WORLD REFERENCE BASE FOR SOIL RESOURCES

INTRODUCTION
World Reference Base for Soil Resources

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Correct citation

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Editors’ Foreword

After four years of intensive work it is our pleasure on behalf of the ISSS Working Group RB to introduce the three volumes of the World Reference Base publications, which highlight the state of the art of the ‘World Reference Base for Soil Resources (WRB)’ at the eve of the 16th World Congress of Soil Science in Montpellier, France. The three publications are:

3. World Reference Base for Soil Resources.

The introduction to the World Reference Base for Soil Resources aims to serve as a first entry into the knowledge of soil diversity and soil distribution, accessible to disciplines other than ‘soil science sensu stricto’ and to a wider public.

After a historical overview of WRB and giving the rationale behind the system, soils are highlighted as they occur in the landscape. First the soil cover is presented as a continuum and lateral relationships which exist among soils as they are linked to natural soilscapes. In Chapter 2 a simplified key to the Reference Soil Groups allows the reader to set a first step towards soil classification. Chapter 3 brings the salient features of the 30 Reference Soil Groups by highlighting history, connotation, correlation with other systems of soil classification, concept and morphology, properties, geography, linkages, land use and management. The link to the real world is made by providing for each Reference Soil Group a typical colour picture as well as a typical landscape in which these soils are commonly occurring.

An attempt is made in this publication to express ideas without using specialized technical language. Occasional use of specific soil science terms has been unavoidable, therefore a glossary is given to explain these terms. For the accurate definitions and technical classification issues, the reader is referred to the “World Reference Base for Soil Resources”.

It is hoped that this publication will contribute to the assertion of soil science in the public debate and in the overall scientific community.

J.A. Deckers, O.C. Spaargaren and F.O. Nachtergaele
Chairman, Vice-Chairman and Secretary of the ISSS Working Group RB
As President of the International Society of Soil Science, and as active member and past-Chairman for 8 years (1986-1994) of the Working Group which has elaborated the WRB, I am pleased to present the first edition of the World Reference Base for Soil Resources.

The credibility of soil science suffers from the lack of a generally accepted system of soil classification. It seems imperative that a universal international agreement should be reached for the formulation and definition of Reference Soil Groups, at least one or two categories at the highest level of generalization. The very great diversity of soils in different countries may justify national systems at lower levels; it is indeed hardly possible that one overall system can simultaneously and adequately meet all global, regional and local objectives.

The World Reference Base is a good positive answer to this problem; WRB is not a complete classification system, but only, and this is essential, a basis, a framework, for better correlation between national systems of soil classification. We also hope that WRB can help the national systems to continue their elaboration.

WRB is the result of a large international cooperation. I want to thank all contributors who have given time and money with a lot of enthusiasm. In particular my thanks go to Jozef Deckers, Chairman of WRB since 1994, Otto Spaargaren, editor of the 1994 draft WRB, and Freddy Nachtergaele, who jointly produced this first edition; the work done is enormous.

This first edition is not a final one. It has to be used, discussed, criticized, completed and updated. It has to be transformed in function of the advances in soil science. A World Reference Base for Soil Resources has to be a complete picture of all scientific data about soils, soil evolution, soil use; WRB is not only for specialists in soil classification and soil cartography; WRB is for all soil science specialists and for all users of soil science results. The contribution of all is necessary to continue the construction of WRB.

Alain Ruellan
President of the International Society of Soil Science
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Chapter 1

Introduction

A common language is vital to the functioning of any science. It is a matter of great concern that after a hundred years of modern soil science a universally accepted system of soil classification has not yet been adopted. The credibility of soil science is suffering from the lack of such a generally accepted communication system. This situation arises partly from the fact that soils constitute a continuum which, unlike easily identifiable plants and animals, needs to be placed into classes by convention.

The International Society of Soil Science (ISSS) now has been working to develop this common language for naming the soils of the world.

• Background

In the early days of pedology the classification of soils was based mainly on soil genesis. The various schemes which were generated, differed according to the concepts of soil formation held by the authors. The first systems of soil classification were developed in environments which were strongly influenced by glacial and periglacial phenomena (Russia, Central and Western Europe, North America), and where geologically young parent material showed the mark of recent climatic conditions. As a result the logic behind these classification systems was difficult to apply to soils formed on older landscapes and developed in the strongly weathered materials of tropical and subtropical regions (Dudal, 1996).

The intensification of international communications and the expansion of soil surveys in the 1950s, both in temperate and in tropical areas, greatly enhanced the overall knowledge of the soil cover. Classification systems were developed which aimed to embrace the full spectrum of the soil continuum. Following consultations which took place on the occasion of the 6th International Congress of Soil Science, in Paris in 1956, it was decided that special attention should be given to develop the classification and correlation of the soils of great regions of the world. As a follow-up, soil maps covering Africa, Australia, Asia, Europe and South America - at scales ranging from 1:5 000 000 to 1:10 000 000 - were presented at the 7th International Congress held at Madison, United States, in 1960. This Congress recommended that ways and means be found to publish these maps, as they reflected a vast amount of knowledge on the properties of soils and on their distribution in different parts of the world.
It soon appeared that nomenclature, survey methods, legends and systems of classification varied so widely that inter-regional comparisons were difficult. Although a consensus had evolved as to the main soil bodies to be separated, major differences persisted with regard to the levels of generalization at which these soils were to be distinguished, the criteria to be used for their separation, and the weight to be attached to different soil properties in a classification system. Differences in terminology and nomenclature were an additional constraint to international correlation.

In response to a recommendation of the Madison Congress, and recognizing the need for an integrated knowledge of the soils of the world, FAO and Unesco, in association with the ISSS, agreed to jointly prepare a Soil Map of the World at scale 1:5 000 000. The project started in 1961. Successive drafts of the soil map and of the legend were prepared - under the authority of an international advisory panel - from a compilation of existing soil survey material, combined with systematic field identification and correlation. The internationally agreed legend was approved by the 9th International Congress of Soil Science, at Adelaide, Australia, in 1968. The first map sheets were published in 1971. Publication of all 18 maps and of 10 explanatory texts was completed by 1981 (FAO-Unesco, 1971-1981). It was the fruit of a worldwide collaboration between soil scientists from a great number of countries. The FAO-Unesco soil map differed from other overviews in that it reflected a consolidation of knowledge and experience of different schools of thought and of widely diverse sources of information. It provided a scientific basis for the transfer of research results between areas of similar environments and served as a useful instrument in planning agricultural and economic development (Dudal and Bøtisse, 1978).

By the time the Soil Map of the World was published, twenty years had elapsed since the project was initiated. During this period numerous soil surveys were carried out for development and investment purposes with the support of UN Agencies or bilateral assistance programmes. If the Soil Map of the World was to retain its value it was necessary to update it on the basis of the most recent information.

In the early 1980’s countries became increasingly interdependent for their supplies of food and agricultural products. Problems of land degradation, disparity of production potentials and of population carrying capacities became international concerns. Against this background FAO felt that a framework should be created through which existing soil classification systems could be correlated and harmonized. Concurrently it would serve as an international means of communication and for exchange of experience. The elaboration of such a framework required a more active involvement of the entire soils community. At the initiative of FAO, in cooperation with Unesco, UNEP and the ISSS, a group soil scientists, representing a broad range of soil institutions, met at Sofia in 1980 in order to enhance international involvement in a follow-up to the Soil Map of the World. The meeting was hosted by the Poushkarov Institute of Soil Science and Yield Programming. The Bulgarian hosts effectively contributed to overcome some geopolitical issues which, at that time, were not entirely absent from scientific gatherings. The meeting decided to launch a programme to develop an International
Reference Base for Soil Classification (IRB) with the aim to reach agreement on the major soil groupings to be recognized at a global scale, as well as on the criteria to define and separate them. It was expected that such an agreement would facilitate the exchange of information and experience, provide a common scientific language, strengthen the applications of soil science, and enhance the communication with other disciplines. The group met a second time at Sofia, in 1981, and laid down the general principles of a joint programme toward the development of an International Reference Base (IRB).

In 1982 the 12th Congress of the International Society of Soil Science endorsed and adopted this programme. A symposium on the IRB was held in 1990 in the framework of the 14th Congress of the ISSS in Kyoto, Japan. The IRB scheme which was presented on this occasion comprised 20 major soil groups compared to 28 first level units distinguished in the Revised Legend of the FAO-Unesco Soil Map of the World (FAO, 1988). At a meeting of the IRB Working Group in Montpellier, in 1992, it was decided that the revised FAO-Unesco legend would be used as the basis for the further development of the IRB and that efforts were to be merged. It would be IRB’s task to apply its general principles to the further refinement of the FAO-Unesco units and to provide them with the necessary depth and validation. The consolidated approach was renamed “World Reference Base for Soil Resources” (WRB), reflecting the involvement of a wide range of soil scientists, rather than of representatives of "national schools" only, and the attention being paid to soils as a resource rather than as mere taxonomic units. Progress in the preparation of the WRB was reported to the 15th Congress of the ISSS at Acapulco in 1994 (ISSS-ISRIC-FAO, 1994). Numerous comments have been received from all over the world, discussed in WRB meetings at Leuven (1995), Kiel (1995), Moscow (1996), South Africa (1996), Argentina (1997) and Vienna (1997).

This volume describes the WRB Reference Soil Groups and their relationships. A second volume shows the distribution of the Reference Soil Groups in the world, whereas a third volume describes the elements of the WRB and the definitions of the diagnostic criteria of the soil groups.

• Objective

Given the great diversity of soils in different countries, national soil classification systems are justified at the lower categorical levels. It is indeed hardly possible that one overall system can simultaneously and adequately meet all global, regional and local objectives. The World Reference Base for Soil Resources (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 will serve as a common denominator through which national systems can be compared and correlated. WRB also serves as a common ground between people with an interest in land- and natural resources. The system draws extensively on the legend of the
FAO/Unesco Soil Map of the World. WRB is not a new international classification system, but a basis for better **correlation between national systems.**

WRB is also a tool for **identifying pedological structures** and their significance. It serves as a **basic language in soil science** and facilitates:

- 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 lateral links 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, architects, etc... with as 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.

WRB aims to **provide scientific depth and background to FAO’s Revised legend** of the Soil Map of the World (1990), incorporating the latest knowledge relating to the global soil resources and interrelationships. To include some of the most recent pedological studies and to expand use of the system from an agricultural base to a broader environment one, it was recognized that a limited number of important changes to the 1990 Legend were becoming necessary.

**Principles**

The general principles on which the WRB is based were laid down at the early Sofia meetings and further elaborated upon by the Working Groups entrusted with its development. These general principles 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 unique qualifiers added to the Reference Soil Groups, allowing very precise characterization and classification of individual soil profiles.

The Reference Soil Groups 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 data bases 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.

**Elements of the World Reference Base for Soil Resources**

For describing and defining the Reference 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 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, smectic mineralogy, gilgai, slickensides, hard consistence when dry, sticky consistence when wet, shrinking when dry and swelling when wet).

Soil horizons are three-dimensional 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 meters; 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 meter to several kilometres. However, a soil horizon is never infinite, it disappears or grades into another horizon.

Reference 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 diagnostic, soil horizons also require a minimum thickness, which must be appraised in relation to bio-climatic factors (e.g. a spodic horizon in boreal regions is expected to be less thick than in the tropics).

The successive steps for defining the Reference Soil Groups have been:
- determination of the soil characteristics to be used in the definitions;
- identification of soil characteristics through observation in the field, supported by laboratory analyses;
- determination of the presence and kind of horizons;
- identification of specific vertical successions of horizons on the basis of which the soil (pedon), considered to be the central concept of the Reference Soil Group, is defined;
- application of the technical key to define the Reference Soil Groups in terms of a specific combination of soil horizons;
- determination and description of lateral linkages which occur in the landscape (composition of soil cover) when the information is available.
Challenges

Even though it is generally recognized that soils are an important resource it appears that available soils information is underutilized or even ignored. It is a challenge for soil science to influence policy and opinion so that decisions with regard to the effective use of natural resources can be made more rationally. Meeting this challenge will require that soil science broadens its constituency beyond traditional agricultural partners, that it applies itself to develop solutions to problems of soil and land management, that it breaks through a reductionist approach, that it enhances communication with different users. If soil scientists fail to address the problems with the skills at their disposal, then others will, with less knowledge and authority.

Soil science has suffered from the lack of a generally accepted system of soil classification which has resulted in a loss of credibility and in a limited interaction with other disciplines. It is hoped that the updating of the Soil Map of the World and the development of the WRB will remedy this situation and will progressively lead to a generally agreed identification of major soil groups and of the criteria to separate them at an international level. The great diversity of the soil cover at country scale justifies national systems at the lower levels. This two-pronged approach will facilitate the establishment of an international consensus.

It is a challenge for the WRB to remedy the widespread ignorance of the soil resource which still prevails. When dealing with the protection of animal species one finds it normal that a distinction be made between endangered rhinos, blue whales or pandas. It is realized that measures must be geared to the specific characteristics and problems of the animal concerned. With soils, even though there is an awareness that they may be different, they are often dealt with as if they were the same. As a result a great deal of misinformation is being generated - about environmental hazards related to agriculture, desertification, degradation - which often leads to decisions which are contrary to sound development. WRB should serve as a first entry into the knowledge of soil diversity and soil distribution, accessible to other disciplines and to a wider public. It is imperative that soil science assert itself in the public debate and in the overall scientific community. A common WRB language could provide the means to do so.

Scope

This publication describes the thirty Reference Soil Groups in terms which are readily understood. The significance of each Reference Soil Group important features are highlighted such as: a short history, connotation, international soil correlation, geographical distribution, the landscapes in which it occurs and its salient morphological features. The chemical and physical properties of the soils are summarised as well as consequences for land use and management. Spatial and temporal linkages form an important element in the description of the WRB soil units. These linkages refer to vertical and lateral successions of soil horizons, associations of soils related to the position in the landscape, and the evolution of soil horizons and soils over time. Placing soils in
their geographical and regional context facilitates formulation of appropriate soil classes at a high level of generalisation. It also demonstrates the continuity of the soil cover and illustrates the reasons for separating the classes.

Pictures of the most typical examples of each Reference Soil Group, chosen with features having a maximum degree of expression, together with a typical associated landscape and their worldwide distribution are presented.
# Chapter 2

## Simplified Key to the Reference Soil Groups*

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<td>Soils in which soil formation is conditioned by human influences</td>
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<td>Wet soils with an irreversibly hardening mixture of iron, clay and quartz in the subsoil</td>
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<td>Soils with a thick, blackish topsoil, rich in organic matter with a calcareous subsoil</td>
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* For the complete key the reader is referred to World Reference Base for Soil Resources. FAO World Soil Resources Report no. 84. Rome 1998.
| Soils with a thick, dark brown topsoil, rich in organic matter and a calcareous or gypsum-rich subsoil | Kastanozems | 93 | 17 |
| Soils with a thick, dark topsoil rich in organic matter and evidence of removal of carbonates | Phaeozems | 113 | 22 |
| Soils with accumulation of secondary gypsum | Gypsisols | 85 | 15 |
| Soils with accumulation of secondary silica | Durisols | 69 | 11 |
| Soils with accumulation of secondary calcium carbonates | Calcisols | 53 | 7 |
| Acid soils with a bleached horizon penetrating into a clay-rich subsurface horizon | Albeluvisols | 33 | 2 |
| Soils with subsurface accumulation of high activity clays, rich in exchangeable aluminium | Alisols | 37 | 3 |
| Deep, dark red, brown or yellow clayey soils having a pronounced shiny, nut-shaped structure | Nitisols | 108 | 21 |
| Soils with subsurface accumulation of low activity clays and low base saturation | Acrisols | 29 | 1 |
| Soils with subsurface accumulation of high activity clays | Luvisols | 104 | 20 |
| Soils with subsurface accumulation of low activity clays and high base saturation | Lixisols | 100 | 19 |
| Acid soils with a thick, dark topsoil rich in organic matter | Umbrisols | 143 | 29 |
| Weakly to moderately developed soils | Cambisols | 57 | 8 |
| Sandy soils featuring very weak or no soil development | Arenosols | 49 | 6 |
| Soils with very limited soil development | Regosols | 131 | 26 |
Chapter 3
The Reference Soil Groups of the World

- **ACRISOLS** -

- **History, connotation and correlation**

  Acrisols (from L. acris, very acid) are characterized by a subsurface accumulation of low activity clays, providing a distinct clay increase with depth, and having a low base saturation. These soils have been named red-yellow podzolic soils, Podzólicos vermelho-amarelo distrôficos a argila de atividade baixa, sols ferrallitiques fortement ou moyennement désaturés (CPCS, 1967), red and yellow earths, Latosols and oxic subgroups of Alfisols and Ultisols. The latter have lately been redefined as kand- and kanhapl-great groups in the USDA Soil Taxonomy (Soil Survey Staff, 1996).

  The name Acrisol originates from the Legend of the Soil Map of the World (FAO-Unesco, 1974) in which they indicated soils with an argic horizon and a base saturation less than 50%. In the Revised Legend of the Soil Map of the World (FAO-Unesco-ISRIC, 1990) an additional requirement of having low activity clays (cation exchange capacity of less than 24 cmol$_c$ kg$^{-1}$ clay) was added, separating Acrisols from Alisols.

- **Concept and morphology**

  Acrisols are diagnosed by an argic horizon in combination with the occurrence of low activity clays and a low base saturation. The ratio of the cation exchange capacity to the clay content identifies the dominance of low activity clays. Increase of the clay content with depth or morphological characteristics related to clay translocation are used to define the argic horizon which has to be present in the Acrisols.

- **Properties**

  Most Acrisols are characterized by a sharp clay increase with depth occurring over a short distance (argic horizon).
The low cation exchange capacity and low base saturation of Acrisols is reflected in weakly developed structures but if an eluvial horizon is present it is often massive. Root penetration is usually poor because of the strongly acid subsoil. Many Acrisols have a high aluminium saturation with values exceeding often 70 percent. The absolute amount of exchangeable aluminium, however, is generally not more than 2 cmol_\text{c} \text{kg}^{-1} \text{ fine earth as a result of the low CEC. Surface horizons of Acrisols are generally thin with a low amount of organic matter, especially in regions with pronounced dry seasons. Only under fairly humid conditions and/or low temperatures, as occur in tropical highlands, is accumulation of organic matter considerable.}

- **Geography**

Acrisols are common in tropical, subtropical and warm temperate regions, on Pleistocene and older surfaces. Acrisols cover an estimated area of almost one billion ha worldwide of which about one-third is found in Southern and Central America and about 25 percent in Southern and Southeastern Asia.

- **Relationships with some other reference soils**

Acrisols are common in tropical, subtropical and warm temperate climates and where, in Pleistocene times, arid and humid climates have alternated. On old erosional or depositional surfaces, or in piedmont areas of the humid regions, they are often the dominant soil group, associated and alternating with Nitisols, Ferralsols and Lixisols. Vertisols, Planosols, Plinthosols and Gleysols occur in depressions and on plains. On ancient shield landscapes in tropical regions Ferralsols and Acrisols are dominant soils. The former are present on the flatter parts, little affected by erosion, or where sediments derived from weathered soils on uplands have been deposited. Acrisols are found in these landscapes on slopes and surfaces subject to erosion. For example, they are found on low hills covered by quartz and ironstone gravel, surrounded by Ferralsols, on pediments or lower surfaces eroded from stable uplands. Where the sandy topsoil becomes thicker than 1 m, Acrisols give way to Arenosols. In mountainous regions Acrisols may be found on stable ridge tops, with Regosols and Cambisols on steeper and less stable slopes. Along valleys Acrisols often occupy the higher terraces, whereas the lower and younger terraces have Luvisols or Cambisols. Old alluvial fans in tropical regions often have Acrisols, with Plinthosols in associated depressions.

- **Land use and management**

Most Acrisols in the tropical regions are still under forest vegetation. This may range from high dense canopy rain forest to open woodland. A large number of the roots
Plate 1.1.  Acrisol profile. Dschang, Cameroun.  
(Photo: R. Langohr)

Plate 1.2.  Acrisol profile. Northern Thailand. (Photo: R. Dudal)

Plate 1.3.  Undulating Acrisol landscape with *Imperata Cylindrica* (Alang Alang) resulting from abandonment of agricultural land. South Sumatra, Indonesia. (Photo: R. Dudal)
(probably more than 80%) is concentrated in the surface layer with only a few tap roots going deep in the soil. With the bulk of the nutrients concentrated in the vegetation, various forms of 'slash-and-burn' have developed to cultivate these soils under traditional agriculture. Shifting cultivation therefore is the most common use of Acrisols. When the fallow period is sufficiently long to allow regeneration of the vegetation, this practice is probably the most sustainable form of agriculture on Acrisols. Continuous cultivation requires recurrent inputs of fertilizers and lime. Moreover, care should be taken to preserve and maintain the surface layer in which organic matter has accumulated as this is the main rooting medium for the plants. Removal of the surface layer will inevitably lead to significant yield decrease as the acid and aluminium toxic sub-soil layers will be exposed at the surface. Perennial crops like oil palm, rubber, cashew, mango and plantations of *Pinus caribaea* are well adapted to these soils. In South America Acrisols are also common under savanna vegetation with a strong dry season. Some of these soils are placed under rainfed and irrigated agriculture after liming and fertilization. Rotation of annual crops with improved pastures is recommended to maintain or improve the organic matter content.
**ALBELUVISOLS**

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**History, connotation and correlation**

Albeluvisols (from L. *albus*, white, and *eluere*, to wash out). The term is connotative of penetrations of coarser, iron-depleted material into the underlying clayey horizon. In the Legend and Revised Legend of the Soil Map of the World (FAO-Unesco, 1974; FAO, 1990) they are named Podzoluvisols. They correlate with the Sols lessivés glossiques (CPCS, 1967) or *Luvisol dégradé glossiques* (AFES, 1995) in France, the Braunerde-Pseudogley and Fahlerde in Germany, the Glossudalfs, Fraglossudalfs, Glossoboralfs, Fragiboralfs, Glossaqualfs, Fragiaqualfs and Ferrudalfs of the USDA Soil Taxonomy (Soil Survey Staff, 1996), and the Derno-Podzolic or Ortho-Podzolic soils in Russia.

