2+}$ and/or has an rH (the negative logarithm of hydrogen pressure) of 19 or less. The topsoil may have features associated with oxidation, either by alternating moist/wet conditions, or by permanent aeration. This depends on variations of the groundwater table, but also on rainfall and evapotranspiration.

**Glossisols** may be found in tropical and subtropical regions with contrasting dry and rainy seasons. These soils can have a temporary perched water table which in lowland areas such as the Mekong Delta in Vietnam may well be above the soil surface. The soil parent materials are mainly alluvial deposits, possibly mixed locally with aeolian sediments. Glossisols in the tropics are frequently associated with hydromorphic soils having plinthite, which normally occupy the slightly lower landscape positions.
5. CORRELATION OF SOILS WITH TROPICAL FOREST ECOSYSTEMS

Well drained tropical forest ecosystems. Perhumid evergreen forest is the most dominant natural vegetation type in regions around the equator. These forests occur in areas without a prolonged dry period and precipitation exceeding 1600 mm annually, often more than 2000 mm (FAO-Unesco, 1971; 1977; 1979). Temperatures are high throughout the year with little variation between the seasons. In well drained sites these conditions favour strong weathering and leaching. Consequently, soils associated with these forests are mainly Ferralsols and Lixisols, and to a lesser extent, Alisols and Nitisols.

Where prolonged dry seasons occur or where soil moisture storage capacity in subhumid regions is too low to supply sufficient water during short dry periods, tropical deciduous and semideciduous forests or open woodlands occur. Dominant soils are Lixisols, associated with Nitisols and Ferralsols with minor occurrences of Alisols, or sandy soils (Podzols or Arenosols).

Semi-arid ("dry subhumid") areas usually have a shrub vegetation cover with isolated larger trees, some of which do have economic value. Soils associated with this vegetation generally are non-acid ("eutric") Lixisols and Arenosols.

In mountain regions with tropical evergreen and semideciduous forests Lixisols and Umbrisols prevail, associated with Leptosols (shallow soils overlying continuous hard rock) and Cambisols (moderately deep soils characterized with slight to moderate soil development). To a minor extent also Nitisols, Alisols and Histosols may be found.

Poorly drained tropical forest ecosystems. These tropical forest ecosystems are found in low-lying areas which are daily, seasonally or permanently inundated with fresh, brackish
or salt waters. Daily inundations, in particular with salt or brackish water, occur along the coastlines in many tropical regions, and give rise to vast mangrove forests. Dominant soils are Fluvisols, many of which contain sulphidic materials in the subsoil. When drained these soils become extremely acid (pH water less than 3.5).

In deltaic regions and other low-lying alluvial plains prolonged seasonal inundations may occur giving rise to fresh water swamp forests of which the different types of vegetation are usually closely related to the duration and depth of flooding. Main soils found here are Fluvisols and Gleysols, associated with Glossisols and Plinthosols.

Areas permanently inundated by fresh water have swamp or bog forests with Histosols and Gleysols as dominant soils.

Poorly drained areas influenced by groundwater at shallow depth often have a savanna woodland vegetation. Gleysols are the main soil type. Where the groundwater level fluctuates, Glossisols and Plinthosols may be dominant.

**Importance of forest cover for maintenance of fragile soil systems.** Many soils in tropical upland regions have in common a surface layer which is highly susceptible to degradation. The organic matter accumulation in the top parts of Ferralsols, Lixisols and Alisols is usually restricted to the first 10 centimetres. Organic matter in these soils contributes significantly to the nutrient holding capacity, water storage, and structural stability. Indiscriminate cutting will expose these fragile topsoils to sun and rain, and the content of organic matter will subsequently be rapidly reduced. This reduction often results in structural decline (compaction, crusting), loss of fertility and difficult regeneration of the vegetation.
The vegetation cover is also of great importance for the soil moisture balance and runoff protection. Under tropical forests the soil is kept almost permanently moist and a rather constant temperature is maintained. The foliage protects the surface from erosion. This is particularly important in areas with Plinthosols. These soils will harden irreversibly if they are not protected from desiccation or erosion. When hardened, Plinthosols are rendered practically useless.

Similarly, desiccation, either by cutting of the vegetation or by drainage, causes Thionic Fluvisols - common soils under mangrove forests - to become extremely acid through oxidation of the sulphide materials present.
6. CONCLUSION

Correlation with existing classification systems. The World Reference Base for Soil Resources (WRB), having taken the framework of the FAO-Unesco Revised Legend as guide, obviously bears many similarities to it. The nomenclature of the Revised Legend has been adopted, and, where necessary, adapted. Its concepts of diagnostic horizons and properties, supplemented by diagnostic soil materials, have been taken up. The original Legend (FAO, 1974) itself has been built on the knowledge and experience of many soil scientists from all over the world, and as such reflects a consensus of a number of classification systems. For instance, the separation of Greyzems, Chernozems and Kastanozems is related to the older Russian classification of Grey Forest soils, Chernozems and Chestnut soils. Similarly, Cambisols coincide largely with the German Braunerde and French Sols bruns, while Ferralsols closely follow the concept of the US Oxisols and Brazilian Latosols.

Many of the definitions in both the original and revised FAO-Unesco legends were adopted from the USDA-SCS Soil Taxonomy (Soil Survey Staff, 1975; 1987). These definitions are in most cases summarized and simplified, in accordance with the requirements of the legend.

The WRB also continues to build on existing classification systems. The proposals for the Anthrosols contain many elements from the recently published Chinese Soil Taxonomic Classification System (Gong, 1994). The description and definition of Andosols is closely related to that of the Andisols in the Référentiel Pédologique Français (RPF) (AFES, 1990); similarly the definition of the Podzols has been influenced by with the RPF criteria for
Podzosols, but to a lesser extent than for the Andosols. On the other hand, some of the proposals result from new ideas not yet reflected in published classification systems.

Definitions of diagnostic horizons, properties and materials derived from existing classification systems, not used in the Revised Legend, but which are proposed for the WRB, concern anthropic horizons, the anthraquic horizon sequence (Gong, 1994), and tephric soil material (Hewitt, 1992).

**Future developments.** The draft World Reference Base for Soil Resources is presently undergoing a period of testing and refining. Only such an exercise will show the strengths and weaknesses of the system. Particular emphasis is placed on determining sound field criteria. Limits between the major soil groups and soil units are checked for usefulness and pragmatism. Gaps are to be identified and removed. "Floating" soils, i.e. soils that are either difficult to classify or that are unsatisfactorily classified, need to be re-assessed and, consequently, the proposed WRB classes may have to be changed. Work continues on defining the second level ('soil units') and the development of the third and possible fourth level of classification.

It is hoped that the final result may become a well described and defined World Reference Base for Soil Resources, which is internationally acceptable by the soil science community and which facilitates the international use of pedological data, not only by soil scientists but also by other users of soil and land, such as geologists, agronomists, hydrologists, ecologists, farmers, foresters, botanists, civil engineers, architects, etc. Funds permitting, it may be supplemented by a publication on "Benchmark Soils of the World", in which the WRB soil units are briefly described and defined, their potential and problems highlighted and are illustrated by a typical pedon with relevant analytical data.
7. REFERENCES