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**Concept and morphology**

The central concept of Albeluvisols is of soils with a brown or bleached topsoil and an argic horizon, the upper boundary of which is irregular because of deep penetrations of a contrasting lighter coloured and coarser textured eluvial horizon. They develop mostly in unconsolidated quartz-rich glacial till, or materials of glacio-lacustrine, fluval origin, or of eolian origin. Most of these soils have a perched water table related to the period of snow melt, or to a season with precipitation exceeding evapotranspiration. Albeluviic tongues have the colour of an albic horizon and the coarser texture of the related eluvial horizon overlying the argic horizon. Periodic saturation of the surface soil and reduction of iron compounds cause strong bleaching of the eluvial horizon. As a consequence iron and manganese oxides concentrate in the better aerated parts of the solum to form mottles or concretions of the pseudogley type. In the forest areas of western Europe which have experienced little or no cattle grazing activities, root penetration and water percolation is largely limited to the albeluviic tongues. When grazing in the forest areas is intensive, or when these soils are manured and limed, a marked increase is observed in burrowing activity by earthworms and moles. In few centuries this process of bioturbation can remove compaction in the subsoil as obstacle for root penetration and water percolation.

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**Properties**

The litter layer on Albeluvisols under a forest cover decays slowly to very slowly. Burrowing animals of the macro- and mesofauna are scarce or absent. As a result there is very little mixing of the organic matter with the mineral soil and the organic-rich surface horizon is often only a few centimetres thick. Windthrown trees may be the only
Plate 2. ALBELUVISOLS

Plate 2.1.
Albeluvisol with clear polygonal pattern of whitish streaks. South Island, New Zealand. (Photo: R. Langohr)

Plate 2.2.
Mixed deciduous forest with fern undergrowth on an acid Albeluvisol. Central Belgium. (Photo: R. Langohr)

Plate 2.3.
Windthrow of beech tree (Fagus sylvatica) on Albeluvisol in löss. Central Belgium. (Photo: R. Langohr)
major bioturbation agent in these soils. When reduction through temporary saturation with groundwater is lacking, the eluvial horizon has pale brown to yellowish brown colours and a relatively large number of roots. This horizon is also known as the “biologically active B horizon”. Where the periodic saturation lasts for long periods, the eluvial horizon becomes bleached and discrete iron enriched nodules may form in the subsoil. When Albeluvisols are uncultivated, they are acid to very acid (pH (H₂O) 4 - 5), with a relatively high C/N ratio and a low activity of burrowing animals.

The low organic matter and iron content of the leached surface soil explain its low structural stability; the eluvial horizon has a low resistance to mechanical stress and is normally somewhat compacted.

- **Geography**

Albeluvisols cover an estimated area of about 320 million ha worldwide, more or less evenly distributed over Europe and North and Central Asia with a minor occurrence in North America. The distribution of the Albeluvisols occurs in two areas, each having a particular range of climatic conditions and presenting soils with a specific morphology.

Albeluvisols of the cold continental regions cover by far the largest area. They are mainly situated in NE Europe, NW Asia and SW Canada. In Europe they form a long west to east oriented belt, starting in the eastern half of the North European Plain (east Poland), extending eastward across the East European Plain to the footslopes of the Urals and then continue in the southern part of the West Siberian Plain. In Canada they are mainly located in the intermontane depressions of the Rocky Mountains in British Columbia and further east of the Rocky Mountains in a west to east oriented band between 51° and 54°N, up to Lake Winnipeg. Albeluvisols in these regions mainly occur on löss deposits with textures ranging from silt, silt loam to silty clay loam.

Albeluvisols of the moist temperate regions are rather common in southwestern France and the central part of northern France, central Belgium, southeastern Netherlands and the western part of Germany. Albeluvisols here occur on löss deposits with silt, silt loam or silty clay loam textures, as well as on other parent materials, such as loamy sand and sandy loams transitional between the löss, coversand deposits and aluvial deposits with less silt and more sand and clay such as on the terraces in the Aquitaine Basin. In the USA they occur mainly in the states situated south and west of the Great Lakes (Minnesota, Wisconsin, Indiana and Ohio).

- **Relationships with some other reference soils**

The Albeluvisols have direct spatial links with Luvisols, Gleysols and Podzols. In the cold continental areas Podzols border Albeluvisols to the north and east. In the transition zone between these soil types, a Podzol may develop in the eluvial horizon, strongly depleted of clay and iron, which overlies the argic horizon. In the temperate
regions, Albeluvisols border Podzols which are developed in the more sandy facies of the aeolian deposits of the last glaciation.

In western Europe large parts of the original belt of Albeluvisols are now replaced by Luvisols as a direct and indirect result of human activities. A direct impact is the erosion of the upper decimeters of the soil and ploughing, often to 30 cm deep. As a consequence the original morphological characteristics of the upper 50-80 cm of the Albeluvisol, mostly including a large part of the albeluvic tonguing, have disappeared. An indirect impact of several millennia of agricultural activities, including manuring and liming, is the increased burrowing activity, mainly by earthworms and moles. This explains why Albeluvisols are mainly observed in forested areas in western Europe.

**Land use and management**

The natural vegetation on Albeluvisols is boreal taiga, coniferous forest or mixed forest. The main limitations for agricultural exploitation are their acidity, low nutrient levels, tillage and internal drainage problems, along with climatic constraints such as short length of growing season and severe frost during spring time. This is why the Albeluvisols of the northern taiga zone remain almost exclusively under forest. In the southern taiga zone small areas are used mainly for livestock farming. By judicious liming and a balanced use of fertilizers, Albeluvisols are suitable for arable cropping, possibly with spring wheat/barley, potatoes, sugar beets and forage maize.
**ALISOLS**

- **History, connotation and correlation**

  Alisols (from L. alumen, alum) form a relatively new group of soils. They were first recognized in the 1988 Revised Legend of the Soil Map of the World (FAO-Unesco-ISRIC, 1990) as one of the major soil groupings defined by an argic B horizon. Separation from the Luvisols, Acrisols and Lixisols, the other important major soil groupings with an argic horizon, is based on a high cation exchange capacity of the clay, indicative for high activity clays, combined with a low base saturation.

  The importance of recognizing Alisols at the highest level of classification is the fact that these high activity clay soils have very high aluminium saturation, but that they may become very productive after heavy fertilization and liming, unlike the Lixisols and Acrisols. Driessen and Dudal (1991) estimate that in the tropics about 100 million ha of these soils are being used for agriculture.

  Alisols correlate partly with high activity Aquulta, Humults and Udults in Soil Taxonomy (Soil Survey Staff, 1996), the Fersialsols of the Référentiel pédologique (AFES, 1995) or sols fersiallitiques très lessivés of the CPCSo (1967), and the Red Yellow Podzolic soils with a high clay activity of the Brazilian soil classification.

- **Concept and morphology**

  In the FAO concept, Alisols comprise the acid soils with a dense horizon of accumulated clay in the subsoil, occurring in humid (sub-)tropical and warm temperate regions. The intense weathering process which is characteristic for these areas, is at a stage where 2:1 layer silicates are being degraded, releasing large amounts of aluminium, and possibly magnesium, thus creating a very acid environment. As a result, chloritized 2:1:1 minerals may coexist with 2:1 clays in the weathering complex which is characterized by a very low content in weatherable primary minerals. This concept separates acid high activity clay soils with a large amount of exchangeable aluminium in intertropical regions from those of the more temperate zones, as the latter still contain a fair amount of weatherable minerals in the non-clay fractions.

- **Properties**

  In the field, many Alisols appear to be well drained soils with a brown coloured surface horizon and massive or weakly developed structures. Subsurface horizons normally have angular blocky or prismatic structures and develop cracks upon drying. They are usually reddish in colour, have a medium to high clay content and are often derived from or associated with basic rocks as parent materials.
These characteristics set Alisols apart from Luvisols, Lixisols and Acrisols. Luvisols generally have (moderately) well structured surface horizons and show subangular blocky structures in the subsoil. Lixisols usually have sandier textures, do not develop cracks upon drying, and soil structures are poorly expressed. Acrisols may show similar characteristics as Alisols in terms of textural differentiation and colour. Their structural development, however, is much weaker and they do not develop cracks. Moreover, Acrisols are often associated with acid rocks (gneiss, etc.).

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**Geography**

Alisols occur in tropical, subtropical and Mediterranean regions. They are reported from Latin America (Ecuador, Nicaragua, Venezuela, Colombia, Peru (foot-hills of the Andes), Brazil, West Indies (Jamaica, Martinique, St. Lucia), West Africa, the highlands of Eastern Africa (Rwanda), Indonesia (Kalimantan and Sumatra). In subtropical regions, they are reported from China, Japan and the South Eastern USA. Alisols have also been reported from Mediterranean European countries (Italy, France, Greece).

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**Relationships with some other reference soils**

Alisols share the argic horizon with Acrisols, Lixisols, Luvisols and Albeluvisols. As compared to Ferralsols, Nitisols, Acrisols and Lixisols, they have a less advanced weathering stage due to the presence of 2:1 clay minerals in fair quantities.

In the **humid tropics**, Alisols occur on slopes where smectitic saprolithes outcrop while Nitisols, Ferralsols and possibly Acrisols are the dominant soil groupings on the plateaus (West Africa, West Indies). On such sloping areas, Alisols are also associated with Cambisols (foot-hills of the Andes). In gentle/flat topographies, Alisol-Acrisol patterns are related to the lithological nature of the sediments (Amazon region, Colombia).

In **tropical and subtropical regions** with a marked alternation of wet and dry conditions, Alisols have been reported in association with Luvisols, both in sloping areas, and with Vertisols in low lying areas (Kenya, Somalia). Alisols also occur in areas characterized by warm wet summer with monsoon type rains and cold dry winter where they are associated with Cambisols on steeply and hilly areas (South Eastern China).

In **Mediterranean areas**, Alisols are reported on old river terraces where their occurrence is likely associated with paleoclimatic conditions. They may also occur on a wide variety of lithologies on the slopes exposed to rain bearing winds.
Plate 3.1.  Alisol profile. Yurimaguas, Peru.
(Photograph by O. Spaargaren)

Plate 3.2.  Oil palm on an Alisol.
Yurimaguas, Peru.
(Photograph by O. Spaargaren)

Plate 3.3.  Alley cropping on an Alisol. Yurimaguas, Peru.
(Photograph by O. Spaargaren)
• Land use and management

In Alisols, most of the base reserve is associated with the clay minerals and the exchange complex is dominated by aluminium. These weathered soils contain low levels of plant nutrients (except for Mg, in some cases) and free Al is present in toxic quantities. Under natural forests, Alisols accumulate organic matter in surface horizons (Sourdat, 1986; Ohta and Effendi, 1992; Sunarminto, 1993).

The major problems in managing cultivated Alisols are (1) Al-toxicity at shallow depth, and (2) the instability of surface horizons and their susceptibility to erosion. The latter constraint can restrict rooting and cause water stress in the dry season. Cultivated Alisols are mostly used for aluminium-tolerant cash crops such as tea, rubber, oil palm, and marginally for coffee and sugar cane. The productivity of Alisols is very low in sedentary subsistence agriculture as these soils have a limited capacity to recover from chemical exhaustion. Nevertheless, Alisols may become productive after heavy fertilization and liming.
• **ANDOSOLS**

• **History, connotation and correlation**

Andosols (from Japanese *an*, black and *do*, soil) have first been recognized in Japan in 1947 (Simonson, 1979). In 1949 Thorp and Smith defined the Great Group of "Andosols". As of 1974 they key out as Andosols in the FAO legend of the Soil Map of the World. They are equivalent to the recently defined Andisols in Soil Taxonomy (Soil Survey Staff, 1996) and the Andosols and Vitrisols in the Référentiel pédologique (AFES, 1995).

• **Concept and morphology**

Andosols are soils developed in volcanic ash, tuff, pumice and other volcanic ejecta of various composition. The rapid weathering of the porous parent material results in an accumulation of amorphous complexes and the presence of short-range-order minerals such as allophane and imogolite.

Andosols are characterized taxonomically by either a *vitic* or an *andic* horizon. The vitric horizon is one dominated by volcanic glass, while the andic horizon covers soil horizons constituted mainly of allophane and similar minerals or in which aluminium-humus complexes prevail.

Andosols characteristically have loamy, dark coloured and often very humic surface horizons with a fluffy, fine crumb ("floury") structure. Subsurface horizons, if any, are brighter coloured and have a similar or fine granular structure. The colour changes considerably upon drying. They are slightly sticky and plastic and friable to very friable. They lack eluvial or illuvial clay or humus horizons but thin layers of accumulated iron-oxides may occur.

The often thick, dark coloured and strongly humus-rich surface horizons are characteristic for Andosols. Humus is intimately mixed with the mineral part from which it cannot be distinguished. Some black and very humus-rich horizons may have in moist condition a smearable consistency. The fine earth fraction has an apparent loamy texture. The structure is generally fine and fluffy, and aggregated in very friable flakes, when dry it becomes very friable, even powdery.

The transition to an underlying brighter coloured horizon is often gradual; there is no eluvial horizon. This indicates that translocation of organo-mineral complexes is minimal. The subsurface horizons, if present, contain an important amount of humus, despite their more vivid colour. The transition to the substratum can be abrupt in the case of hard volcanic materials (lava, tuff) or gradual in soft materials. Recent pyroclastic materials may be heterogeneous because of successive depositional layers. In such cases horizonation does not only result from pedogenesis, but may also be
Plate 4. ANDOSOLS

Plate 4.1. Buried profile under a typical Andosol. Japan. (Photo: P. Quantin)

Plate 4.2. Andosol developed in stratified volcanic ash with a thick, dark coloured surface horizon. Central Valley, Chile. (Photo: R. Langohr)

Plate 4.3. Andosol landscape with Osorno volcano in background. Central Valley, Chile. (Photo: R. Langohr)
linked to depositional differences. When there are age differences between the pyroclastic layers the entire soil may be polygenetic.

The material near to the surface is the youngest and the least altered. In old volcanic products the complexity of the soil is less evident and it becomes only clear after a thorough study of the mineral composition. Rooting in Andosols is dense and roots penetrate deeply in the soil. Mesofaunal activity is intense.

- **Properties**

A number of physical properties are typical for Andosols, i.e. a low bulk density, a high microporosity, varying between 60 and 90 percent, a high water retention capacity, a high irreversible dehydration value, a good stability of the microaggregates, little dispersion of the colloidal fraction, high susceptibility to erosion and a high friability after drying out (powdery state, low density, floating aggregates). Macroscopic porosity is highly developed in the surface horizons, but there is restricted macroporosity in the subsurface horizons. Andosols have a high permeability and a generally a large moisture storage capacity.

Chemically, Andosols are rich in plant nutrients if not extremely leached. They exhibit some unique properties including a pH dependent variable charge of the cation exchange capacity (CEC). Phosphate retention is normally more than 85%, because aluminium hydroxide groups present have a strong affinity for phosphate ions.

- **Geography**

The Reference Soil Group of Andosols is large and very variable, covering an area slightly over 110 million ha worldwide, concentrated in the circum-Pacific region corresponding with areas where volcanoes and earthquakes are common. They occur in a wide range of climates, landscapes, parent materials and may differ in age considerably. Important occurrences are on the West coast of South America, Central America, the Rocky Mountains, Alaska, Japan the Philippine Archipelago, Indonesia, Papua New Guinea and New Zealand. They are also the predominant soil of many islands in the Pacific: Fiji, Vanuata, New Hebrides, New Caledonia, Samoa and Hawai. In Africa, Andosols occur along rift systems in Ethiopia, Kenya, Rwanda, Cameroon and Madagascar. Other Andosol areas are the West Indies, Canary Islands, Italy and Iceland.

- **Relationships with some other reference soils**

Andosols, being a group of soils occurring worldwide in a large variety of environmental conditions, have linkages with almost all other Reference Soil Groups. They are distinguished from them by the presence of an andic horizon within 30 cm of the surface. In tropical highlands, such as Ethiopia and Kenya, they are often associated
with Nitisols. In the Higher Cordillera in South America, typical topo-sequences occur with Andosols prevailing at higher elevations and Cambisols, Luvisols and Vertisols developing downslope towards the inter-Andean depression.

*Land use and management*

Andosols are often considered to be very fertile, because of their recent age, the large amount of weatherable glasses and primary minerals and their high content in nitrogen, phosphorus and sulphur included in the organic matter. In their natural state and under the original vegetation, Andosols have a sufficient porosity and stable structure to permit a good rain water infiltration and to limit erosion risks. Deep cultivation, such as deep tillage, can modify the physical properties of Andosols and may produce excessive soil dehydration. The soil then becomes very friable and looses a large part of its water retention capacity, transforming itself into a loose, easily erodible sandy loam.

However, some Andosols have a rather poor fertility, as a result of their high phosphorus retention, their acidity and aluminium toxicity, the slow turnover of organic matter and oxygen deficiencies in some very hydrated subsurface horizons. The high phosphorus retention capacity can be overcome by ‘satisfying’ the phosphate demand.

The main constraint in some Andosols is their sandy texture, giving rise to a large macroporosity, low water retention capacity and low cation exchange capacity. Other types of Andosols have excessive wetness which often leads to oxygen deficiency in the subsurface horizons and when drained to cultivate, these soils become very friable and erosion-prone. In addition, these soils present severe constraints to mechanization because of their low carrying capacity and tendency to become fluid under pressure.

Depending on climatic conditions and the altitude at which they occur, Andosols are used for a wide variety of crops, including sugar cane, tobacco, sweet potato, rice, tea, horticultural crops (flowers, vegetables) and wheat, or remain under forest where slopes are steep.
• **Anthrosols**

• *History, connotation and correlation*

The Anthrosol major soil grouping was introduced in 1988 in the Revised Legend of the Soil Map of the World (FAO, 1990) to include those “soils in which human activities have resulted in a profound modification or burial of the original soil horizons, through removal or disturbance of surface horizons, cuts and fills, secular additions of organic materials, long-continued irrigation, etc.”. Many national classifications have in one way or another made provision for these soils. In the newly established Chinese soil taxonomic classification (CSTC Research Group, 1994), a separate soil order of Anthrosols is recognized, which contains various anthropogenic soil types. At present the American system of soil classification does not recognize a separate order of Anthrosols although man-influenced (or man-made) soils are included at the suborder, great group and subgroup levels (Soil Survey Staff, 1996). Recent proposals for a genetic classification for the soils of the former USSR recognize several types of anthropogenic soils (agrozens, irrigational soils) with a separate division for anthropogenic-accumulative soils (Rozanov, 1990; Shishov, 1990).

• *Concept and morphology*

Anthrosols are soils that have been transformed by anthropogenic processes to the extent that the original soil is no longer recognizable or remains only as a buried soil. Several distinct anthropogenic processes have been recognized, including deep working, application of plaggen manure, additions of extraneous materials, irrigation with sediment-rich waters, and long-standing paddy cultivation. Anthrosols are usually found in areas of old cultivation. The human influence is mostly restricted to the surface horizons, which may be described as anthric horizons. A buried soil can still be intact at some depth and testify to soil conditions which existed before the land was modified.

A special case of Anthrosols are the so-called Plaggen soils. They consist of a thick, man-made, humus-rich surface layer which has been produced by long continued manuring with earthy admixtures. It commonly contains artefacts such as bits of brick and pottery throughout its depth and usually has a high phosphate content. Calculations indicate that the thickest plaggen soils have been accumulated over a period of more than thousand years.

• *Properties*

Anthrosols vary widely in physical and chemical properties. Organic matter management is one of the main common features of Anthrosols. As a result, many of the
anthropogenic horizons have a moderately high to high organic carbon content, with the exception of the paddy soils. In most cases C/N ratios are low (10 or less), indicating a high microbial activity. Part of plaggen horizons have C/N ratios around 15, low pH and low microbial activity. Most of the anthric horizons are well supplied with nutrients and have favourable physical properties (well structured, high porosity, high water retention capacity).

- **Geography**

The extent of man’s influence upon soils increased rapidly in the last 25 years, becoming more widespread and more intensive. Anthrosols occupy about 0.5 million ha in Western Europe (mainly in The Netherlands, Belgium, Germany, Scotland, England, Wales and Ireland). Large tracts of Anthrosols occur in the paddy fields of south-east Asia. Minor areas occur in every country of the world eg. the ‘Terras pretas do indios’ in the Amazon. As the world population grows, the area of Anthrosols will increase as other Reference Soil Groups are profoundly modified.

- **Relationships with some other reference soils**

Anthrosols are likely to be associated with most of Reference Soil Groups where soils have been strongly influenced by man. Linkages between other soil groups and Anthrosols are likely to reveal the genesis of these anthropogenic soils and their place in the soil cover. Figure 1 illustrates some spatial linkages of Anthrosols with other soils.

- **Land use and management**

Since characteristics of Anthrosols are very variable in properties and requirements, no generalised account of their management can be given. The Plaggen soils of Western Europe are among the more favourable ones, where good drainage and dark colour of the surface soil allows them to be tilled and crops sown early in the season. Traditionally, European Anthrosols were used to grow winter rye, oats, barley and tobacco. Now they are used for forage maize, potatoes, horticultural crops, tree nurseries and for pasture land.
Plate 5.1.
Plaggic Anthrosol with spade marks.
(Photo: R. Langohr)

Plate 5.2.
Wet Anthrosol in Northern Belgium.
(Photo: J. Van Damme)

Plate 5.3.
Raised surface of a Plaggic Anthrosol under long-continued horticulture. Kempen, Belgium. (Photo: R. Langohr)
Figure 1  Some spatial linkages of Anthrosols.
ARENOSOLS

**History, connotation and correlation**

Arenosols (from L. *arena*, sand), or sandy soils with slight to moderate profile development, are recognized as a separate grouping in universal, regional and local soil classification systems, mostly at a medium to high hierarchical level. In the USDA Soil Taxonomy (Soil Survey Staff, 1996) sandy soils without marked profile development, including shifting sands, are classified as Psammments or Psammaquents. Other names for Arenosols in other soil classification systems include the following: sols minéraux bruts (France), siliceous, earthy and calcareous sands and various podzolic soils (Australia), red and yellow sands (Brazil), soils belonging to the Namib, Fernwood, Hutton and Clovely Forms (South Africa), as well as their sandy soils with a neocarbonate B horizon, and Arenosols (FAO).

**Concept and morphology**

A fundamental concept of Arenosols is the sandy nature of these soils, which dominates their characteristics and properties. The texture of Arenosols is loamy sand or sand. There is no restriction as to the minimum degree of soil development required. The limits of Arenosols with other Reference Soil Groups are determined by the maximum degree of soil development permitted.

**Properties**

Arenosols do not have diagnostic horizons other than an ochric or an albic horizon. Soil structure is normally absent (apedal) or only weakly developed. Arenosols are very permeable and have rapid infiltration, high hydraulic conductivity and low water holding capacity. There may be quite large variations in the content of organic matter and nutrients. CEC ranges from very low to moderate level; pH and base saturation are very variable.

**Geography**

Arenosols are widely distributed and form one of the most extensive Reference Soil Groups in the world, covering about 900 million ha or 7 percent of the land surface. If shifting sands and active dunes are included, the coverage would be about 10 percent. The vast expanse of deep aeolian sand covering parts of the central African plateau between the equator and 30° southern latitude is the largest sand body on earth. Popularly

Plate 6.2. Arenosol landscape with stabilized and shifting sands in a coastal dune area. Somme River Estuary, France. (Photo: R. Langohr)
known as the Kalahari Sands, it is bordered by the Congo river in the north and the Orange river in the south. Other major areas of Arenosols are found in the Sahel region of Africa, various regions in the Sahara desert, central and western Australia, the deserts of the Middle East and China. Sandy coastal plains and coastal dune areas are of smaller geographic extent, but ecologically very important.

Although most Arenosols are found in arid and semi-arid regions, they are typical azonal soils and occur in the widest possible range of climates, from very arid to very humid and from cold to hot. Arenosols occur predominantly on aeolian sands, either as dunes or sand sheets, but they have also formed on marine, littoral and lacustrine sands of beach ridges, lagoons, deltas and lakes. In addition, Arenosols are found on weathered coarse-grained rocks, mainly sandstone, quartzite and granite.

There is no limitation as to age or period in which soil formation took place. Arenosols occur on very old surfaces as well as on very recent landforms, and may be associated with any type of vegetation.

- **Relationships with some other reference soils**

Spatial linkages between Arenosols and other Reference Soil Groups are found typically in two major environments:

a. areas where sand is the predominant parent material (mainly aeolian depositional environments); and

b. areas where sandy deposits alternate with non sandy sediments or weathering materials.

With increasing time of soil formation, under acidifying vegetation sandy soils may evolve into Podzols, e.g. the ‘Giant Podzols’ in tropical and subtropical areas. In arid and semi-arid environments stabilized or shifting dunes with Arenosols may be found in association with playas and other depressional areas or with deflated terrain, characterized by a variety of soils such as Solonchaks, Regosols, Calcisols, Leptosols, etc.

- **Land use and management**

In arid areas Arenosols are predominantly used for extensive grazing. In the nomadic livestock farming areas of North Africa and the Middle East Arenosols are in fact the mainstay of the farming enterprise. Vegetative growth reacts much faster in the sandy areas than in areas with finer-textured or shallow soils, as the little rain that falls occasionally, is much more effective.

Where rainfall exceeds 400 - 500 mm per annum, Arenosols can be used for rainfed cultivation.

The texture and depth of the soil and the nature of the underlying material are important factors determining agricultural success which can be achieved on Arenosols in semi-arid areas. Both the clay content and the sand grade play an important role in determining the plant-available water storage capacity of these soils. It has been found in the semi-arid western Highveld of South Africa that Arenosols containing about 10
percent clay and dominated by fine sand, the plant-available water storage capacity is about 125 mm per meter soil depth, which is considerable. High yields of small grains, melons, pulses and fodder crops have been obtained in irrigated Arenosols. In the central irrigation schemes of South Africa small grains, vegetables, maize, groundnuts, lucerne, citrus, peaches, grapes and pecan nuts are amongst the wide variety of crops which are produced very successfully on fine sandy Arenosols with 8 to 10 percent clay.

Successful dryland or irrigated cropping of Arenosols in semi-arid to sub-humid areas requires well-adapted management practices. The main problem on these soils is their extreme vulnerability to wind erosion, which needs to be controlled - e.g. by means of wind breaks. In the marginal cropping areas a low risk approach is advisable under dryland conditions. This means aiming for relatively low yields, using low planting densities and low fertilizer inputs. The high infiltration capacities and hydraulic conductivities make surface and drip irrigation impracticable on most of these soils.

Furthermore, the well-sorted, well-rounded fine sandy aeolian Arenosols (especially those with 8 to 15 percent clay) are extremely vulnerable to soil compaction, i.e. the development of “traffic pans”, under intensive mechanized farming. Rooting depth may be impeded through hard setting in the subsoil. This is aggravated under irrigation by an increased tendency to cultivate soils when they are too wet. Zero tillage is not the answer because of the fairly high natural degree of compaction of these soils. It can be overcome by, for instance, the use of tined implements and controlled traffic.

Arenosols in the humid tropics are best be left under their natural vegetation, especially the deeply weathered Albic Arenosols. Clearing of these soils may produce infertile badlands without ecological or economic value. Under a humid tropical climate, cashew nuts intercropped with pineapple can provide a profitable cropping system on Albic Arenosols as is the case on the Makonde plateau in south Tanzania.
**CALCISOLS**

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**History, connotation and correlation**

The name Calcisols is connotative of *L. calx*, or soils in which there is a substantial accumulation of calcium carbonate. It was first used in 1952 in the United States to indicate soils on highly calcareous parent materials in the arid and semi-arid regions (Harper, 1957). It has since been introduced in the revisions of the U.S. soil classification up to 1959, in the Revised Legend of the Soil Map of the World (FAO-Unesco-ISRIC, 1988) and the Référentiel pédologique (AFES, 1995). They correspond more or less to the Calciorrhic great group of the Soil Taxonomy (Soil Survey Staff, 1996), to the Pale- great groups of the Alfisols and Aridisols, and to calcic and petrocalcic subgroups. Formerly they were grouped mainly with the Desert soils (Baldwin *et al*, 1938). In the USSR these soils keyed out as Desert soils or as Takyr.

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**Concept and morphology**

The central concept of Calcisols is that of soils in which an accumulation of calcium carbonate, forming a calcic horizon, is or has been the most dominant soil forming process. A calcic horizon is a horizon in which calcium carbonate has accumulated either in a diffuse impregnation of the soil matrix, or as discontinuous concentrations as pseudomycelia, cutans, soft powdery lime, nodules (soft or hard), veins, or as continuous layers which may be cemented. Calcium carbonate is the main component but magnesium and other carbonates may be present as well. The carbonates can be of different origin. They may be translocated from the surface layers and precipitated deeper in the solum, or originate from lateral enrichment along toposequences. They can also be derived from carbonate-rich groundwater or airborne dust. Calcisols usually show little horizon differentiation apart from the calcic horizon(s) present.

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**Properties**

The morphology of Calcisols is largely determined by the dominant presence of an accumulation of calcium and other carbonates. Soils with calcic horizons often have subangular or angular blocky structures. Calcic horizons may have a platy structure or a massive appearance and tend to have higher bulk densities than non-calcareous related horizons. This is caused by the partial infilling of the pore space with calcium carbonate segregation. These horizons therefore act as a barrier through which roots penetrate with great difficulty. A crusty surface may occur especially when the soils are silty. Calcisols invariably have a high base saturation. The exchange complex of the clay minerals is usually large and dominated by a high cation exchange capacity.
The pH (H₂O) is neutral or slightly alkaline, and many Calcisols are low in organic matter.

- **Geography**

Calcisols are fairly extensive with a total estimated area of about 800 million ha. The regions with main occurrences of Calcisols are located in Mediterranean climates and in the semi-arid subtropics of both hemispheres.

- **Relationships with some other reference soils**

The limits of Calcisols and the lateral transitions to other soils are largely determined by a change in expression of the surface layers and the appearance of other horizons between the surface and the calcic horizon. The lateral transitions are a function of the relief (at local level) and of climate and geological variations (at a regional scale). The three-dimensional picture of redistribution of calcium carbonates and resulting calcic horizon is a function of vertical and lateral movements, of airborne additions, and of time (age). The differentiation of the calcic horizon along a slope or a pediment, from diffuse distributions through discontinuous concentrations to continuous concentrations, increases downslope. Moving along toposequences towards calcic horizons richer in calcium carbonates, the upper boundary becomes sharper and the increase in calcium carbonate content between the overlying horizon and the calcic horizon becomes more pronounced as precipitation of carbonates occurs mainly in the upper part of the calcic horizon.

In time, calcic horizons also show a progressive evolution from diffuse distributions, pseudomycelia, cutans, soft and hard nodules, veins of non-layered calcrete to layered or platy calcrete or compact calcrete. The distribution of the calcic horizon in space and time shows that both vertical and lateral redistribution movements have occurred. Of these, lateral movements are probably more important than vertical redistributions. Airborne additions also play a role in the formation of calcic and hypercalcic horizons.

The vertical and lateral sequences and relationships between the various forms of calcic horizons in space and time described above are shown in figure 2.

- **Land use and management**

Being closely related to arid and semi-arid environments, Calcisols usually carry a sparse vegetation and are frequently used for extensive grazing. Under rainfed conditions some drought resistant crops may be grown. When irrigated, crops grown should be tolerant of the high calcium levels and care should be taken to prevent soil salinization and surface crusting.

Plate 7.2. Shrubby vegetation on Calcisol. Hedaru, Northern Tanzania. (Photo: J. Deckers)
Figure 2  Relationships between calcic, hypercalcic and petrocalcic horizons in space and time in an area in Morocco.
**CAMBISOLS**

**History, connotation and correlation**

The name Cambisol comes from *L. cambiare*, to change, thus soils with horizon differentiation through changes in colour, structure and/or texture. Cambisols or moderately developed soils characterized by slight or moderate weathering of the parent material, have been recognized in the early soil classification systems, originally as 'Brown forest soils', Braunerde, Brunisols, Sols bruns. Subsequently these 'brown' soils were further subdivided according to their base status in 'acid/poor' and 'eutrophic/rich' ones. In USDA 'Soil Taxonomy' they were classified under the Inceptisols as Dystrochrepts and Eutrochrepts.

**Concept and morphology**

Cambisols represent soils which show soil formation characterized by a certain development of their structure or by colours indicating moderately pronounced alteration and development features. Alteration are recognized by soil structure, absence of rock structure, stronger chroma, redder hue or a higher clay content with respect to the parent material. They do not have appreciable quantities of illuviated clay, organic matter, aluminium and/or iron compounds. Cambisols are generally considered as soils of limited age, however this is not necessarily the case. The main characteristic is the presence of a horizon of alteration, which in Cambisols must be seen as a 'minimum B-horizon' with beginning soil formation, a cambic horizon. A cambic horizon can also occur in other Reference Soil Groups but there it is not a differentiating characteristic because other properties are given higher priority, for example gleic properties in Gleysols. Many Cambisols are in a transitional stage of development from a young soil to a mature soil. Nonetheless, a cambic horizon can be quite stable, viz. where the environment counteracts pedogenetic change, e.g. by low temperatures or even permafrost, or by low precipitation, or impeded drainage, or highly calcareous or weathering-resistant parent materials, or by a continuous supply of ions to replenish ions lost by leaching, or by a slow but continuous rate of erosion that is in equilibrium with weathering processes. In practice, a cambic horizon is any section of a soil profile situated between a humus-enriched surface horizon and a relatively unaltered substratum. It has soil structure rather than rock structure and differs from the substrate in colour and/or clay content.

**Properties**

It is hardly possible to sum up all mineralogical, physical and chemical characteristics of Cambisols in one generalized account because these soils occur in such widely dif-
Plate 8.1. Cambisol on chalk. Normandy, France. (Photo: R. Langohr)

Plate 8.2. Landscape of smoothly undulating high plateaux and steep slopes in an area with a moist temperate climate; stony Dystric Cambisols are common on the forest-covered slope positions. Ardennes, Belgium. (Photo: R. Langohr)
ferring environments. However, most Cambisols contain at least some weatherable minerals in the silt and sand fractions. Cambisols are medium textured and have good structural stability, high porosity, a good water holding capacity and good internal drainage. They occur in regions with a precipitation surplus but in terrain positions that permit surface discharge of excess water. In most cases Cambisols have a neutral to weakly acid soil reaction, a satisfactory chemical fertility and an active soil fauna.

• Geography

Cambisols cover about 1.5 billion ha worldwide and form as such one of the largest Reference Soil Groups. Cambisols are particularly common in temperate and boreal regions which were under the influence of glaciation during the Pleistocene, partly because the soil’s parent material is still young, but also because soil formation is slow under the low temperatures (or even permafrost) of the northern latitudes (northern Russia and Canada). Erosion and deposition cycles are the main reason why Cambisols occur frequently in mountainous areas (Himalayan footslopes, the Alps), whereas moderate weathering and absence of clay migration on a parent material which limits clay movement or a climate that inhibits leaching (summer rains) are the main reasons for their predominance in temperate climates (west and central Europe).

Cambisols are relatively uncommon in the tropics and subtropics, where extensive weathering and old parent materials are the rule rather than the exception. The largest continuous surface of Cambisols in these regions is found in the (young) alluvial plains and terraces of the Ganges-Brahmaputra system. Cambisols are widespread in areas with active geologic erosion and are also quite common in arid climates.

• Relationships with some other reference soils

The wide variation among Cambisols is perhaps best illustrated by outlining a number of typical situations where these soils occur in association with other soils:

• In the humid tropics, Cambisols are widespread in highland regions and in hilly to mountainous terrain, mainly at medium altitudes. The steepest slopes have no soil, or only Leptosols. Cambisols occur on moderately steep hillsides and (residual) Acrisols or Ferralsols in more stable sites.

• In the drier subtropics, Cambisols may form upon erosion of Luvisols or Kastanozems. Cambisols occur in association with Vertisols on the Deccan Plateau in India, where long-continued cultivation and soil erosion have produced shallow soils which do not qualify for Vertisols.

• In the temperate zone, Cambisols are particularly common in alluvial, colluvial and aeolian deposits. The majority of all Cambisols in the northern hemisphere are in boreal areas.

• In wetlands, Cambisols can be found in association with Gleysols and Fluvisols, and, in somewhat better drained positions such as terraces, together with Luvisols, Acrisols and Plinthosols.
Land use and management

Management of Cambisols largely depends on the climate in which they occur. (permafrost, arid zones, humid tropics). It is difficult, therefore, to make a generalized assessment of management methods. In general, Cambisols make good agricultural land and are intensively used. The base-rich Cambisols of the temperate zone are among the most productive soils on earth. Acid Cambisols, though less fertile, are used for (mixed) arable farming and as grazing or forest land. Stoniness and shallowness are the most common limitations in the temperate zone. Cambisols on steep slopes are best kept under forest. Cambisols in (irrigated) alluvial plains in the dry zone are intensively used for the production of food and oil crops. Desaturated Cambisols of the humid tropics are poor in nutrients but still richer than neighbouring Acrisols or Ferralsols as they have a higher cation exchange capacity. The Cambisols of the river terraces under paddy rice are highly productive soils.
• History, connotation and correlation

The name Chernozem stems from Russian chern, black and zemlja, earth, land, connotative of soils rich in organic matter having a black colour. The soil was identified by Dokuchaev in 1883 as the “zonal” soil of the tall grass steppe or tall grass prairie in the continental part of Russia. International correlations are: Rego Black and Orthic Black soils, Calcareous Black soils, Eluviated Black soil (Canada), Chernozem modal (France), Boroll (USA), Typic Chernozems or Podzolized Chernozems (former USSR), Chernozems (FAO).

• Concept and morphology

Large parts of the temperate climatic belt have cold to very cold winters and short warm to hot summers. Rainfall is relatively low, about 350-600 mm per year and the upper limit just matches the annual potential evapotranspiration. Soil parent materials in these areas are largely calcareous löss or löss-like sediments. The natural vegetation is dominated by annual tall grass species with a high biomass production, called the tall grass steppe in Eastern Europe and Asia, and the tall grass prairie in North America. The natural grass vegetation may produce 4 to 6 t/ha/year of dry root mass, concentrated in the upper 60 cm of the soil, with 80% of all roots concentrated in the top 10 cm. This type of vegetation together with a very rich soil fauna results in soils characterized by a deep, very dark grey, humus- and nutrient-rich surface horizon, that may extend to a depth of 2 m because of intense activity of worms and burrowing animals.

Chernozems therefore have a deep humus-rich mollic horizon with a well-developed crumb structure resulting from a high annual biomass production and a very high biological activity in the soil. The very high bioturbation is further evidenced by the occurrence of krotovinas (from Russian krot, a Eurasian mole, Talpa europaea), which is a typical feature of the Chernozems. Concentrations of soft powdery lime occur in the lower part of the soil profile as a main diagnostic property, separating the Chernozems (and Kastanozems) from the Phaeozems.

• Properties

Chernozems may contain 4 to 16% organic matter and therefore have a high porosity and a high moisture storage capacity. The micro-aggregate structure of the humus-rich topsoil is very stable which makes these soils suitable for irrigated farming. Downward percolation in spring leaches nutrients from the topsoil and lime accumulates in the subsoil which shows up as soft whitish powder, mycelium-like streaks or small concre-
tions. In the wetter (colder) areas at the boundary of steppe and deciduous forest, clay may also accumulate to form an argic horizon in the subsoil. The soils have a neutral soil reaction and are highly saturated with bases, especially calcium.

- **Geography**

Worldwide Chernozems cover an estimated area of about 230 million ha. Major occurrences are in the middle latitude steppes of Eurasia and North America.

- **Relationships with some other reference soils**

In North America and in Russia (east of the Urals), the Chernozems are associated with Greyic Phaeozems and with Albeluvisols, mainly in the northern part of the zone. Toward wetter and warmer areas Chernozems merge into the Phaeozem belt, whereas towards the drier steppe Chernozems grade into Kastanozems.

- **Land use and management**

The favourable physical and chemical properties, especially the high porosity and available water capacity, the high levels of organic matter and nutrients, and neutral pH values make these soils very fertile. Wheat, barley, maize and vegetables are the principal crops grown on these soils, while a part of the Chernozem zone is used for livestock rearing. Short growing periods in the cold temperate climatic belt allow only wheat and barley besides vegetables as principal crops. In the warm temperate climatic belt maize (besides vegetables) grow well on these soils. However, drought stress in drier years limits their production potential. Irrigation may therefore be necessary for good yields of maize. Russian soil scientists rank the deep, central Chernozems among the best soils in the world. With less than half of all Chernozems in the former USSR being used for arable cropping, these soils constitute a formidable resource for the future.
Plate 9.1.
Mole holes (krotopinas) in Chernozem.
Kurzk, Russia. (Photo: J. Deckers)

Plate 9.2.
Cultivated Chernozem.
Kurzk, Russia.
(Photo: J. Deckers)
CRYSOSOLS

History, connotation and correlation

The name Cryosols comes from Gr. *kraios*, cold, ice, and refers to soils which are perennially frozen within 100 cm from the soil surface. Permafrost soils have previously been described in Russia as Peaty Frozen and Taiga Frozen soils, and more recently as Homogenous (or Peaty-Duīf) and Thixotropic Cryozems (Sokolov, 1980). In the Canadian soil classification permafrost soils are classified as Cryosols and are recognized as a group of mineral and organic soils in which cryogenic processes dominate soil genesis. In Soil Taxonomy the new Gelisol Order will encompass the Cryosols. In the FAO/Unesco legend they came at second level as gelic subgroups of other Major Soil Groups. Only recently the importance of Cryosols was recognised for their role in global climate equilibria and environmental issues. Cryosols were introduced in the World Reference Base for Soil Resources as of 1994.

Concept and morphology

Cryosols have a perennially frozen subsoil (permafrost), and their genesis and properties are the result of cryogenic processes, which include the freeze-thaw cycle, cryoturbation, frost heave, cryogenic sorting, thermal cracking and ice segregation.

Freeze-thaw is the process consisting of a repeated cycle of freezing and thawing of water in the soil, and is responsible for frost heave of coarse materials, cryoturbation and mechanical weathering (Washburn, 1980). During the freezing part of this cycle, freezing fronts move both from the soil surface downward and from the permafrost table upward. As this happens, moisture is removed from the unfrozen soil material between the two fronts, resulting in desiccation. Desiccation is responsible for the development of blocky structures in these soils, but a combination of cryoturbation and desiccation is responsible for the granular structure common in fine-textured Cryosols. In addition, the cryostatic pressure that develops as these two freezing fronts approach and eventually merge results in soil compaction.

Cryoturbation (or frost churning) is the process which mixes soil material, resulting in disrupted soil horizons, involutions, organic intrusions, organic matter accumulation in the subsoil, oriented rock fragments, silt-enriched layers and silt caps on stones and boulders.

Frost heave occurs as a result of the volume change that takes place when water is converted to ice or because ice build-up in the subsoil causes cracks to form in the soil. Cryogenic sorting results in separation of coarse from fine soil materials leading to patterned ground.

Thermal cracking occurs when frozen materials contract as a result of continuous rapid cooling. The cracks that develop are usually several centimetres wide, and lead to
the development of ice or sand wedges. Ice segregation is manifested by ice lenses, vein ice, ice crystals and some ground ice.

**Cryogenic properties** of Cryosols include perennial segregated ice, cryoturbated soil horizons, and macro- and microstructures resulting from cryogenic processes. The characteristic platy and blocky macrostructures in Cryosols result from vein ice development.

**Patterned ground** such as hummocks, circles, nets and polygons, is commonly associated with Cryosols. On coarse textured materials weak podzolisation may produce a thin eluvial horizon. In desert environments salinization and alkalinization occur where soluble salts accumulate in the absence of a water table.

- **Properties**

Freeze-thaw leads to granular, platy, blocky and vesicular structures of the surface mineral horizons. The sub-surface horizons often have massive structures of high bulk density, especially in fine-textured soils. Cryoturbated soil profiles are characterized by irregular or disrupted soil horizons and oriented stones in the soil and sorted and non-sorted patterned ground features on the surface. Almost all Cryosols are associated with ice in the form of ice crystals, ice lenses, ice layers (vein ice), ice wedges or massive ground ice, often to a thickness of several meters. Fine textured Cryosols generally have higher a higher ice content than do coarse-textured soils. Cryosols or portions of the soil, are generally saturated during the early part of the thaw season as a result of the melting of seasonally frozen soil water, resulting in greyish colours and redoximorphic features. Almost all Cryosols are therefore associated with ice in the form of ice crystals, ice lenses, ice layers (vein ice), ice wedges or massive ground ice, often to a thickness of several metres. Soil texture is one of the factors controlling ice content in mineral soils. Fine-textured Cryosols have a higher ice content than do coarse-textured soils. Large amounts of organic matter may be stored in Cryosols which, as a result, are especially effective carbon sinks. Salt crusts are common on the high arctic islands of Canada.

The active layer of the soil is subject to annual thawing and re-freezing. This layer not only supports biological life, but also protects the underlying permafrost. The thickness of the active layer is controlled by soil texture and moisture, thickness of the surface organic layer, vegetation cover, aspect and latitude.

- **Geography**

Cryosols occupy approximately 1770 million ha and occur in the Arctic, Antarctic, Subarctic and Boreal regions under cold continental, sub-humid or semi-arid climatic conditions. They are widespread in Canada and Alaska and cover large areas in Russia, Mongolia and China. They also occur in smaller areas in the countries of northern Europe, in Greenland, in the ice-free areas of the Antarctic coast, and at high elevations in
**Plate 10.1.** Ice layers at shallow depth in Cryosol. Yukon Territory, Canada. (Photo: C. Tarnocai)

**Plate 10.2.** Sorted polygons in Cryosol landscape. Yukon Territory, Canada. (Photo: R. Langohr)

**Plate 10.3.** Lowland polygonal Cryosol landscape. Rathurst Island, Canada. (Photo: C. Tarnocai)
Plate 10.4. Cryoturbation in a Cryosol. Spitsbergen, Norway. (Photo: B. van Vliet)

Plate 10.5. Mass movement (slumping) in a Cryosol area. Canada. (Photo: C. Tarnocai)

Plate 10.6. Solifluction in a Cryosol area. Yukon Territory, Canada. (Photo: R. Langohr)
mountainous regions such as the Rocky Mountains (North America), Andes (South America), Himalayas (Asia) and Alps (Europe).

- **Relationships with some other reference soils**

All Cryosols occur in the permafrost zone. However, in zones with intermittent permafrost they may be associated with soils such as Histosols, Gleysols, Podzols, Planosols and Cambisols. Cryosols are also associated with non-permafrost soils in areas with deep active layers (>100cm) and at high elevation. In these high elevation areas Cryosols are commonly found on polar-facing slopes, while on sun-facing slopes Cryosols may be associated with non-permafrost soils (Tarnocai *et al*, 1993).

- **Land use and management**

Cryosols support non-vegetated to continuously vegetated tundra (arctic), open-canopy lichen coniferous forest (subarctic forest), closed-canopy coniferous forest (boreal forest), or mixed coniferous and deciduous forest (boreal forest). Cryosols not only support the natural ecosystems and human structures, but also protect the underlying permafrost. In temperate regions the bush can be cleared, the soil can be ploughed, or the surface organic layer can be burned or removed and, in most cases, the damage is confined to the erosion of a small amount of top soil or reduction in the soil carbon. For Cryosols, however, removal of the surface peaty layer or vegetation and disturbance of soil materials often leads to drastic and rapid change, with possible resultant damage to the environment and human structures. Most areas of Cryosols in North America and Eurasia are in natural state and support vegetation for grazing animals such as caribou, reindeer and musk oxen. Large herds of caribou still migrate seasonally in the northern part of North America while reindeer herds are an important industry in the northern areas of both Asia and Europe. In some of these areas, especially northern Europe, overgrazing is a problem that can lead to environmental damage such as erosion. Human activities, mainly relating to agriculture, oil and gas production and mining has had a major impact on these soils. Lack of knowledge of soil conditions has led to severe thermokarsting on land cleared for agriculture. Improper management of pipelines and mining can cause both serious damage to the soil and very serious, long-lasting pollution.
History, connotation and correlation

The name Durisols is derived from L. durus, hard. They are characterized by the presence at shallow depth of a duripan or a layer consisting mainly of durinodes. Durisols are new to the World Reference Base for Soil Resources. They were introduced in 1996 during the WRB workshop in South Africa, where they have been reported as "dorbank" since 1940. In Australia they are known as "red and brown hardpan soils" (Stace et al., 1968; Wright, 1983) as well as "Wiluna hardpan" (Bettenay & Churchward, 1974). In Soil Taxonomy (Soil Survey Staff, 1996) soils with a duripan in arid and semi-arid climates are grouped under the Great Group of Durorthid or Durargid. However, they are also accommodated in other soil orders, e.g. Alfisols and Inceptisols. In the FAO Legend of the Soil Map of the World, Durisols are recognised as soils with "duripan phase" which commonly occurs in Calcisols or other soils from the arid and semi-arid zones.

Concept and morphology

Durisols are well-drained, coarse-textured soils associated with arid and semi-arid environments that have a duripan or durinodes as a layer within 100 cm from the soil surface. The duripan (a continuous compact soil layer) or durinodes (discontinuous nodules) are cemented by secondary silica (SiO₂, presumably opal and microcrystalline forms of silica). Dry fragments do not slake during prolonged soaking in water or in hydrochloric acid.

Silcrete (a hard, superficial quartzite rock formed by the cementation of sand and gravel, and which occurs as cappings on older mesas in both Australia and South Africa, may be confused with a duripan. However, silcrete is considered to be non-soil (i.e. hard rock), whereas a duripan is considered part of the solum.

Duripans range in thickness from about 30 cm to more than 4 m and occur at shallow depth (<50 cm) from the surface. Two main morphological types of duripans are distinguished, i.e. massive duripans, or those with a platy or laminated structure.

The durinodes (also called "durinodes" by Soil Survey Staff (1996) are usually red or reddish brown weakly cemented to indurated nodules, firm to very firm, but brittle when wet. Most durinodes are roughly concentric when viewed in cross section. They do not slake in water although some softening can take place after prolonged soaking. Horizons containing curinodes are not very common and they are considered to be the predecessor for curipan formation.

A typical Durisol profile consists of a red coloured, non-calcareous topsoil on top of the duripan. They may have an argic, cambic or calcic horizon above the duripan. If unconsolidated material underlie a duripan, they appear to be weakly structured and
the material is either calcareous or gypsiferous, or calcareous immediately below the duripan or the accumulation of durinodules, followed by gypsum deeper in the soil.

The division of Durisols is based on (1) soil depth to a duripan and (2) the occurrence of other diagnostic horizons such as an argic, cambic, calcic or vertic horizon.

- **Properties**

Durisols are important because their compact cemented duripan at shallow depth reduces rooting depth, water holding capacity and anchorage of vegetation. In general, Durisols are sandy throughout (clay less than 10%). pH values are high (>8.3) in the topsoil, decreasing in the duripan layer. A sharp increase in salt content from the surface horizon towards the sub-surface horizons, including the duripan, is common. Usually all horizons in a Durisol have high levels of exchangeable sodium and a low carbon and extractable iron content.

- **Geography**

Durisols occur in arid and semi-arid, as well as in Mediterranean climates. They were extensively reported in Australia, South Africa and the USA. Minor occurrences are reported from Central and South America, where duripans are known as tepetates, and from Kuwait (‘gatches’). Durisols occur in level to slightly sloping terrain mainly along footslope positions.

- **Relationships with some other reference soils**

As Durisols are typical for dry ecological zones, they are bound to occur in association with Gypsisols, Calcisols, Vertisols, Arenosols and Cambisols. In areas where silcrete covered mesas occur, Durisols usually occupy the lower-lying parts of such landscapes. In areas where they are associated with Calcisols, Durisols are usually found on the older parts of the landscape.

- **Land use and management**

The agricultural use of Durisols is limited to extensive grazing (rangeland). The soils generally support enough native vegetation to slow down erosion in the arid regions. Nevertheless, erosion of the soil material above the duripan has taken place in many areas. The resistant nature of the duripan has lead to formation of stable landscapes under dry conditions.

In areas where irrigation water is available, Durisols may be cultivated successfully. As the duripan forms a barrier for both root and water penetration, it may need to be broken up or removed physically. Because free or excess salts are common in Durisols, physical loosening followed by over-irrigation or heavy rains may lead to salinization.

Duripan material is, because of its hardness, frequently used for road construction.
Plate 11.1.
Silica-cemented horizon ("Petroduric horizon") in Durisol. Corsica, France.
(Photo: R. Langohr)

Plate 11.2.
Patchy vegetation on an eroded Durisol. Western Australia.
(Photo: F. Ellis)
**FERRALSOLS**

**History, connotation and correlation**

The name Ferralsols comes from L. *ferrum* and *alumen*, connotative of a high content of sesquioxides. Ferralsols were first identified as Lateritic soils or later as Latosols, which referred to the deep red soils of the humid tropics. The name 'Kaolisols' was coined during the early surveys in the Congo basin. Kaolisols comprised the Ferrisols and the Ferralsols. The former were to become the Nitosols in FAO legend (1974) and the latter are synonymous of Ferralsols proper.

Local names usually refer to the red colour of Ferralsols: in English speaking countries red earths or vernacular synonyms are used such as 'ekundu' in Kiswahili.

Internationally Ferralsols correlate to: Ferralsols (FAO/Unesco, 1990), Latosols (Brazil), Oxisols (USA), Sols ferrallitiques (France), Lateritic soils, Ferrallitic soils (Russia).

**Concept and morphology**

Ferralsols are soils that have a ferralic horizon at some depth between 30 and 200 cm from the mineral surface. A ferralic horizon is a subsurface horizon resulting from long and intense weathering (ferralitization), in which the clay fraction is dominated by low activity clays (mainly kaolinite) and the silt and sand fractions by highly resistant minerals such as goethite, hematite and gibbsite. Extreme weathering is assessed by a relative low activity of both the physical and chemical characteristics of the colloid fraction and by the low amount of weatherable minerals. An advanced stage of weathering is also characterized by the absence of rock fragments that contain weatherable minerals with the potential to weather and release nutrient cations. Furthermore strong breakdown of the silt particles through extreme weathering results in a low silt/clay ratio.

Ferralsol morphology is characterized by its uniformity in terms of the lack of distinct horizonation. If there is sufficient iron in the original material, the soils are reddish, or yellowish, depending of the soil moisture regime. Generally, the macrostructure seems to be moderate to weak at first sight, fine crumby. However, typical ferralic horizons have a strong near spherical microaggregation ('pseudosand'). In many Ferralsols the macrostructure is massive. The consistence is usually friable, which gives the appearance of 'the soil material flowing like flour between the fingers'. Illuvial features such as clay skins and pressure faces are generally lacking, although some illuviation cutans may occur in the lower part of the horizon. Boundaries of ferralic horizons are normally diffuse and little differentiation in colour or particle size distribution within the horizon can be detected. Ironstone nodules and iron pans, inherited from previous land surfaces are common.
Ferralic horizons are associated with old and stable geomorphic surfaces. The environmental conditions promoting the formation of Ferralsols, is provided by the high ambient temperatures and rainfall of the humid tropics.

• **Properties**

Physically, Ferralsols have a stable, weakly expressed soil structure, a low silt/clay ratio and a very low content of weatherable minerals. They are deep to very deep and generally show yellowish or reddish colours. The physical characteristics of these soils usually are quite favourable for cultivation; because of their depth, high permeability and stable micro-structure they are less prone to erosion. Water holding capacity in Ferralsols usually is low. Soil porosity is high, so roots are going deep in Ferralsols. Ferralsols are easy to work but the surface is liable to contraction and crusting if heavy machinery is used to clear forest or if they are overgrazed.

Ferralsols are chemically poor, with a low cation exchange capacity, and nutrient reserves that are easily depleted by agricultural practices, while inactivation of phosphorus is a major problem (>85% phosphate fixing capacity). The content of aluminium usually is low but may reach toxic levels, as may manganese. Ferralsols typically have a variable charge (CEC). This means that the CEC is dependent on the pH of the soil and may increase up to five fold as pH increases from 5.0 to 7.0. At very low pH the CEC comes near zero. In some cases the soil colloids develop positive charges so that anions (e.g. phosphates) get fixed. Most of the CEC as well as nutrient reserves in Ferralsols are located in the organic matter fraction.

• **Geography**

These soils occur essentially in the humid tropics on the continental shields of South America (Brazil) and Africa (Congo, southern Central African Republic, western Angola, Guinea and eastern Madagascar). These areas have in common that they have been very stable throughout geological history, were not affected by folding or glacial action. Outside these areas Ferralsols are restricted to regions with easily weatherable basic rock and hot humid climate e.g. southeast Asia and some Pacific islands. The total area is estimated as 750 million ha.

• **Relationships with some other reference soils**

As mentioned previously Ferralsols occupy geomorphologically old land surfaces. They are associated with Cambisols where solid rock lies near to the surface. They occur together with Acrisols, which seem often to be related to the presence of more acidic parent materials (e.g. gneiss). On more basic rocks (e.g. dolerite) they are associated with Nitisols. Near valleys Ferralsols merge into Gleysols and Plinthosols.
Plate 12.1. Very homogenous Ferralsol in seasonally dry tropics. Dschang, Cameroun. (Photo: R. Langohr)

Plate 12.2. Ferralsol in humid tropics under oil palm. Sumatra, Indonesia. (Photo: R. Dudal)

Plate 12.3. Small-scale mixed farming on Ferralsols. Dschang, Cameroun. (Photo: R. Langohr)
On continental scale of Africa, a clear zonality has evolved along a climatic gradient. Ferralsols coincide with the humid zone of Central Africa, whereas Acrisols become dominant in a circle in the subhumid zones of West and East-Africa. In South America a comparable zonality exists with Ferralsols in the oldest more humid part of the eastern Amazon basin and Acrisols in the western Amazon. Ferralsols commonly occupy the oldest upper positions of the landscape (e.g. plateau tops). The rejuvenated lower positions are dominated by Acrisols.

**Land use and management**

At present major areas of tropical rainforests are located on Ferralsols. Tropical rainforests are particularly well suited to this soil because their root systems exploit a large volume of the deep soil to tap nutrients and to protect the trees of drought stress. The land is protected against raindrop impact and direct insolation so that organic matter is preserved. This organic rich surface horizon in Ferralsols contains nearly all fertility and is therefore of vital importance for sustainable land use on these soils.

When taken into cultivation, nutrient supply capacity of these soils decreases very quickly after bush clearing. This means that after two to three years of cultivation a fallow period is required of up to 5 - 9 years for natural soil fertility to restore in a shifting cultivation system. For continuous cultivation chemical constraints of these soils may be overcome in part by careful supply of all nutrients, including both phosphate and lime, but attention must be paid to both mode and timing of application.

Organic matter is mainly concentrated in the topsoil and should be conserved at all cost because it buffers chemical change, retains cations, is a major source of nitrogen, and plays a key role in plant available phosphate dynamics. Moderate applications of lime are beneficial as long as they do not result in accelerated mineralisation of organic matter or create micro-nutrient deficiencies (zinc, copper). Usually 0.5 to 2 tons/ha of lime, or preferably dolomite, will be sufficient to supply calcium as a nutrient and to buffer the low pH in Ferralsols.

Because of low water holding capacity, annual crops are more exposed to drought in Ferralsols compared with other soils having comparable clay content. Ferralsols are stable and resistant to soil erosion.
**FLUVISOLS**

*History, connotation and correlation*

The name Fluvisol comes from *L. fluvius*, connotative of floodplains and alluvial deposits. The concept of a group of soils developed from alluvial sediments has been a consistent feature in soil classifications in modern times, and their presence as a discrete group of soils can be observed from earlier writings about soils onwards. Already in the last century Fallou (1862) and Richthofen (1886) recognized categories of alluvial soils in their attempts to classify soils. Dokuchaev, in one of his classifications developed between 1880 to 1900 included alluvial soils as a member of the “abnormal” soils, together with swamp soils and aeolian soils. Subsequently, Sibirtzev (1901) allocated the alluvial soils to the group of azonal soils. Following correlations are made: alluvial soils (Australia), Regosols (Canada), Sols tropicaux récents; Sols minéraux bruts d’apport alluvial ou colluvial, Sols peu évolués non climatiques d’apport alluvial ou colluvial (France); Fluvents (USA); Auenböden (Germany); Alluvial soils (Russia), Fluvisols (FAO).

*Concept and morphology*

The environmental conditions during the process of sedimentation, invariably results in the stratified parent material of alluvial soils. Therefore, stratification is the major characteristic used to distinguish these soils from other soils.

In many cases stratification may be easily detected through the occurrence of layers showing different particle-size distribution and organic matter content. If the successive deposits are homogeneous, as often happens in clayey lacustrine deposits where the environment during sedimentation was characterized by slowly flowing or stagnant water, stratification of the deposit may be difficult to detect. In this case, the irregular differences in organic carbon content of the layers may reveal the stratified character of the sediment. Fluvisols are soils that receive fresh materials (fluviatile, marine and lacustrine sediments) at regular intervals, or have received them in the recent past.

*Properties*

Fluvisols are young soils and therefore show weak horizon differentiation. Chemically, Fluvisols usually are rich, with a near neutral soil reaction. However, soil salinity and high sodium levels may be a problem in coastal sediments. A special case are the Thionic Fluvisols (or acid sulphate soils) which contain large quantities of pyrite in the subsoil. Upon drainage pyrite is oxidized and in the process sulphuric acid is released which in turn may lead to toxic levels of free aluminium in the soil solution.
Plate 13.1. Finely stratified alluvial deposits in a Dystric Fluvisol. Hamburg, Germany. (Photo: R. Langohr)

Plate 13.2. Mangrove vegetation in brackish creeks on Thionic Fluvisols. Sine Saloum delta, Senegal. (Photo: R. Dudal)

Plate 13.3. Thionic Fluvisol containing acid sulphate. Mekong Delta, Vietnam. (Photo: R. Langohr)
Plate 13.4.
Aerial view of the Luangwa alluvial plain with Fluvisols.
Zambia.
(Photo: O. Spaargaren)

Plate 13.5.
Tidal flats with Fluvisols developing along the North Sea coast.
Mouth of the Elbe River, Germany.
(Photo: R. Langohr)

Plate 13.6.
Floating rice field on Fluvisol in Southern Thailand.
(Photo: R. Duddal)
Physically, Fluvisols may be wet through the presence of groundwater or flood water. Freshly deposited Fluvisols usually are unripe and have a low bearing capacity. The clayey types in the backswamps have low infiltration rates, whereas the more silty or loamy types on the river terraces are more porous and have a high hydraulic conductivity. Apart from the Thionic types, Fluvisols are colonized by organisms such as crayfish in river and coastal areas, moles and worms in riverine lowlands.

**Geography**

By definition, Fluvisols occur on materials deposited in aqueous sedimentary environments. 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 salt marsh environments, of which deltas are a special case. Fluvisols are found on all continents under all climatic conditions. They occur mainly on flood plains, fans and deltas of rivers. In the upper part of the drainage basin, they are normally confined to narrow strips along the river. In marine deposits, Fluvisols occur on barriers, tidal flats and accretionary areas bordering higher terrain. Fluvisols cover an estimated area of over 350 million hectares worldwide, more or less proportionally distributed over the continents. Vast areas are found (1) in the large deltas (Ganges-Brahmaputra, Indus, Mekong, Mississippi, Nile, Zambezi, Niger, Orinoco, Rio de la Plata, Po, Rhine), (2) along major and minor rivers and lakes (the Amazon basin, the Ganges plain of India, the plains near Lake Chad in Africa, marshlands of Bolivia and northern Argentina and (3) in coastal lowland zones (Sumatra, Kalimantan and Irian Jaya in Indonesia). Thionic Fluvisols occur in the coastal lowlands of southeast Asia (Indonesia, Vietnam, Thailand), West Africa (Senegal, the Gambia, Guinea Bissau, Sierra Leone, Liberia) and along the north-eastern coast of South America (Venezuela, the Guyanas).

**Relationships with some other reference soils**

Soil forming processes, other than the formation of a surface horizon through accumulation of organic matter, have not left their mark on Fluvisols. These juvenile soils show few or no evidence of weathering and soil formation below 25 cm depth except possible gleying. Permanent or seasonal saturation with water, causing recurrent anaerobic conditions and low or absent biological activity, tends to preserve the original stratified nature of the original deposits. Consequently, the more important linkages of Fluvisols are with other weakly developed soils: Cambisols, Regosols, Arenosols, Leptosols, Gleysols and Solonchaks.

Permanent or seasonal saturation with water, because of permanent or recurrent anaerobic conditions and low biological activity, tends to preserve the original stratified nature of the original deposits. But in the course of time, when the effects of pedogenetic agents such as soil animals, roots, repeated wetting and drying proceed
downward in the profile, a cambic horizon may form. This implies the transformation of the Fluvisol into a Cambisol or Gleysol, depending on the drainage conditions.

- **Land use and management**

Many floodplains have a natural swamp vegetation. Tidal plains in tropical coastal areas are normally under mangroves, and other halophile vegetation elsewhere.

Fluvisols are used for a wide range of crops or are under grassland. They are usually fertile but may need flood control through polders, dikes and drainage. Special precautions are required for cropping actual (oxidized) Thionic Fluvisols because they are highly acidic and usually contain toxic amounts of aluminium.

Many Fluvisols in the humid tropics of southeast Asia are under highly productive rice cropping systems, whereby three crops per annum are possible. However, it is important that the paddy land is allowed to dry for at least a few weeks every year (Driessen and Dudal, 1991). This will prevent the soil’s redox potential from becoming so low that nutritional problems (iron toxicity, H₂S gas) develop. During a dry rest period microbial activity is stimulated which promotes mineralization of organic matter and hence release of plant nutrients.
**GLEYSOLS**

**History, connotation and correlation**

The name Gleysol stems from the Russian local name *gley*, meaning mucky mass, connotative of an excess of water. They have always been recognized in national soil classification systems. Correlations are: Rego Gleysols (Canada); Sols à gley peu profond peu humifères (France); Gley (Germany); Aquents, Aquepts, Aquolls (USA); Meadow soils (Russia); Groundwater Rendzina (Australia); Borowina (Germany); Lacovisti (Romania).

**Concept and morphology**

Gleysols, or soils with gleysic properties, are either permanently or temporarily wet and reduced at shallow depth. The upper part of the soil is therefore either mottled (in case of temporary aeration) or has colours reflecting reduction. Gleyic properties are formed when the soil is completely saturated with groundwater, unless drained, for a period that allows reducing conditions to occur. This period may range from a few days in the tropics to a few weeks in other areas.

*Reduced* soil materials that are permanently saturated have a characteristic gleysic colour pattern (white to black or bluish to greenish) in the soil matrix. In loamy and clayey materials blue-green colours dominate. Material rich in sulphur shows black colours caused by the presence of iron sulphides. In sands colours are light grey to white through impoverishment of iron and manganese. The upper part of a reduced soil layer typically has a rusty appearance, mainly around channels of burrowing animals or plant roots (“rusty root channels”).

*Oximorphic properties* apply to soil materials in which reducing and oxidizing conditions alternate, as is the case in the capillary fringe zone and surface layers of soils with fluctuating groundwater levels. The oximorphic properties are evidenced by the presence of reddish brown (ferrihydrite), orange (lepidocrocite) or bright yellowish brown (goethite) mottles. In acid sulphate soils bright yellow (jarosite) mottles occur as well. In loamy and clayey soils, the iron (hydr)oxides are concentrated on aggregate surfaces and walls of larger pores, like old root channels which in extreme cases can be entirely filled with such oxides, while the cores still show reduction colours.

It is important to distinguish Gleysols from stagnic subunits of other Reference Soil Groups, which also have gleysic properties but have a different hydrology and morphology. Stagnic subunits normally have a slowly permeable dense layer in the solum above which water stagnates. They are usually very wet in the upper part of the profile, but well drained in the subsoil, and commonly occur in upland positions. Gleysols
have a permanent groundwater table and are found in valleys. There are also pronounced differences in the ecology and utilization of Gleysols and stagnic subunits (Schlichting, 1972).

- **Properties**

Chemically, Gleysols are rather fertile, because they generally have a finer soil texture and a slower organic matter decomposition, and enjoy an influx from ions from adjacent (higher) lands. Physically, Gleysols are saturated with water for long periods during the year. Repeated wetting and drying may also cause an increase in soil density by weakening interparticle boads during saturation and contraction of soil particles upon drying (Driessen and Duda, 1991). This results in poor aeration of the rooting environment and unsuitable conditions for most fauna except adapted species, such as crayfish.

- **Geography**

Gleysols are found in nearly all climates, from perhumid to arid conditions, and cover an area of almost 720 million ha worldwide. The largest extent of Gleysols occurs in the boreal and cool parts of the world as well as in Zaire, Angola, Botswana, Mali and China.

- **Relationships with some other reference soils**

Soils in other Reference Soil Groups may have evidence of water saturation by groundwater at deeper levels than required for the Gleysols. These soils form intergrades towards the Gleysols.

In the lowlands of the temperate latitudes they occur associated with Fluvisols near river beds and in coastal areas, and with Histosols. In moraine and löss landscapes they occupy depressions with a high groundwater table and occur together with Histosols with Luvisols and Cambisols occupying the higher landscape positions.

In the semi-humid steppes, Gleysols are associated with Chernozems or Phaeozems in higher landscape positions. In the humid tropics they are found in valleys associated with Acrisols, Lixisols, Nitisols, Alisols or Ferralsols occupying the better drained positions of the surrounding uplands.

In arid regions they are also concentrated in valleys, sometimes together with Solonchaks and Solonetiz. Higher landscape positions are normally occupied by Calisols or Gypsisols as well as Cambisols, Regosols, Arenosols and/or Leptosols with yermic surface properties.

- **Land use and management**

Most Gleysols have a natural swamp vegetation or are used for grazing. In the tropics and sub-tropics they are widely planted with rice. They can be used for arable crop-
Plate 14.1. Reduced and oxidized layers in a Gleysol with organic matter accumulation at the surface. Romania. (Photo: R. Dudal)

Plate 14.2. Rice growing on Gleysols. Bangladesh. 
(Photo: R. Dudal)
ping, dairy farming or horticulture provided the groundwater table is lowered or groundwater seepage from the uplands is intercepted. Special precautions must be taken in case of Thionic Gleysols, which may acidify irreversibly upon oxidation after drainage.

Trafficability usually is a problem with Gleysols; if the soil is cultivated in too wet a condition, soil structure is likely to deteriorate (Driessen and Dudal, 1991).
GYPSISOLS

History, connotation and correlation

The name Gypsisol comes from L. gypsum and refers to soils with substantial accumulation of calcium sulphate. In the FAO 1974 legend of the Soil Map of the World, Gypsisols were classified under the Yermosols and under the Xerosols. As of 1988 Gypsisols were taken up to the highest hierarchical level in the FAO Legend. In Soil Taxonomy Gypsisols key out under the Aridisols as Gypsiorthids. In the USSR Gypsisols are included with Desert soils.

Concept and morphology

The main feature of Gypsisols is the occurrence of a gypsic horizon. This is a horizon which contains a secondary accumulation of gypsum (CaSO₄·2H₂O). Primary gypsum, such as gypsum rock and mobile gypsum sand, are excluded from the definition of gypsic horizons. Sources of secondary gypsum are the weathering of gypsum-bearing rocks, gypsum dust, run-off and gypsum dissolved in the groundwater.

Gypsic horizons are found either at the soil surface or at depth within the solum. Differences occur in the total amount of gypsum present and in their morphological expression. Five main types of gypsic accumulation are recognized in the field: (1) pseudomycelia gypsum, (2) compact powdery gypsum, (3) coarse-sized crystalline gypsum, (4) the strongly cemented gypsum crust and (5) the polygonal gypsum crust (Stoops et al, 1981). The petrogypsic horizon represents the ultimate stage of pedogenetic accumulation of gypsum.

A special kind of gypsic accumulation occurs under certain hydromorphic conditions. These accumulations, known as “arziky” in Kazakhstan, are found in medium textured Quaternary deposits where sulphate-rich groundwater occurs at shallow depth. The soils, which are at least 100 cm thick, contain between 10 and 25 percent gypsum in the form of spots, powdery coatings, etc., distributed throughout the solum without a clear formation of a gypsic horizon. In so-far-as these soils do not qualify for Solonchaks, they are grouped with the Gypsisols rather than Gleysols, as gleysic properties are usually not evident.

Properties

The soil colour depends often on the amount of gypsum present. Soils with a maximum gypsum content (about 90%) have whitish colours. Texturally they vary, often depending on the sedimentary environment in which they occur.
Plate 15.1. Mining of the petrogypsic horizon. Makanya, Tanzania. (Photo: J. Deckers)

Plate 15.2. Gypsisol with petrogypsic horizon at 80 cm depth. Makanya, Tanzania. (Photo: J. Deckers)
On river terraces especially, the gravel component can be important. Soil structure is usually weakly developed but it generally becomes massive when the gypsum content exceeds 20 percent.

If the water table is at shallow depth, capillary rise may bring salts into the profile. Of importance to this aspect of salinity is the total content and type of ions being brought into the system. Non-saline Gypsisols are characterized by a low electrical conductivity and a slightly alkaline reaction (pH values of 7 to 8).

**Geography**

Gypsisols are found mainly in areas with arid climates. They cover about 90 million ha of the earth surface, mainly concentrated in the driest part of the arid climatic zone: the Libyan and Namib deserts, Yemen, Somalia, northern Iraq and Syria. They often occur in association with Calciisols in Uzbekistan, Kazakhstan, southeast and central Australia and southwestern USA. They form a large portion of the range lands in these countries.

Precise information of their distribution is mostly lacking. Consequently, it is difficult to assess a real or even approximate figure for the proportion of land covered by these soils in the world.

The proximity to water sources is of special importance to the geographical distribution of these soils. For instance, in Syria Gypsisols are dominant on all river terraces of the Euphrates, Khabour and Balikh rivers (Ilaawi, 1983).

Gypsisols in Iraq occupy a major part of the Mesopotamian plain between and adjacent to the Tigris and Euphrates rivers.

**Relationships with some other reference soils**

The gypsic horizons as defined previously are diagnostic for the Gypsisols but are not exclusive to them. Gypsic horizons may also occur in other Reference Soil Groups, e.g. in Vertisols, Solonchaks, Solonetzs and Kastanozems, but these soils are also characterized by the presence of other diagnostic horizons or properties which are absent in the Gypsisols.

The lateral linkages of the different forms of gypsic horizons with non-gypsic horizons is a function of the following factors:

- **Topography.** Petrogypsic horizons occupy the summits in areas with dominant gypsic formations whereas gypsic horizons occur on slopes. Calcic horizons are found in the lower parts and in depressions. If both gypsum formation and calcification has taken place in old geomorphic surfaces, summits are usually occupied by petrocalcic horizons while gypsic and petrogypsic horizons occur at lower levels.

- **Age.** The degree of expression of the gypsic horizons is influenced by time. The volume of gypsum crystals in recent Quaternary saline depressions and valleys does not only reflect the rate of salinization, but also the age of the salinization process. As gypsic horizons age, they have a tendency to petrify.
- Water. This plays a key role in transporting and redistributing gypsum. For example, where gypsiferous rocks crop out in semi-arid hilly or mountainous regions, gypsum is transported by run-off and deposited eventually in lower lying areas far distant from the point of origin.

- Land use and management

Gypsisols that occur in association with younger geomorphic surfaces such as alluvial deposits of the first and second river terraces and colluvial sediments in intermontane valleys and depressions are important from an agricultural point of view. They have a relative low gypsum content and are usually located close to water resources so that irrigation is possible. Many irrigation projects are established on such soils using both surface and groundwater.

The petrogypsic horizon has to be considered as a depth limiting layer if soil potentiality is taken into account. Consequently, attention must then be paid to the material which overlies the petrogypsic horizon.

If the gypsum content in the upper 30 cm is not more than a few percent, Gypsisols are suitable for small grains, cotton and alfalfa. With gypsum contents of 25% or more, crops like wheat, maize, apricots, maize and dates can be grown under irrigation. Quick dissolution of gypsum may cause problems of land subsidence, and caving-in of canal walls. Corrosion of concrete structures can occur through crystal growth.
**HISTOSOLS**

**History, connotation and correlation**

The Reference Soil Group of the Histosols (from Gr. *histos*, tissue) includes a wide variety of peat and muck soils ranging from moss peat of the boreal tundra, reeds/sedge peat and forest peat of the temperate zone and the mangrove and swamp forest peat of the humid tropics. International correlations are Moor peat (Australia), Organic soils (Canada), Sols hydromorphes organiques (France), Moorböden (Germany), Histosols (USA), and Bog soils (former USSR).

**Concept and morphology**

Histosols are unlike all other soils in that they have a histic horizon, which is formed in 'organic soil material' with physical, chemical and mechanical properties that differ strongly 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. Organic soil material is defined as soil material that contains more than 20 percent organic matter. Organic materials accumulated in different environments are generally of different composition and have different chemical, physical and mechanical properties. The degree of decomposition of the organic soil material varies also and is an important additional criterion in the subdivision of Histosols. The combination of specific environmental conditions, the actual composition of the organic soil material and the degree of decomposition leads to different types of Histosols.

**Properties**

The composition of the mineral component in Histosols seems to have only a marginal effect on their properties, their management and (agricultural) use possibilities; the cation exchange capacity and most other chemical soil characteristics are controlled by the content and properties of the organic component and so are the mechanical properties. Specific density and volume density of the material are of particular importance among the mechanical, physical and chemical properties of Histosols. They determine the total pore volume and influence greatly the bearing capacity of the soil, its trafficability and the rate of subsidence of the soil surface if drainage is installed. Most Histosols are loosely packed in their natural state, and virgin peat retain considerable quantities of water.
The range in pH is very large. Alkaline peat with a pH of 7.8 have been reported from the Maldives (Hammond, 1971). Extremely acid Histosols with a pH of less than 2 may occur where peat containing pyritic material have been drained. Generally eutrophic basin peat are about neutral in reaction, with a pH over 6, while raised peat of an oligotrophic nature are commonly acid or very acid (pH range 3 to 4.5). The cation exchange capacity of most Histosols is variable.

**Geography**

The total extent of Histosols in the world is estimated at 275 million ha, of which roughly half are located in the arctic zone of the northern hemisphere, one-third in the temperate lowlands and cool montane areas, and one-sixth in the tropical lowlands. Histosols dominate in i.e. central Canada, south of Baffin Bay, northern Finland, western Scotland, and east of the Ural mountains. They occur in association with other ill-drained soils, mainly Gleysols in Alaska and the whole northern part of Russia. Some 20 million hectares of acid forest peat border the Sunda Strait in southeast Asia.

**Relationships with some other reference soils**

Histosols overlying permafrost occur mainly in boreal regions. Their high organic matter content results from the slow decay of organic debris, caused by frost in the cold season, and waterlogging of the thawed surface soil during summer. Therefore, boreal Histosols are likely to be associated with soils having both gleyic and stagnic properties. Where the boreal zone grades into the cool temperate zone associations with Podzols can be expected.

Histosols under the permanent influence of groundwater (‘low moor peat’), unless artificially drained, occur in low-lying positions in fluvial, lacustrine and marine landscapes, mainly in temperate regions but to a limited extent also in the tropics. Other soils occurring in the same environment are Fluvisols, Gleysols and, in coastal regions, Solonchaks (e.g. adjacent to coastal mangrove peat). In lacustrine landforms Histosols may be associated with Vertisols. Histosols in which the water regime is conditioned by high precipitation (‘high moor peat’), unless artificially drained, occur in many environments. Oligotrophy and prolonged wetness are primarily accountable for the low decay rate of organic debris. In the wet tropics (mainly the region surrounding the Sunda Strait), their formation is also conditioned by the high rate of organic matter production by the climax rain forest vegetation. Lateral linkages exist with a variety of other Reference Soil Groups, including Andosols, Podzols, Fluvisols, Gleysols, Cambisols and Regosols.
Plate 16.1. Histosol with buried Podzol. Ekelmoor, Lower Saxony, Germany. (Photo: R. Langohr)


Plate 16.3. Excavating peat in Ireland. (Photo: A. Ruellan)

Plate 16.4. Commercial peat excavation. Germany. (Photo: R. Langohr)
- **Land use and management**

The characteristics, management requirements and use possibilities of such soils are determined, inter alia, by the properties of the soil material (stratification/decomposition, packing density, wood content, floristic composition) and the type of peat bog (basin peat, raised bog, etc.), notably the position of the present and future land surface relative to the drainage base. Management requirements and use possibilities of Histosols are largely conditioned by characteristics such as the low bulk density and high compressibility (poor trafficability, poor anchorage of root systems), and the high rate of decay upon drainage (subsidence), liming, fertilization, etc. Reclamation measures alter precisely those conditions which retarded the decomposition of organic matter and caused organic material to accumulate. As a result, the mineralization rate of the organic soil material increases sharply after drainage. In addition to this oxidative loss of soil material, reclaimed Histosols suffer from loss of soil volume because of compaction and/or settlement of organic soil material, e.g. when natural, water-saturated Histosols are drained and the buoying force of the groundwater is removed. However, when they are carefully drained in order to avoid subsidence, and eventual acidification if sulphidic materials occur at shallow depth, they offer some potential for cropping. Both arable crops and horticulture can take place, subject to judicious management of plant nutrition including liming, NPK fertilizers and micronutrients. Peat lands may be used for various forms of extensive forestry and/or grazing or are unused. Some are used for fuel production. Deep peat formations are best left in their natural state.
KASTANOZEMS

History, connotation and correlation

Kastanozems (from L. castanea, chestnut and Russian zemlja, earth, land) or "dark chestnut" soil, were considered the "normal" or "zonal" soils by Docuchaev for the short grass steppe in the continental part of the temperate climatic belt. International correlations are: Brown and Dark Brown soils (Canada); Chestnut soils of the Dry Steppes (Russia); Sols châtains (France); Ustolls, Borolls (USA), Kastanozems (FAO).

Concept and morphology

Kastanozems are soils of the drier warmer areas of the steppe. Here the natural vegetation is dominated by early ripening grasses that produce 3 to 4 t/ha/year of dry root mass, 50% of which is concentrated in the upper 25 cm of the soil, resulting in a brown surface horizon with an organic matter content generally of 2 to 4%. Consequently, compared to Chernozems and Phaeozems, Kastanozems have a less deep mollic horizon which, moreover, is not black to very dark grey but has a dark grey brown to dark brown colour. This is due to the drier semi-arid to almost arid climate where consequently biomass production is lower. Krotovinas (burrows of small rodents filled with surface soil material) as macromorphological evidence of high bioturbation are present but less frequent and less deep than in the Chernozems probably because of the milder winters. Kastanozems, in contrast to Chernozems, may have a gypsic horizon or concentrations of gypsum crystals in the lower part of the soil or in the parent material. A gypsic horizon occurs only in drier areas where the parent material is rich in gypsum.

Properties

Kastanozems are neutral to mildly alkaline in reaction. This results in concentrations of soft powdery lime already in the lower part of the mollic horizon and in the horizon transitional to the parent material. It is a main diagnostic property, separating the Kastanozems (and Chernozems) from Phaeozems. Kastanozems are chemically rich soils, highly saturated with bases. The lower humus content of the surface horizon, particularly in the lighter Kastanozems, is associated with a lower degree of microparticulate aggregation, which manifests itself in a lower pore volume (40-55 percent), a denser packing of the soil and a lower permeability to water. Being less deep in comparison with Chernozems, Kastanozems have a lower available water capacity. Wind and water erosion are a problem when these soils are cultivated.
Plate 17.1.  
Reddish dark brown colour of Kastanozem.  
Morocco.  
(Photograph: A. Ruellan)

Plate 17.2.  
Kastanozem landscape of the dry steppe of southern Russia. (Photograph: R. Dudal)
• **Geography**

The total extent of Kastanozems is estimated at about 465 million ha, mainly concentrated in the short grass steppe of Eurasia (southern former USSR, central Mongolia), the short grass prairie in North America (southern Canada to Texas and throughout Mexico). In South America, they occur in the pampas of northern Argentina and in the Gran Chaco of Paraguay.

• **Relationships with some other reference soils**

Kastanozems border the Chernozems, which develop under tall grass steppe or prairie, at the drier and warmer side of the cold and temperate climatic belt. They are also found adjacent to the Phaeozems of the subtropical climatic belt. At the dry end, Kastanozems border with Caleisols and Gypsisols. Here they also form associations with Solonchaks and Solonetzes.

• **Land use and management**

Potential fertility of Kastanozems is high. The main obstacle to high yields is the lack of soil moisture mainly during the growing period. Irrigation is therefore nearly always necessary to produce sufficient yields of arable crops. Care ought to be taken to avoid secondary salinization of the topsoil. When used in dryland farming, wind erosion is a serious problem especially during the fallow period. Extensive grazing is another important land use on Kastanozems. However, the sparsely vegetated grazing lands are inferior to the tall grass steppe on Chernozems and many areas are already overgrazed.
**LEPTOSOLS**

- **History, connotation and correlation**

  Thorp and Smith (1949) were the first to use the word Lithosol to denote a group of azonal soils having an incomplete solum or no clearly expressed soil morphology and consisting of a freshly or incompletely weathered mass of hard rock or hard rock fragments. The term has been used in many classification systems including the USA, French, and FAO legend. Sibirtzev already made reference to Leptosols under the name Rendzina for shallow soils on calcareous rocks. The term Rendzina originates from Polish and is connotative of the noise a plough makes as it passes over shallow, stony ground.

  The name Leptosol stems from Gr. leptos, thin. It correlates with Entisols, Lithic subgroups, Rendolls (USA), Lithosols (FAO, 1974), Rendzina (FAO, 1974), Rendzines (France), Dern-carbonate soils (USSR), Rankers (France, Germany), and Humuskarbonatböden (Switzerland).

- **Concept and morphology**

  Leptosols are soils which either are limited in depth by continuous hard rock within 25 cm of the soil surface, or contain or overlie within the same depth material with a very high calcium carbonate content, or are very gravelly throughout. Leptosols represent the initial phases of soil formation or may be the product of severe erosion. As such they are of great significance in the soil mantle because they are the forerunners of the young or weakly developed soils of the other Reference Soil Groups. So the maximum development in Leptosols will often be the minimum criteria required for one of the other soil groups. The concept of Leptosols includes all shallow, or very stony soils overlying rock, partially altered rock or strongly calcareous material, or soils with a limited amount of fine earth material. Leptosols are soils which are distinguished by “the absence, throughout appropriate depths, of any recognized elementary assemblages of characteristics that are diagnostic for any other group of soils”. Leptosols have not been sufficiently subjected to the processes of alteration and horizon differentiation to display morphologic features and properties that meet the requirements of a diagnostic horizon or assemblage that is necessary for recognition of any other Reference Soil Group.

- **Properties**

  Leptosols have a range of chemical, physical and biological characteristics, strongly conditioned by the nature of the parent material. Calcareous Leptosols are chemically
Plate 18. LEPTOSOLS

Plate 18.1.
Skeletic Leptosol with core stones on basalt. Bambouto Mountains, Cameroun. (Photo: R. Langohr)

Plate 18.2.
Leptosol on hard calcareous rock. Piedmont of Mont Ventoux, France. (Photo: R. Langohr)

Plate 18.3.
Gravelly surface of Leptosol on limestone. Southern Poland. (Photo: R. Dudal)
richer than the non calcareous ones. Leptosols have a rather limited water holding capacity, a limited volume of soil for root anchorage, are well drained and lack high levels of soluble salts.

Earthworms, enchytraeid worms, arthropods and bacteria are the chief soil organisms. The soil fauna may be temporarily inactivated through drought.

- Geography

Leptosols are together with the Cryosols the most widespread Reference Soil Group, covering globally an area of approximately 1655 million ha. These soils occur in all parts of the world from the tropics to the cold polar tundra surrounding the ice caps and from sea level to the tops of the highest mountains. Leptosols are the most important soils of mountain regions. Their greatest extent is found in the mountainous areas of Asia and South America, the Saharan and Arabian deserts, the Ungava peninsula of northern Canada and the Alaskan mountains. Elsewhere, Leptosols may occur on rocks which are resistant to weathering or where erosion has kept pace with soil formation as on the crests of escarpments, keeping soil depth to a minimum. Leptosols may also be found on lands where accelerated erosion has removed the major part of the soil profile.

- Relationships with some other reference soils

Much of the steeply sloping lands in the mountainous parts of the world carry Leptosols where there is no chance for a deeper weathered mantle to accumulate in which, for example, a Cambisol might form; erosion removes any excess regolith as quickly as it is formed. Included within the mountainous regions are many hard and resistant rocks of older geological systems upon which soil formation can be extremely slow. Within the less mountainous areas outcrops of resistant igneous rocks or sedimentary strata, such as a dolerite sill or a quartzite may result in an area of Leptosols, co-incident with the crest of hills or escarpment faces.

- Land use and management

Most Leptosols are under natural vegetation, which is generally richer on calcareous parent materials than on the acid types. The main physical constraint of Leptosols is their low water holding capacity, which make them very susceptible to drought stress. Chemical fertility of most Leptosols usually compares more favourably than other soils developed from the same parent material. Leptosols have severe physical limitations for arable cropping, but have a certain potential for trees, the roots of which find anchorage by entering fissures, and for extensive grazing. The most productive Leptosols are the ones developed on limestone under a humid climate. In montane regions, soil erosion is a major problem with Leptosols under arable crops. In South-east
Asia, Leptosols of hilly areas are cultivated in humid cool tropical climates. If they are utilized in a slash and burn system they degrade after a few years with severe soil erosion. They can be stabilised by terracing, under permanent grassland or by means of strip cropping.
• LIXISOLS •

• History, connotation and correlation

Lixisols (from L. *lixivia*, washed out substances) are strongly weathered soils in which clay has been washed out from an eluvial down to an argic horizon of low activity clays (less than 24 cmolₖ kg⁻¹ clay) and a moderate to high base saturation. The name Lixisol was first introduced in the Revised Legend of the Soil Map of the World (FAO-Unesco-ISRIC, 1988) as a name for soils with an argic B horizon dominated by low activity clays and a base saturation less than 50%. Formerly, Lixisols soils have been called red yellow podzolic soils (Brazil), Podzólicos vermelho-amarelo eutróficos a argila de atividade baixa (Brazil), soils ferrugineux tropicaux lessivés and soils ferrallitiques faiblement désaturés appauvris (CPCS, 1967), red and yellow earths, Latosols and oxic subgroups of Alfisols (Soil Survey Staff, 1996).

• Concept and morphology

Lixisols are characterized by a clay accumulation in an argic horizon in combination with the occurrence of low activity clays and a moderate to high base saturation. The ratio of the cation exchange capacity to the clay content identifies the dominance of low activity clays. The argic horizon in Lixisols often lacks clear illuviation features and most Lixisols are therefore characterized by a sharp clay increase occurring over a short distance.

• Properties

The higher base saturation tends to give Lixisols somewhat better developed structures than the weak ones normally encountered in Acrisols. Often an eluvial horizon is present which is massive. When dry, the eluvial horizon in Lixisols may become very hard (so-called "hard setting"). Root penetration is usually good as there are no chemical barriers like in Acrisols. Stone lines or a ferric horizon in the subsoil may impede root growth however. The absolute amount of exchangeable bases is generally not more than 2 cmolₖ kg⁻¹ fine earth due to the low cation exchange capacity. Many surface horizons of Lixisols are thin with a low amount of organic matter, especially in regions with pronounced dry seasons. Accumulation of organic matter may be considerable only where fairly humid conditions and/or low temperatures prevail as in tropical highlands.

• Geography

These soils are found mainly in the seasonally dry tropical, subtropical and warm temperate regions and in areas with frequent additions of airborne dust, on Pleistocene and
older surfaces. Lixisols cover an estimated area of about 435 million ha, of which more than half occur in Africa and about one-quarter in South and Central America.

- **Relationships with some other reference soils**

Other soils characterized by an argic horizon are Nitisols, Alisols, Acrisols, Luvisols and Albeluvisols. Lixisols are differentiated from the Nitisols by lacking a nitic horizon. Nitisols also exhibit gradual to diffuse transitions to both the overlying and underlying horizons. Limits and linkages of Lixisols, Acrisols, Alisols and Luvisols are entirely based on analytical properties. Therefore, in areas where soils have cation exchange capacities close to 24 cmol_c kg^{-1} clay, they will merge into each other. However, separation in the field may pose problems.

Lixisols mostly occur in the drier parts of the (sub-)tropics, they are less leached and have higher base saturation and pH. Field pH determination may therefore be an indication but additional criteria need to be found to make positive identification in the field possible. Field separation between Luvisols/Alisols on one hand and Acrisols on the other faces similar problems. Generally Luvisols and Alisols tend to have better developed structures and have a higher content of weatherable minerals than Acrisols. These criteria, together with the pH, may be used as field indicators. However, until better criteria for use in the field are available, one will have to rely on laboratory data as well.

Lixisols border a number of soils with which they have other strong linkages. Lixisols are derived mainly from parent materials with moderate to high levels of weatherable minerals. They occur in tropical, subtropical and warm temperate climates with a pronounced dry season where they form a transition between Acrisols and soils of more arid environments. In these regions their high base status is often maintained by regular additions of airborne dust, e.g. in the Sahel zone in Africa. They also occur in areas where arid and humid periods have alternated in Pleistocene times. On old erosional or depositional surfaces or in piedmont areas of the humid regions, they are often an important soil, associated with Nitisols when on basic rocks, or with Vertisols, Planosols, Plinthosols and Gleysols in depressions and on plains. On ancient shield landscapes in tropical regions Lixisols are found associated with Ferralsols. The latter are present on the flatter parts, little affected by erosion, or where sediments derived from weathered soils on uplands have been deposited. Lixisols may be found in these landscapes on slopes and on surfaces subject to erosion. Along valleys Lixisols often occupy the higher terraces, while the lower and younger terraces have Luvisols or Cambisols. Old alluvial fans in tropical regions often have Lixisols, with Plinthosols in associated depressions.

- **Land use and management**

The natural vegetation of most Lixisols in the tropical and subtropical regions is savanna and open woodland. Such areas with Lixisols are often used for extensive graz-
Plate 19.1.
Cultivated Lixisol. North Benin.
(Photo: J. Deckers)

Plate 19.2.
Erosion control by grass strips on Lixisols. North Benin.
(Photo: J. Deckers)
ing. Because Lixisols are relatively well supplied with nutrients, they are also much sought after for cultivation. The low absolute levels of nutrients require maintenance of soil fertility on a regular basis. The low cation exchange capacity often dictates split applications to prevent fertilizer loss. Continuous cultivation is quite possible, but it is necessary to take into account recurrent inputs of fertilizers and/or lime. Other land management practices may be needed such as occasional ripping and deep ploughing. Moreover, care should be taken to preserve and maintain the surface layer in which organic matter has accumulated, mainly to avoid decline of soil structure and subsequent sealing and crusting.

Significant yield decreases caused by adverse surface soil characteristics are regularly recorded on these kind of soils. Rotation of annual crops with improved pastures are recommended to maintain or improve the organic matter content. Soil erosion control is of paramount importance especially in Lixisols with stonelines or ferric properties in the solum. Perennial crops like cashew, mango, citrus and other fruit trees are well adapted to these soils, although some supplementary irrigation may be required in the drier parts of the tropics and subtropics or where stonelines occur at shallow depth.
• **LUVISOLS**

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**History, connotation and correlation**

The name Luvisols was coined from the L. *luere*, to wash, connotative of clay being ‘washed out’ from the upper part of the soil. The dominant characteristic of Luvisols is the textural differentiation in the profile showing a surface horizon depleted in clay and an accumulation of clay in a subsurface argic horizon. These soils are further characterized by moderate to high activity clays and a low aluminium saturation. They are known as ‘sols lessivés’ in France, Parabraunerde in Germany, pseudo-podzolic soils in Russia, grey-brown podzolic soils in earlier USA terminology or as Alfisols (*pro parte*) in USDA Soil Taxonomy. In the FAO legend they are called Luvisols.

The term ‘podzolic’ formerly used for these soils, on account of the lighter coloured surface horizon, was particularly confusing as the formation of these soils is not the result of the process of podzolisation.

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**Concept and morphology**

The characteristics used to define Luvisols are essentially the textural differentiation (presence of a diagnostic argic horizon), the cation exchange capacity of the clay and the low aluminium saturation. The genesis of an argic horizon in Luvisols is ascribed to eluviation of clay from an eluvial horizon near the surface to the subsurface argic horizon.

The presence of an argic horizon is a mark of a stable land surface. If an argic horizon is formed mainly by illuviation it also indicates a seasonally dry period during which clay can flocculate on ped surfaces in the form of clay coatings or argillans. Although the argic horizon normally occurs in the subsurface parts of the soil it might occur near or at the surface when surface horizons have been removed by erosion. An argic horizon may occur either as a continuous layer of clay accumulation or in the form of lamellae. It must have a minimum thickness and show a well defined increase in clay with respect to the overlying layers (unless eroded) in order to qualify as a diagnostic horizon. Deposition of surface materials which are coarser than a subsurface horizon may enhance the pedogenic textural differentiation. However, a mere lithological discontinuity, such as may occur in alluvial deposits, does not qualify as an argic horizon. If an argic horizon is formed by clay illuviation, clay skins (cutans) may occur on ped surfaces, in fissures, in pores and in channels.

The colour of the argic horizon ranges from brown to red in relation to the nature of the iron compounds present. Reddish colours normally point to soil formation in present or earlier warm climates. Luvisols may occur in environments which are no longer conducive to clay movement. The argic horizons occurring in arid and semi-arid areas are generally relicts from more humid conditions.

Plate 20.2. Undulating löss plateau of the Luvisol belt. Central Belgium. (Photo: J. Deckers)

Plate 20.3. Clear horizon differentiation in a Luvisol. Central Belgium. (Photo: R. Langohr)
**Properties**

Luvisols are usually well drained. In case of a compacted argic horizon, internal permeability may be low so that water stagnates in the upper horizons. Water holding capacity in the argic horizon is high and ranges between 15 to 25% of volume. Luvisols in löss regions have a high silt content and are vulnerable to erosion.

The moderate to high cation exchange capacity, indicates the presence of high activity clays. A low aluminium saturation reflects a limited leaching, a fair content of plant nutrients, a medium pH and a good level of fertility (high base saturation).

The rather favourable physical and chemical fertility status results in a relatively high status of biological activity in Luvisols, especially where fertility has been upgraded through long standing applications of organic and mineral fertilizers.

**Geography**

Luvisols cover some 650 million ha worldwide, the greater part in the humid to subhumid temperate regions of central and western Europe, the USA, the Mediterranean region and Southern Australia. To a lesser extent they occur in subtropical regions, mainly on young land surfaces.

**Relationships with some other reference soils**

The argic horizon as described above is diagnostic for Luvisols but is not exclusive to them. Argic horizons are diagnostic features for the Reference Soil Groups of Lixisols, Acrisols, Nitisols and Albeluvisols and also in some Chernozems, Kastanozems, Phaeozems, Gypsisols, Calcisols and Arenosols. In these soils, however, other diagnostic horizons or properties occur which distinguish them from the Luvisols.

These other characteristics occurring in combination with an argic horizon are sufficiently significant genetically and geographically, and are sufficiently important from the point of view of land use and management to justify a separation from the Luvisols. The process of textural differentiation may occur in different environmental conditions and is not alone a sufficiently diagnostic feature to characterize soils at the highest level of generalization.

Luvisols are mineral soils which differ from other soils in terms of the nature and thickness of the argic horizon and exchange characteristics. The differences between the Luvisols and most other Reference Soil Groups can be deduced from the key to the units.

Luvisols are linked to a number of Reference Soil Groups with which they share common properties or show characteristics less pronounced than in the Reference Soil Group to which the linkage exist.

Vertisols are distinguished by the presence of a vertic horizon in combination with a heavy texture throughout and the occurrence of cracks. Gleysols may have an argic horizon but differ from Luvisols by having either hydromorphic features or gleic
properties at shallow depth. Gypsisols and Calcisols may have an argic horizon, however, the dominant presence of either gypsum or calcium carbonate separates these soils from the Luvisols.

Some Luvisols may have an umbric horizon and, consequently, they grade into Umbrisols when the requirements for the argic horizon have not been fulfilled.

The variability of physico-chemical properties in Luvisols should be seen against the background of horizontal linkages which are very often influenced by land use history. A typical example in the Belgian löss belt are the undisturbed Luvisols under natural forest versus the enriched Luvisols under agriculture. The former link up with Albeluvisols, having a lower clay content and lower base saturation in the argic horizon. In the enriched Luvisols the tonguing has disappeared through bioturbation and the base saturation in the B horizon is high.

- **Land use and management**

The physical and chemical properties of Luvisols are in most cases favourable for crop growth, as long as they are well drained. The eluvial horizon is depleted and can have an unfavourable platy structure with pseudogley as a result. This is the reason why truncated Luvisols are far better for farming than the non eroded original profiles. The illuvial argic horizon is a good rooting environment with a water storage capacity of some 15 - 20% of volume. Most Luvisols do contain reserves of weatherable minerals, however, a balanced fertilizer applications is required to ensure good yields. Dystric Luvisols can give good crop yields provided the low pH is adjusted by liming.
• **NITISOLS**

• **History, connotation and correlation**

During the early soil surveys in the Kivu Region of Congo, Nitisolso were already recognized under the name of ‘Sols Fersialitiques’ or ‘Ferralsols’. They usually were developed on strongly weathered basaltic volcanic deposits. In the 1974 FAO/Unesco legend special provision was made for these soils under the name “Nitrosols”, from L. *nitisus*, shiny, connotative of shiny ped faces in the subsoil. The Nitisol concept was further elaborated by Sombroek *et al.* (1981). In the revised Legend of the FAO soil map of the world the name Nitrosols was changed into Nitisols, and ‘nitic properties’ were specified more precisely. The reason for their distinction at the highest level of classification was that although they are strongly weathered and resemble Ferralsols, Nitisols proved to be far more productive soils. In Soil Taxonomy (Soil Survey Staff, 1996) Nitisols key out under the kandic groups of Alfisols and the Ultisols. Other international correlations are: Red earths (England), Ferrisol (France), Krasnozems (Australia and Russia), Terra Roxa estruturada (Brazil).

• **Concept and morphology**

Nitisols are deep, well drained soils with a typical nutty or polyhedric blocky structure and shiny ped faces. They are dusky red or dark red and have a clayey texture. These soils have an argic horizon with deeply stretched clay bulge such that they do not show a relative decrease from its maximum of more than 20 percent within 150 cm of the surface. Typically the transition between the surface layer(s) and the subsoil is gradual or diffuse. Diagnostic for the nitic horizon are ‘nitic properties’, i.e. the soil material must have 30 percent or more clay, a moderately strong to strong angular blocky structure with flat edged (polyhedric or nutty) elements and shiny ped faces.

Laterally, a nitic horizon may wedge out or decrease in thickness, or dip below a ferralic or argic horizon. It may replace either or change into a cambic horizon. It also may acquire properties typical for vertic or ferric horizons. Such lateral changes characteristically take place gradually, often hardly perceptible within distances of 5 to 10 meters. There are no irregular or broken horizon transitions, unless an abrupt change in parent material or abrupt erosional features are involved.

Nitisols are formed in intermediate to basic parent materials under a vegetation type ranging from wooded grassland to (montane) rain forest (Driessen & Duda, 1991). Nitic properties come into existence as a consequence of different processes. Firstly, there is very strong weathering which is called ferralitization. This process is comparable to what happens in Ferralsols, but it is still in an early stage. Secondly, the shiny pedes are formed by a micro-swelling and shrinking. Manganese and ferrhydrite which move in between the microcracks form microcoatings on the ped faces. Thirdly
there is the process of biological homogenization by termites, ants, worms and other soil fauna, which leads to the subangular soil structure in the topsoil and diffuse soil boundaries.

- **Properties**

Nitisols are hard when dry, very friable to firm when moist, and sticky and plastic when wet. The porosity is high (50-60%). Aggregate stability is high and rooting is easy.

The effectively available water holding capacity of Nitisols per unit of volume (5-15%) is only fair despite the high porosity. However, because of the great depth of the rootable zone - often more than 2 m - the total moisture storage is quite high.

Permeability is moderately rapid to moderate (about 50 mm per hour) and tillage operations can be carried out easily a day after moisening without damage to the soil structure. Usually no gravel or stone sized concretions are present, but some fine iron-manganese concretions ('shot') may occur.

Nitisols may contain variable amounts of organic matter and be acid or neutral in reaction. They have in common that they are predominantly composed of low activity clay minerals. P-sorption capacity is high but this does not, however, result in acute P-deficiencies.

- **Geography**

Nitisols cover more than 200 million ha globally of which more than half is found in Eastern Africa. Large areas occur in Ethiopia, Kenya, Northern Tanzania and Eastern Zaire. Other main regions with Nitisols are South Brazil and Central America, the Caribbean Islands (Cuba) and Southeast Asia (Java, Philippines).

- **Relationships with some other reference groups**

Frequently Nitisols occur associated with other soils having an argic horizon (Lixisols, Acrisols, Alisols), with Ferralsols, with Vertisols and Cambisols, and with Andosols. They are set apart from the group of soils with an argic horizon by the presence of a nitic horizon which is unique for the Nitisols. Often Nitisols are derived from weathering products of basic rocks. Rapid weathering of these rocks results in deep profiles with a nitic horizon.

In the landscape many lateral relationships may be observed, described below and illustrated in figure 3. The factors controlling these relationships include the topographic/hydrologic position, the age of the landscape elements, and the degree of admixture with airborne materials, especially volcanic ash:
Plate 21.1.
Sugar cane on Nitisols. Australia. (Photo: R. Dudal)

Plate 21.2.
Nitic horizon. Central Cuba. (Photo: J. Deckers)

Plate 21.3.
Nitisols in association with Ferralsols. Brazil. (Photo: A. Ruellan)
a. In undulating landscapes on basic and ultrabasic rocks, Nitisols often occupy the upper and middle slopes, merging into Vertisols or vertic units of other Reference Soil Groups on the lower slopes and in valleys.

b. On volcanic landscapes Andosols are found on the upper slopes while Nitisols occur on the lower slopes.

c. On uplifted and remodelled plateau landscapes of old land surfaces Nitisols occupy the slope positions while Ferralsols occur on the flatter plateau sites.

d. On landscapes formed on limestone Nitisols may occur as pockets and frequently in association with shallower reddish soils (Luvisols, Chromic Cambisols).

Figure 3  Some lateral linkages between Nitisols and other soils.

•  Land use and management

Nitisols are much sought after for smallholders’ farm and plantation crops such as cocoa and coffee, despite the low CEC and frequently low base saturation. The good tilth, easy workability of the soil and other physical attributes have contributed to the presence of sustainable low-input agriculture on these soils.

Micronutrients and potassium are likely to be in sufficient supply from the relatively easily weathering parent materials but the reported high P-sorption capacities
and low “available P” values do not indicate a steady supply of soil phosphorus to the plant. Added P fertilizer, moreover, does not show up well in higher available P values although plant growth responds favourably (Hinga, 1977).
**PHAEOZEMS**

**History, connotation and correlation**

The name Phaeozem comes from Gr. phaios, dusky and Russian zemlja, earth, land, connotative of soils rich in organic matter having a dark colour. International correlations: Brunizem, Brunizem con B textural (Argentina), Rego Dark Gray soils (Canada), Brunizem (France), Tschernozem, Parabraunerde-Tschernozem (Germany), Udolls, Aquolls (USA), Degraded Chernozems, Podzolized Chernozems (former USSR).

**Concept and morphology**

Phaeozems are typical soils of the wetter and warmer steppe (prairie) regions. They occur in more humid environments than the other steppe soils. Consequently biomass production is higher but also weathering and leaching is more pronounced in these soils. Like Chernozems and Kastanozems, Phaeozems are developed on unconsolidated basic materials, mainly löss and löss-like sediments or glacial till. In comparison to Chernozems, calcium carbonate is usually absent in the soil profile, but leaching is not so intense that the soils have become depleted of bases and nutrients. According to the tall grass steppe (prairie) to forest-steppe (prairie) environment, the biomass production is very high as is faunal activity. Earthworms (*Lumbricidae* and *Enchytraeidae*) especially, and burrowing mammals homogenize the soil, the latter mainly in the (cold) temperate climatic belt. Krotovinas show the mixing of surface and subsurface horizons. Consequently, Phaeozems often have a deep dark grey to grey to dark brown topsoil rich in organic matter (molllic horizon).

**Properties**

The topsoils of Phaeozems are usually thinner than those of Chernozems and perhaps somewhat less dark. Phaeozems are porous, well-aerated soils with stable structures, relatively rich in nutrients and make excellent farm land. Many Phaeozems have a clay accumulation in the subsoil which increases their water holding capacity, but Phaeozems still may be short of water in the dry season.

**Geography**

The largest distribution area is found in the Central Lowlands and easternmost parts of the Great Plains of the USA (about 70 million ha), which has a (sub-) humid climate.
The second major Phaeozem region, almost 50 million ha, is found in the moister part of the pampas of Argentina and Uruguay in the subtropical climatic belt. The third large Phaeozem area is situated in the humid parts bordering the semiarid climate of northeastern China around Chang-Chun, Harbin and north to northeast of the latter city. This area covers about 18 million ha. Smaller, mostly discontinuous areas are found in central and southeastern parts of Central Europe, the Danube area of Hungary and adjacent parts of Yugoslavia, covering an area of about 9 million ha.

In total, Phaeozems cover an area of almost 190 million ha worldwide.

- **Relationships with some other reference soils**

Phaeozems occur in steppe to forest-steppe or forest-prairie areas including the drier parts of broad-leaf forests, as far as the former natural vegetation can be reconstructed. Consequently, these soils border the more humid side of the Chernozems of the temperate climatic belt and Kastanozems in the subtropical climatic belt. In the Northern hemisphere, Phaeozems are geographically situated on the wetter side of the Chernozem areas of Eurasia and North America. In the area bordering the Albeluvisols, Phaeozems occur which have uncoated silt and sand grains on structural ped surfaces (“white powder” or “salt and pepper”). In South America, Phaeozems are associated with Planosols, Solonchaks and Kastanozems.

- **Land use and management**

The natural vegetation on Phaeozems is tall grass and/or forest. The favourable physical and chemical properties, especially the stable structure, high porosity and high available water capacity, high levels of organic matter, relative richness in nutrients and medium to high base saturation make these soils excellent farm land. In the warm temperate and subtropical climatic belt with a humid (udic) soil moisture regime, maize with soybeans and vegetables give high yields without irrigation. The relict Phaeozems in today’s arid climate prevailing in the natural short grass prairie of, for example, the High Plains in Texas allow high yields, especially of cotton, when irrigated. However, the amount of irrigation water available is a limiting factor, as most of it is derived from fossil groundwater, the supplies of which have been overexploited. In the cold temperate climatic belt with a shorter growing period wheat and barley as well as vegetables, are the principal crops. In the USA and Argentina, Phaeozems are widely sown to wheat and in the USA, to soybean. Large areas of Phaeozems are used for cattle rearing and fattening on improved pastures. Periodic drought, and wind and water erosion are the main limitations.
Plate 22.1.
Phaeozem with deeply distributed organic matter and dense rooting pattern. Argentina.
(Photo: S. Pazos)

Plate 22.2.
Phaeozems in the humid Pampas of Argentina.
(Photo: S. Pazos)
History, connotation and correlation

Planosols (from L. planus, flat) have a bleached, light-coloured eluvial horizon abruptly overlying a dense subsoil with a significantly higher clay content. They typically occur in seasonally or periodically wet, plateau areas, often above normal flood levels of nearby rivers or estuaries. Planosols also occur on gentle or very gentle slopes, but there they have a much smaller extent. These soils were included in the somewhat wider concept of the "clayey podzols" as described by Glinka (1914) and in the Pseudogley soils of several European authors. However, neither of these soil groupings required an abrupt textural change from the bleached layer to the underlying dense horizon. The U.S. soil classification of 1938 was the first to use the term Planosols; the present Soil Taxonomy (Soil Survey Staff, 1996) and its revisions include most of the original Planosols in the Albaqualfs, Albaquults and Argialbolls. The original and revised Legends of the Soil Map of the World (FAO, 1974; FAO-Unesco-ISRIC, 1990) recognize the Planosols as a main soil group in its own right.

Concept and morphology

The central concept of Planosols is of soils with a silty or loamy grey surface or shallow subsurface horizon showing signs of periodic wetness and overlying a dense subsoil horizon with an abruptly higher clay content on which water stagnates.

The abrupt textural change from the topsoil to the subsoil is caused by the process of ferrolysis, a progressive breakdown of clay minerals under alternating wet and dry conditions. The eluvial horizon in Planosols often shows a peculiar clay distribution. It may either contain less clay than the surface layer, or have its minimum clay content in the lowest few centimetres just above the abrupt contact with the underlying B horizon (figure 4).

Properties

The structure of the eluvial horizon is weakly developed and unstable. The light topsoil is hard when dry but not cemented. The clayey subsoil has a coarse angular blocky, prismatic or even a massive structure. Slow permeability in the subsoil is the cause of waterlogging in the upper layers of the soil. Chemically, Planosols are degraded: the cation exchange capacities of the clay fraction in the surface layers and eluvial horizons of Planosols are significantly lower than in the underlying horizons.
- **Geography**

The main extent of Planosols occur in Latin America, from Argentina to southern Brazil, in southern and eastern Africa, and in Australia. Smaller areas are found in southeast Asia, from Bangladesh to Vietnam, in the eastern United States, and in the Sahelian region of Africa. They cover about 130 million ha worldwide, of which about one third occurs in Australia and well over 40 percent is found in Latin America. Most Planosols occur in climates with a marked alternation between wet and dry seasons.

- **Relationships with some other reference soils**

Planosols may be found on generally low, nearly level river or marine terraces, on other level or nearly level land or in shallow depressions. They also occur in a narrow band along the low and flatter margin of hillslopes adjoining riverplains, in extensive but frequently discontinuous areas on very gentle, long slopes below well drained uplands, and above plains or basin areas which may be occupied by Vertisols. The adjacent better drained upland soils may be of different Reference Soil Groups, but are often Acrisols or Luvisols.

In all these positions Planosols are most extensive in climates with a strong seasonal variation in rainfall. Some former Vertisols in presently humid, seasonally wet climates have grey or light grey, silty upper soil horizons of variable thickness abruptly overlying heavy clay, with silty material “etched in” along cracks into the underlying
Plate 23.1.
Light coloured sandy layer abruptly overlaying a dark clayey subsoil in a Planosol. Bulgaria. (Photo: R. Dudal)

Plate 23.2.
Enclosed grassland depression on Planosols. Zambia. (Photo: R. Dudal)

Plate 23.3.
Water stagnation on Planosols. Pampa, Argentina. (Photo: R. Dudal)

Plate 23.4.
Dust of topsoil thrown up behind a lorry on Planosols. Ghana. (Photo: O. Spaargaren)
clayey material. Planosols may thus have been formed by clay removal or clay destruction, or both, in former Vertisols when seasonal wetness of the climate increased. Other Planosols, with a similar physical appearance, may have formed through degradation (clay removal or destruction) of the upper soil horizons and gradual replacement of exchangeable Na by Ca in the B horizon of formerly strongly sodic soils. A very thin, discontinuous micro-podzol may be found in the upper 5-10 cm of the soil under natural vegetation in a humid climate.

- Land use and management

Planosols support a natural vegetation such as herbaceous plants or shallow rooting trees and shrubs, which is adapted to seasonal waterlogging conditions. The seasonal or intermittent water saturation and reduction of the upper soil horizons limits the range of dryland crops that can be successfully grown in the rainy season, and lowers the productivity of those that can be grown. Intermittent dry spells may affect the moisture availability for wetland rice. The dense B horizon inhibits root growth and the generally low water holding capacity of the soil profile above this layer restricts productivity of crops in the dry season, or prevents their cultivation where the dry season is pronounced.

The commonly low organic matter content of Planosols provides little mineralized N for the crops; other plant nutrients, including K and Ca, are generally low as well. Sulphur deficiency has been observed in wetland rice on some Planosols. Plant nutrient management is more difficult than on other soils because of the low cation exchange capacity and the low organic matter content. For these reasons many Planosols remain unused or are used for extensive grazing. Strongly developed Planosols may carry a very sparse savanna vegetation with scattered small trees, leaving much of the soil surface bare even where adjacent more fertile and better drained soils are covered by high evergreen seasonal forest. Trafficability of many Planosols is poor in the rainy season because of the low bearing capacity of the flooded, or water saturated, upper soil horizons.

Where population pressure is high and farmers are familiar with wetland rice cultivation, this crop is grown mostly on rainfed, bunded fields. This may be in the tropics or outside the tropics where temperatures are adequate during the summer. Fodder crops may be grown locally as well, but give poor yields.
History, connotation and correlation

Plinthosols (from Gr. plinthos, brick) are soils either containing at shallow depth a layer indurated by iron (petroplinthite), or at some depth mottled material that irreversibly hardens after repeated drying and wetting (plinthite).

These soils are known as Plinthosols (FAO-Unesco-ISRIC, 1990), “Groundwater Laterite soils”, “low-level Laterite”, “Lateritas hidromórficas” (Brazil), “Sols gris latéritiques” (France) or “Plinthaquoix” (Soil Survey Staff, 1996).

Concept and morphology

The concept of Plinthosols is 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 mottled layer has been formed which irreversibly hardens when exposed to the air. Included in the concept are those soils that have such a hardened layer at shallow depth. Two types of iron components are important in Plinthosols: (1) plinthite, an iron-rich, humus-poor mixture of kaolinitic clay with quartz and other constituents. It commonly occurs as red mottles in platy, polygonal or reticulate patterns, and changes irreversibly to a hardpan or to irregular aggregates on exposure to repeated wetting and drying with free access of oxygen. In a perennially moist soil, plinthite is usually firm but it can be cut with a spade; and (2) petroplinthite, a continuous layer of indurated material in which iron oxides are an important cement and in which organic matter is absent, or present only in traces; iron oxide content is generally more than 30 percent. The continuous layer may be either massive, or in a reticulate or inter-connected platy or columnar pattern that encloses non-indurated material.

Properties

The most important characteristic of Plinthosols is the presence of plinthite or petroplinthite. The plinthite layer is dense and obstructs the flow of water as well as deep penetration of roots. The capacity to harden is a potential danger of all Plinthosols.

Chemically, all Plinthosols have a high content of iron and/or aluminium, a low amount in organic matter, and generally show a low base saturation.
Plate 24. PLINTHOSOLS

Plate 24.1. Plinthosol. Ghana. (Photo: ISRIC)

Plate 24.2. Plinthosol landscape. Lake Kyoga, Uganda. (Photo: J. Deckers)

Plate 24.4. Making of building blocks from plinthite. India. (Photo: R. Dudal)

Plate 24.5. Petroplinthite under sand. Senegal. (Photo: J. Deckers)
**Geography**

The global extent of soils with plinthite is estimated at about 60 million ha. These soils occur mainly in the tropics but examples can also be found in old landscapes of subtropical and temperate regions, such as the raña surface of central Spain. Those with a shallow petroplinthic horizon were known as “(high level) Laterites”, “Ironstone soils”, or “Sols ferrugineux tropicaux à cuirasse”. They have widespread occurrence in western Africa, especially in the Sudano-Sahelian region where they cap structural tablelands; they are also common in central-southern India, the upper Mekong catchment, northern Australia and the eastern part of the Amazon region. They are found in extensively flat terrains with poor external drainage, such as the Late Pleistocene or Early Holocene sedimentary plains of eastern and central Amazonia and the central Congo basin. The soils may also occur on straight gentle slopes with an impermeable substratum, and at the feet of concave slopes in rolling or tableland landscapes (springline situations). In sedimentary areas, especially with pre-weathered and rather sandy parent materials, the plinthic layer is rather thin (approximately 50 cm) and often overlain by an eluvial horizon. Where iron-rich (or iron-enriched) and fine-grained parent materials are involved, such an eluviation is often minimal and the plinthic layer is several meters thick.

**Relationships with some other reference soils**

Plinthosols dominantly occur in intertropical regions and, as such, have linkages with Ferralsols, Alisols, Acrisols and Lixisols. Apart from stony units, they exhibit both gleic and stagnic properties, and are therefore linked to Gleysols. Well-drained soils with loose ironstone concretions are frequent in the tropics and subtropics, in many landscape situations. This secondary material is the result of former plinthite formation, subsequent hardening, re-weathering and transport. The soils concerned are geomorphologically related to Plinthosols, but may belong to plinthic soil units of other Reference Soil Groups. Plinthosols may occur in distinctly different positions in the landscape. Petric Plinthosols occupy dominantly the higher positions, often as a result of landscape inversion due to lowering of the erosion base. They now form tablelands (see figure 5) and are usually freely drained. The other Plinthosols, in contrast, are found mainly in depressions or other areas with impeded drainage conditions. Locally, Petric and other Plinthosols may have direct lateral linkages, for instance, where a stream cuts into soils with a plinthic layer. Some lateral linkages are shown in figure 6.

Petric Plinthosols often occur in association with Leptosols and shallow units of other soils, as a result of erosion. Other Plinthosols are found in association with Gleysols in areas conditioned by hydromorphy, and with Ferralsols, Alisols, Acrisols and Lixisols, which occupy the better drained positions in the landscape.
Figure 5  Inversion of relief in landscapes with plinthite and petroplinthe.

Figure 6  Distribution of Plinthosol units in facets of a present-day landscape.
Land use and management

The imperfectly and poorly drained soils with a plinthic horizon have a less luxuriant natural vegetation than geographically associated well-drained soils, for instance tree savanna or grassy savanna instead of closed-canopy high forest. The land use on such soils is often restricted to extensive grazing because arable crops would suffer from poor rooting conditions; artificial drainage of the soils would entail a serious hazard of irreversible hardening of the plinthic material. This hardening liability is, however, an asset for non-agricultural uses, such as mining (for iron ore, manganese, bauxite), road construction, terracing or house building material.

Well-drained soils with a shallow petroplinthic horizon have poorer natural vegetation than geographically related soils without such a hardpan. Arable cropping and tree planting is problematic because of the stoniness of the soils, but the latter feature is regarded as an asset by construction engineers.
• **PODZOLS**

• *History, connotation and correlation*

  The name Podzol means ‘soils with a subsurface horizon that has the appearance of ash due to strong bleaching by aggressive organic acids: from Russian pod, under, and zola, ash.

  Podzols are probably the best known of all soils among laymen because of the prominent appearance of the dark humus or reddish iron horizons which underlay the ash-grey eluviol horizon. The name ‘Podzol’ is therefore readily recognizable in many soil classification systems: Podzol in the European and Russian classification systems, Podzol (FAO). However, the USDA Soil Taxonomy names these soils Spodosols.

• *Concept and morphology*

  Podzols are soils characterized by the presence of a spodic horizon. In this horizon amorphous compounds have accumulated consisting of organic matter and aluminum, with or without iron or other cations. The process of translocation (‘cheluviation’) and accumulation (known as ‘chilluviation’), is usually shown by the occurrence of an albic horizon underlain by a spodic horizon. The illuviation of organic compounds can often be demonstrated by the presence of thick cracked organic coatings on the sand grains within the spodic horizon.

  The soil forming conditions promoting the eluviation processes are provided by cool and wet climates - the boreal climatic zone, high mountain environments -, acting upon quartzitic parent materials, and by a heath and/or coniferous vegetal cover. Thus, although cheluviation affects large areas of soils in the boreal zone, it is not limited to this zone. It is well known that the process is active in all the humid regions of the world, especially in the temperate zone, but also in the equatorial zone, where many examples of ‘Giant Podzols’ have been described.

  In coarse sandy materials, in well drained conditions, the morphology of Podzols is well expressed and strong contrasts can be observed between eluvial and illuvial horizons. For these soils the morphology (presence of an albic horizon) and micromorphology (thick cracked organic coatings in the spodic horizon) or the cmentation of the spodic horizon are adequate criteria to accurately identify cheluviation and to distinguish between more and less strongly expressed Podzols.

  In loamy or clayey materials, the podzol morphology is less pronounced (no albic horizon). The presence of a water table (or excess of water) leads to a greater mobility of iron and induces changes in the morphological and chemical characteristics of Podzols. The spodic horizon becomes diffuse and fades out towards the groundwater table. Surface waters often develop a black colour with the presence of mobile fulvic acids.
Plate 25.1. Densic Podzol with bleached white sand overlying cemented black humus and reddish iron accumulation horizons ("Ortstein"). Versigny, France. (Photo: R. Langohr)

Plate 25.2. Humus-loaden river water in a Podzol area in the tropics. Indonesia. (Photo: R. Duda)

Plate 25.3. Coversand landscape with Podzols and heath vegetation, grazed by sheep. Lüneburgerheide, Germany. (Photo: R. Langohr)

Plate 25.4. Detail of typical heath vegetation (*Molinia coerulea, Calluna vulgaris*) on Podzols. Lüneburgerheide, Germany. (Photo: R. Langohr)
The occurrence of a placic horizon (or thin iron pan) within or below the spodic horizon may be explained by temporary reduction phenomena in some part of the soil profile. This horizon comprises a black to dark reddish layer cemented by iron and manganese, or by an iron-organic matter complex.

**Properties**

Most Podzols have a coarse texture ranging from sand to sandy loam less than 10 percent clay. The capacity for water retention is low, less than 50 mm per meter soil depth and, although Podzols are characteristic of humid climates, they often show moisture stress. Movement of water is usually free and rapid except, where the spodic horizon is strongly cemented. If this is the case root penetration will also be restricted.

Podzols are very acid soils, with a pH ranging from 3.5 to 4.5 in the surface horizons. The pH may increase to 5.5 in the lower horizons. The cation exchange capacity is mostly caused by the presence of organic compounds and base saturation is always very low. Organic matter has high C/N ratios, especially in the surface horizons (C/N=25 or more) and in the spodic horizon (C/N=20 or more), indicative of low biological activity and slow degradation of the organic materials.

**Geography**

Podzols cover about 485 million ha worldwide, mainly in temperate and boreal regions of the northern hemisphere. They are mainly concentrated in Scandinavia, the northwest of Russia and in Canada south of Baffin Bay. Tropical Podzols occur extensively along the Rio Negro and in the Guyanas in South America, in Northern Australia and in Indonesia (coastal zones of Kalimantan, eastern Sumatra and Irian Jaya). Podzols are rather uncommon in Africa, but are reported to occur in western Zambia.

**Relationships with some other reference soils**

The limits of the Podzols are determined by the minimum expression of the spodic horizon and the minimal contrast between the eluvial and illuvial horizons. Soils showing evidence of illuvial organo-Al/Fe complexes but lacking sufficient amounts of it to qualify for Podzols, form intergrades with Cambisols, Arenosols or Gleysols.

Podzols may be associated with Histosols, Gleysols, Cryosols, Cambisols, Andosols, Ferralsols, Planosols, Albeluvisols and Anthrosols.

Podzol-Histosol-Gleysol sequences are typical of the soil mantle on sandy plains with poor quartzitic materials affected by a shallow water table.

Cryosol-Podzol linkages occur at high latitudes. Sloping lands on acid crystalline rocks (granite) in the mountain areas frequently have a Cambisol-Podzol sequence of soils. Podzols may be associated with Andosols in regions with a volcanic ash cover.
A cheluviation process may develop as a secondary process in soils affected by a strong superficial clay impoverishment such as Albeluvisols, Planosols or some degraded Ferralsols. Anthrosol-Podzol transitions occur in areas where earthy manures have been applied as fertilizer.

**Vegetation, uses and management**

Low nutrient status, sandy texture and low pH value make Podzols infertile soils. Aluminum toxicity, restriction of nitrification and phosphorus deficiency are the major problems encountered when growing crops on Podzols, but good corn yields may be obtained if fertilizers, liming and irrigation are practised. However, Podzols are used more often for forestry, extensive (sheep) grazing or are left fallow.
Plate 26. Regosols

Plate 26.1. Regosol on acid rock. Corsica, France. (Photo: R. Langohr)

Plate 26.2. Regosol landscape in the badlands of Death Valley. USA. (Photo: J. Deckers)
**REGOSOLS**

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**History, connotation and correlation**

The name Regosols (from Gr. *rhēgos*, blanket) is connotative of a mantle of loose material overlying the hard core of earth, or soils with weak or no development. Genetically-based classification schemes of soils have always had a class of very weakly developed mineral soils, or those that are so recent that they do not reflect an imprint of pedogenesis. These unconsolidated materials have been considered to be regolith, pedolith or non-soils, consequently the term Regosols has been widely used.

Originally Regosols could accommodate soil of any texture even the sandy ones. FAO (1974) focused the concept of Regosols to well drained, medium textured, deep mineral soils derived from unconsolidated materials and separated them from shallow soils (Lithosols, Leptosols, etc.) and from those with sandy or coarser textures (Arenosols). Regosols correlate with skeletal soils (Australia), Soils peu évolués régolsoliques d’érosion, Sols minéraux bruts d’apport éolien ou volcanique (France), Rohböden (Germany), or Entisols (USA).

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**Concept and morphology**

Conceptually, Regosols are the initial state for pedogenesis representing recently deposited, or recently exposed, earthy materials at the earth surface. Thus, geomorphic processes of erosion and deposition give rise to the first step of soil development, namely the accumulation or exposure of a parent material. Soil formation remains limited and the subsurface reflects generally the weathered rocks on which the Regosols developed.

Thus, the central concept of a Regosol is a deep, well drained, medium textured, non-differentiated mineral soil that has a minimal expression of diagnostic horizons, properties or materials other than an ochric horizon.

Regosols are formed in localities where soil forming processes had very little effect because a limited time for soil formation had elapsed, or as a consequence of soil erosion. On the other hand they may be the result of conditions that retard soil formation such as dry and hot desert climate or permafrost. A special case of Regosols are the colluvial soils in undulating to rolling landscapes covered with löss. After deforestation severe historical soil erosion caused truncation of the soils in the upper slopes and deep (50-100cm) sedimentation in the low-lying landscape positions.

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**Properties**

Most properties of Regosols are associated directly with the parent materials themselves and the climate, not with genetically developed soil features. Chemically,
Regosols may have a high or a low base status. In cold climates a thin poorly decomposed humus layer occurs. Organic matter content is low in hot and dry climates.

The near absence of soil formation explains the low coherence of the soil material, which make them vulnerable to soil erosion, especially if located on sloping terrain. On agricultural land of the löss belt in the northern hemisphere Regosols continuously accumulated on footslopes at a rate of several mm per annum and possess a clear stratification pattern.

- **Geography**

There are examples of initial stages of soil development in all landscapes throughout the world. The areal extent is often limited, therefore many Regosols are inclusions in other map units at a scale of 1:1 million. Regosols cover about 4% of the land surface. The largest extent of these weakly developed soils occurs in the polar and boreal zones (278 million ha). Formerly classified as Regosols, they are now separated as Cryosols. Regosols occur on about 170 million ha in the arid zone, 52 million ha in the dry tropics, and 36 million ha in mountain areas.

- **Relationships with some other reference soils**

Some Regosols, associated or interspersed with different soil units in the landscape, are intergrades with properties merging or tending towards Andosols, Podzols, Gypsisols, Calcisols, Umbrisols, Cambisols, Ferralsols, Cryosols or Arenosols.

Extragrades include features which have been recognized as phases and thus are not specific to a particular group of soils. Examples are high and low base saturation, and calcic or gypsic soil material.

Thus, Regosols are found in all landscapes throughout the world and in relation with many other soils. Regosols are mostly associated with degrading or eroding areas, while other soils occur on aggrading, depositional or stable areas. As time passes and soil formation begins, Regosols may develop into soils of other units, depending on the influence of the soil forming factor(s).

- **Land use and management**

In steppe regions Regosols can be used for agricultural production if irrigation is available. Regosols in montane zones may be used for extensive grassland, forestry, or left idle.

The Regosols of colluvial origin in the löss belt of northern Europe and north America are among the best soils for agriculture and are mostly cultivated. Most of them are under intensive agriculture and planted to wheat, barley and sugar beet or are used for apple or pear orchards.
When freshly deposited, the colluvial material can form a surface seal which may hamper germination of seedlings. Regosols are vulnerable to gully erosion and need special protection through grassed water ways.
**SOLONCHAKS**

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**History, connotation and correlation**

The name Solonchak is derived from Russian *sol*, salt, and *chak*, salty area. Solonchaks have always been distinguished at highest categoric level from the early classification systems onwards. Dokuchaev placed the salt-affected soils under the transitional soils and his successor Glinka put them under the azonal soils. International correlations are: Solonchaks (Russia and Australia), Salorthids (USA), Saline subgroups (Canada), Sols salins (France).

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**Concept and morphology**

Solonchaks are soils with high concentrations of salts at some time of the year in the topsoil. This may occur in areas where evapotranspiration greatly exceeds precipitation for at least part of the year and where salts are present in moderate to high amounts in the parent material of the soil (salinization). Two chemical criteria are used to define the salt-affected soils. These are (1) the solubility product of the accumulated salts or of salts that may form, and (2) the ion concentration in the soil solution. To be considered salt-affected, soils must contain an important quantity of salts that are more soluble than gypsum. The total salt concentration of the soil extract, expressed by the electrical conductivity (EC) serves to delineate the group: the soils must have within a shallow depth and at a given time of the year a salt concentration that is in excess of a minimum value of the electrical conductivity.

Salts responsible for salinity have various origins: marine, petrographic, volcanic, hydrothermal, and aeolian. Often salinity is man-induced through agricultural and other practices (irrigation, groundwater manipulation, fertilizers, the use of nutrient solutions in glasshouses and in soil-less cultures, urban wastes, etc.).

The presence of these salts, the amount of osmotic pressure of the soil solution, or the toxicity of a given ion leads to special landscapes, either occupied by salt-tolerant (halophyte) vegetation, or characterized by the complete absence of vegetation (salt lakes, salt lagoons, salt pans, etc.), depending on the degree of salinity.

The cations involved are sodium, calcium, magnesium and potassium, of which sodium is the most important. High sodium concentration in the solution, like that of magnesium in non-calcareous environments, leads inevitably to adsorption of sodium on the exchange complex (Bolt, 1979). Many authors have distinguished different soil types, based on the ratio between the various cations present, in particular the bivalent versus the monovalent cations (Duchaufour, 1988; Loyer et al., 1989):

- **Calcium dominated** saline soils, characterized by a dominance of calcium and magnesium over sodium and potassium in the soil solution and on the exchange complex. The ratio of Ca+Mg/Na+K is between 1 and 4 and Ca/Mg is 1 or more.
The structure of these soils remains stable even after desalinization. A slight increase in pH may take place.

b. **Sodium dominated** saline soils, in which sodium is preferentially fixed on the exchange complex. Ca+Mg/Na+K in the soil solution is less than 1. Strong alkalization occurs after desalinization. Subsequently, the structure tends to degrade.

c. **Magnesium dominated** saline soils, which, in near-absence of calcium, are structurally similar to sodium dominated soils. Ca+Mg/Na+K is more than 1, Ca/Mg equals 1 or less and Na/Mg is less than 1. Upon desalinization hydrolysis of the magnesium complex results in a strong alkalization followed by structural degradation.

It is clear that sodium and magnesium may have an adverse effect on the soil structure, depending on the presence or absence of calcium.

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**Properties**

The only common characteristic of Solonchaks is the high salt content. They show a considerable diversity in their hydrological, physical and chemical properties.

Under extreme climatic conditions (low rainfall, high evaporation) salts present in the soil solution can precipitate at the surface in various forms (white efflorescence, salt crusts, non-aggregated brown powder, black salt deposits, evaporative salt crystals, etc.). This process is discontinuous in distribution in both space and time, occurring in low-lying patches which may be washed free of salts if it rains, after which they reform. The disintegration of aggregates which result from salt concentrations at the surface and which manifests itself seasonally as a powdery surface horizon, cannot be considered as a structural degradation *sensu stricto* like sodium hydrolysis. It represents a crystallization of salts which, in turn, provokes a secondary effect of swelling followed by structural disaggregation. Degradation of the soil structure does not take place as long as significant quantities of salts are present in the soil solution, even if a certain amount of sodium from this solution is absorbed by the exchange complex (alkalinization). The aggregates remain stable and flocculated and the hydrodynamic properties of the soil are unchanged. After desalinization cations from the soil solution may be absorbed on the exchange complex and only then degradation of the soil structure will be enhanced. Unlike Solonetz, a typical structural expression does not exist in Solonchaks.

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**Geography**

Solonchaks occur in many parts of the world. They cover an area estimated between 260 million (Dudal, 1990) and 340 million hectares (Szabolcs, 1989), depending on the degree of salinity taken into account. Widespread in the arid and semi-arid regions they occur in the former USSR, Australia, South and North America, China, the Mid-
dle East, North and South Africa, Namibia and Chad. In most places they are often associated with Solonetz.

- **Relationships with some other reference soils**

The Solonchaks are separated from most other soils by having a high salt content at or near to the surface. However, some soils may also have a salic horizon, viz. Histosols, Vertisols and Fluvisols. The respective salic soil units and subunits are intergrades to Solonchaks as these soils have additional properties that are as important or more important than the saline character.

In the landscape, natural Solonchaks occupy the lower parts where runoff, seepage and shallow groundwater cause the accumulation of salts. In central parts of closed basins in arid regions salts accumulate at the surface, forming a salt pan, while in the surrounding areas most salts are contained in the soil.

- **Land use and management**

The high salt accumulation limits plant growth to salt tolerant plants, because either it is toxic, limits growth because nutrients are proportionally less available, or it creates physiological drought as a consequence of high osmotic pressure of the soil solution.

![Figure 7](image)

**Figure 7** Possible evolutions of salt-affected soils after desalinization.
Plate 27.1.
Puffy surface of a Solonchak.
Death Valley, USA.
(Photo: J. Deckers)

Plate 27.2.
Salt accumulation in Solonchak.
Pakistan. (Photo: R. Duda)

Plate 27.3.
Detail of surface features of a Solonchak. Death Valley, USA.
(Photo: J. Deckers)
The agricultural use of these soils is delicately balanced. Rainfed agriculture is only possible in the more humid regions, where rice and millet can be grown as well as fodder crops and salt-tolerant trees. Reclamation, though, may be necessary before use.

In the more arid regions irrigation has to be applied. This necessitates particular management practices, and above all, appropriate leaching and drainage to eliminate the excess in salts and to control the groundwater level. The problems related to the avoidance of salinization, the chemical degradation and the regeneration of salt-affected soils (figure 7) are presently of prime importance, especially in the light of the expansion of irrigated land in developing countries.
History, connotation and correlation

Solonetz (from Russian sol, salt and etz, strongly expressed) were for a long time combined with Solonchaks into one group of soils, the salt-affected soils. However, these two soil groups differ not only in their chemical character, their morphological, physical and physico-chemical properties, but also in their geographical distribution. Reclamation methods of these soils are different as well. Solonetz are therefore separated at high categoric level in many rational soil classification systems: Solonetz (Canada), Sols sodiques à horizon B et Solonetz solodisés (France), Natrustalfs, Natrustolls, Nattrixeralfs, Natrargids, Nadurargids (USA), Solonetz (former USSR, FAO).

Concept and morphology

Dry conditions and inherent salinity of soils, parent materials and groundwater are conducive to the formation of Solonetz. They are widely spread in areas characterized by a semi-arid, dry steppe climate with very hot and dry summers (annual precipitation 400 - 500 mm), in flat topographic positions with impeded vertical and lateral drainage, and on inherently saline parent materials (e.g. marine clays or saline alluvial deposits). They carry a specific natural vegetation, mainly of halophytic plants.

In such environments salt accumulation takes place in the middle or lower parts of the soil, with upward movement during the summer (dry) season and downward movement during the winter (rainy) season. When soils are affected by neutral sodium salts, mainly sodium chlorides and sodium sulphates, Solonchaks are formed. Solonetz are developed under the influence of such salts as NaHCO₃, Na₂CO₃, Na₂SiO₃ and MgCO₃ (alkalinization).

The natric horizon associated with humus-rich surface horizons and saline subsoils is characteristic for Solonetz. A bleached layer (an ‘albic horizon’) may be present between the surface and the natric horizon. The natric horizon is a dense subsurface horizon which has a greater clay content than the overlying horizon(s) similar to the argic horizon but with a high amount of exchangeable sodium and/or magnesium. The colour ranges from brown to black and its structure is coarse columnar, prismatic or even massive. Both characteristics depend on the composition of the exchangeable cations and the soluble salt content in the underlying layers. Often it shows thick and dark coloured clay cutans, especially in the upper part of the horizon. Soil reaction is strongly alkaline with a pH (H₂O) of more than 8.5.

The surface horizon, usually rich in organic matter, naturally overlies the natric horizon. This horizon of humus accumulation varies in thickness from a few centimetres to more than 25 cm. An albic horizon may be present between the A horizon and the natric horizon (‘solodized soils’).
Plate 28.1.
Columnar structures in the sodium rich subsoil of a Solonetz. South Africa.
(Photo: ISRIC)

Plate 28.2.
Solonetz in loess over coastal plain alluvium on nearly level Pleistocene terraces. Louisiana, USA.
(Photo: R. Langohr)

Plate 28.3.
Horizontal section showing columnar structures in a Solonetz. Canada.
(Photo: ISRIC)

Plate 28.4.
Intermittent sodium-tolerant vegetation on Solonetz. Pangani Valley, Tanzania.
(Photo: J. Deckers)
Properties

Solonetz generally show differentiation within the profile with respect to colour, structure, bulk density and particle size distribution. Low-lying Solonetz may have thick and well structured surface horizons. On terraces surrounding saline lakes, thin surface layers frequently dominate with well developed albic horizons below. Although the natric horizons may differ in structure, colour and bulk density, they have in common a very slow permeability in wet state (infiltration rate is practically zero).

The dominant physical features of Solonetz are the poor aggregate stability, the impermeability under wet conditions and the hardnes of the natric horizon when dry. The main chemical characteristics are the high amounts of sodium or sodium plus magnesium at the adsorption complex and the high pH (H₂O) which is frequently more than 9.0.

Geography

More than ten percent of the global land area is covered by different types of salt-affected soils. About 40 percent of it, 135 million ha, is affected by high sodium levels. Major occurrences are recorded from Ukraine, Russia, Kazakhstan, Hungary, Bulgaria, Romania, China, USA, Canada, South Africa and Australia.

Relationships with some other reference soils

Lateral sequences in Solonetz landscapes are governed by microrelief, water logging at the surface, salinity in the profile and in the groundwater. Solonetz may be associated with:

a. Histosols, which may be saline, occurring on terraces surrounding lakes and on old stream beds within the löss-covered steppe landscape with impeded drainage and some salt accumulation;

b. Chernozems, mainly on löss-like loams in a landscape with poor surface drainage and some microrelief;

c. deep dark coloured Chernozem- and Kastanozem-like soils that are developed in depressions of löss plains (e.g. the flat landscapes of the Volga delta in Russia or the central part of the Canadian shield);

d. Solonchaks and Kastanozems in arid and semi-arid regions in large depressions ('liman', etc.) and in the peripheral parts of depressions;

e. Vertisols in premontane plains on clays, that are affected by saline groundwater.

Land use and management

Vegetation on Solonetz is very specific and indicative for these soils within a complex soil cover. Solonetz with thick humus-rich surface layers are characterized by a grass
and herb vegetation and are used as pastures. Predominant among the grasses are Festuca sulcata, Pyrethrum acillefolium and Artemisia maritima incana, in association with Parmelia vagans lichen and Nostoc commune algae.

When the thickness of the humus horizon decreases to 5 cm and soluble salts appear, the vegetation becomes very sparse and the composition of the grass species changes into dominantly Artemisia maritima salina, Statice gmelini, Camphorosma monspeliacum and Kochia prostata. In the case of a high groundwater table some halophytes such as Salicornia herbacea and Saudea corniculata appear.

Solonetz are problem scils when used for agriculture. Some salt-resistant crops as mustard and sorghum can be cultivated on Solonetz with humus-rich surface horizons without amelioration. Solonetz reclamation depends much on the thickness of the humus-rich surface layers and the presence of carbonates close to the surface. Deep ploughing and mixing the carbonate or gypsum containing horizon with the A horizon is used to improve Solonetz. Ameliorants such as gypsum are found to be the most effective on Solonetz under irrigation. After reclamation crops like wheat may be grown. However, in many parts of the world Solonetz are used for extensive grazing or left idle.
History, connotation and correlation

Umbrisols (from L. umbra, shade) constitute a new Reference Soil Group within the WRB system. Although not previously recognized at such a high level, soils conforming to Umbrisols have been separated at the lower categoric levels within both the 1988 Revised Legend (FAO-Unesco-ISRIC, 1988) (Humic Cambisols and Umbric Regosols) and in the USDA Soil Taxonomy (Soil Survey Staff, 1996) (Umbrepts and Humitropepts). In other systems, they have been differentiated as Brown Podzolic Soils (Avery, 1980), Humic Ochric Brown Soils (Duchaufour, 1988), Cambissolo and Regossolo with prominent or humic A horizon, Sombric Brunisols and Humic Regosols (CSSC, 1987), Humose Orthic Brown Soils (Hewitt, 1992), and Brunisols désaturés humiques and humifières (AFES, 1995).

The objective in separating a Reference Soil Group of Umbrisols is to group together at the highest level, all deep, free draining, immature soils in which desaturated organic matter has accumulated at the surface to such an extent that it significantly affects the behaviour and utilization of the soil.

Concept and morphology

The central concept of Umbrisols is that of deep drained medium textured soils in which the only significant feature is the presence of a well developed, dark coloured, organic-rich, acid surface horizon. It is meant to group such soils at the first categoric level in the system because certain vegetation and/or climatic zones favour the rapid development of so-called umbric horizons. Umbric horizons can thus be present both in young, relatively underdeveloped soils lacking other diagnostic horizons, and in more developed soils.

In either case, the presence of significant amounts of desaturated organic material at the soil surface is of overriding importance because, unless affected by man's activities, it determines the initial physico-chemical nature of the downward percolating soil solution and thus the subsequent development of the soil. The desaturated superficial organic-rich material which characterizes Umbrisols can comprise a variety of humus forms that have been variously described as acid or oligotrophic mull, moder, raw humus and mor. Under natural or semi-natural conditions, such material is thought to have developed because of low biological activity and turnover of organic matter caused by acid conditions, low temperatures, surface wetness, or a combination of these. However, Umbrisols are not sufficiently weathered, cold or wet to have developed diagnostic histic horizons or stagnic or gleyic properties. Spodic horizons may occur, but only at greater depth (deeper than 100 cm below the surface). The main characteristic used to recognize and define Umbrisols is the presence of an umbric ho-
horizon. The Umbric horizon is characterized by the presence, at or near the soil surface, of a minimum specified thickness of materials with dark colours, significant organic matter content and low base saturation, and an absence within the same specified thickness, of any characteristics that indicate 'hard setting' surface horizons or comprehensive and deep human modification, both of which would significantly alter the soil's behaviour as determined by its inherent umbric characteristics.

The set of characteristics used to define the umbric horizon also ensures that it can be recognized in the field using simple measurements of colour, depth and pH, complemented if necessary by laboratory measurements of organic carbon content and base saturation.

**Properties**

The diagnostic characteristics used to recognize the presence of an umbric horizon are dark colour, well-developed soil structure and absence of hard setting, a low chemical fertility level (low base saturation), a high organic carbon content, thickness and absence of human induced artifacts, spade marks or artificial accumulation of material.

**Geography**

Umbrisols are usually developed in cool, humid, often mountainous regions with little or no soil moisture deficit. They occupy about 100 million ha throughout the world. In south America Umbrisols are found in the Andean ranges of Colombia, Ecuador and, to a lesser extent, Venezuela, Bolivia and Peru. They also occur at lower altitudes in the Serra do Mar around Curitiba in Brazil. In north America Umbrisols are confined mainly to the north-western Pacific seaboard in Washington and Oregon, USA. Similarly, in Europe they are mainly confined to the north-western Atlantic seaboard in Iceland, the British Isles and north-western Portugal and Spain. In Asia they are found in association with Leptosols and Cambisols in the mountain ranges east and west of Lake Baikal, and the Himalayan fringes of India, Nepal, China and Burma, but also occur at lower altitudes in Manipur and the Chin Hills. In Australasia Umbrisols are confined to the upper slopes of mountain ranges in Sumatra and Irian Jaya and the Snowy mountains of south-east Australia.

**Relationships with some other reference soils**

Most of the limits between Umbrisols and other Reference Soil Groups are defined simply by the absence of characteristics of any diagnostic horizon or property other than an umbric horizon, with or without an albic or a cambic horizon. This means that, theoretically, Umbrisols can be linked to almost any other soil group. In practice, however, the most common linkages occur under cool-temperate, moist, free-draining con-
ditions and depend on the interaction between the age of the landscape and local conditions (figure 8).

In the coolest and/or wettest areas, the youngest land surfaces will have Regosols and Leptosols, sloping surfaces of intermediate age will have Umbrisols and the oldest land surfaces, or those of intermediate age in ‘receiving’ sites will have Histosols. Another type of linkage occurs where a fluctuating groundwater table affects soils in low lying areas. Here Umbrisols on lower slopes merge into Gleysols and Histosols in depressions, whereas upslope more usual linkages occur with Cambisols, Regosols and Leptosols occur (figure 9).

The most problematic set of linkages results from human activities (figure 10). Where Umbrisols have been cleared and cultivated, lime is usually applied, the base saturation increases and the umbric horizon comes to resemble a mollic horizon. Where this practice has continued for a long period, all the horizons down to bedrock or at least to 100 cm depth may have their base saturation raised above 50 percent and the soil is then transformed into a Phaeozem. In other cases, Umbrisols have been improved for agriculture by the bulk addition of organic manures or other anthropogenic material. Here the umbric horizons are gradually transformed into plaggic or terric horizons. Thus in ‘marginal’ agricultural landscapes, a complex mosaic of linkages be-

![Diagram](image)

**Figure 8** Linkages of Umbrisols with other soils in time and space under cool and moist climatic conditions and free drainage.
Figure 9  Linkages of Umbrisols with other soils under wet conditions.

Figure 10  Linkages of Umbrisols with Phaeozems and Anthrosols resulting from human activities.
Plate 29.1.
Detail of Umbrisol. Corsica, France.
(Photo: R. Langohr)

Plate 29.2.
Landscape with Umbrisols on acid rocks.
Corsica, France.
(Photo: R. Langohr)
tween Umbrisols, Phaeozems and Anthrosols are likely to exist, along with the other linkages previously described.

- **Land use and management**

Most Umbrisols remain under their natural or semi-natural vegetation. Short grasses of low nutritional value are found either above the tree line in the Andean, Himalayan and central Asian mountain ranges, or at lower altitudes in north and western Europe where the former forest vegetation has been largely cleared. Coniferous forest predominates in Brazil (*Araucaria* species) and in the USA (mainly *Thuja, Tsuga* and *Pseudotsuga* species), whereas tropical montane evergreen forest occurs in south Asia and Australasia. The predominance of sloping land and the characteristic wet, often cold climatic conditions tend to restrict utilization of Umbrisols to extensive grassland. Management measures focus on improving grass species and raising soil pH by liming. Where conditions are locally more favourable, cash crops may be grown, either cereals and root crops in the USA, Europe and south America, or tea and coffee in south Asia and Indonesia.
**History, connotation and correlation**

As early as 1898 the black clayey soils covering a substantial part of Peninsular India attracted the attention of scientists (Leather, 1898). In the early days of soil classification these soils were allocated to the order of 'Pedocals' (Marbut, 1928). Because of their black colour such soils were named by the Russian school of pedologists Tropical Chernozems. However, further field studies indicated that the cracking clays were much unlike the Russian Chernozems because of their low organic matter content, the very typical structural profile and the deep cracks developed during the dry season. Because of the process of constant turn-over of soil material, Soil Taxonomy coined the name ‘Vertisols’, connotative for L. vertere, to turn. Many local names exist for these soils. Dudal (1965) lists some 50 names, of which the most important ones are: regur (India), adobe (USA, Philippines), gilgai (Australia), tirs (Morocco, N. Africa) and margalite (Indonesia).

**Concept and morphology**

Vertisols are deep clayey soils (>30% clay) dominated by clay minerals such as smectites, that expand upon wetting and shrink upon drying. They form wide cracks from the soil surface down to at least 50 cm depth when drying out. The upper part of the soil commonly consists of strong and prism-like blocks. In the subsoil a typical vertic structure develops that as a result of shrinking and swelling has either slicken-sides, or wedge-shaped or parallelepiped structural aggregates with shiny and grooved curved surfaces (vertic horizon). At the surface a linear frequency of microknolls and depressions may occur, collectively known as ‘gilgai’ microrelief’. Gilgai is a consequence of churning of soil material as a result of swelling and shrinking.

The nature of Vertisols is conditioned by the parent material. They are mainly derived from fine grained rocks, such as basalt, tuff, basic metamorphic rocks, limestone, marl, and from fluvial, lacustrine or marine alluvium.

**Properties**

During the rainy season, the cracks disappear and the soil becomes sticky and plastic with a very slippery surface which makes Vertisols in-trafficable when wet. The shrinking and swelling of the soil mass often results in small mounds and depressions at the surface, a phenomenon called ‘gilgai’.

Although they have a relatively high water holding capacity, shallow rooting crops may suffer from drought stress. The most important physical characteristics of
Plate 30.1.
Vertisol in an area with a Mediterranean climate. Central Valley, Chile. (Photo: R. Langohr)

Plate 30.2.
Gilgai surface pattern on Vertisols. Queensland, Australia. (Photo: R. Dudal)

Plate 30.3.
Eutric Vertisol on limestone and marls in an area with a Monsoon climate. Central Java, Indonesia. (Photo: R. Langohr)

Plate 30.4.
Stacking structural polygons of Vertisols for drying and subsequent breakdown into a finer structure, suitable for seedbed preparation. Vietnam. (Photo: A. Ruellan)
Vertisols are a low hydraulic conductivity and stickiness when wet and a high flow of water through the cracks when dry. They become very hard when dry. Vertisols are relatively rich chemically, having a large reserve of weatherable minerals. Frequently they are dark coloured but have a moderate to low organic matter content. Vertisols generally have a high cation exchange capacity (CEC) for plant nutrients. The pH(H₂O) is neutral or slightly alkaline in most cases. Base saturation is usually high, because many Vertisols have an accumulation of lime.

• Geography

Vertisols occur mainly in tropical and sub-tropical regions with a marked alternation of wet and dry conditions. Of the estimated 335 million ha of Vertisols in the World, major occurrences are in Australia, India, Sudan, Ethiopia, southwestern USA (Texas), Uruguay, Paraguay and Argentina. They are typically found in lower parts of the landscape such as, river terraces, dry lake bottoms and other periodically wet areas.

• Relationships with some other reference soils

The combination of topographic position, climatic conditions and parent material determines the spatial and temporal linkages of Vertisols with other soils. Vertisols normally occupy the lower parts of the landscape, comprising nearly level to gently undulating piedmont, flood and coastal plains in association with Calcisols, Luvisols, and Cambisols which usually occur in relatively higher positions. In similar topographic positions Vertisols will merge on the arid side of the climatic spectrum into soils with accumulation of soluble components such as Calcisols, Gypsisols and Solonchaks. On the more humid side accumulation of organic matter starts to prevail because of a more luxuriant vegetation, giving rise to Phaeozems and Chernozems. In tropical and subtropical regions underlain by basic rocks frequently toposequences with Nitisols/Luvisols on the slopes and Vertisols/Planosols in low-lying positions occur. Sodium-rich parent materials are important in associations of Vertisols and Solonetz, with the latter soil in a transition position between prevailing upland soils (often Luvisols) and Vertisols.

• Land use and management

Though Vertisols have great agricultural potential, they are difficult to work, being hard when dry and very sticky when wet. Many Vertisol areas in the semi-arid tropics still remain unused. Agricultural use ranges from very extensive (rough grazing, firewood production, charcoal burning) through smallholder post-rainy season crop production (millet, sorghum, cotton, chick peas) to small-scale (rice) and large-scale irrigated crop production (cotton, wheat, sorghum). Management practices for crop production ought to be primarily directed to control water dynamics besides maintaining
or improving soil fertility. Because Vertisols have very low infiltration rates, excess water during the rainy season has to be drained and possibly stored in the soil for post-rainy season use ('water harvesting'). Several management practices have been devised to improve the water dynamics. Surface drainage can be achieved by making broadbed and furrows. These protect crops from waterlogging in the rooting zone. The drained water may be stored lower in the catchment in small ponds for other uses such as watering cattle or growing vegetables. The International Livestock Research Institute (ILRI) in Ethiopia developed the oxen drawn broad bed and furrow maker which is now widely used by peasants of the Ethiopian highlands. Traditionally only one crop is grown towards the end of the rainy season utilizing residual soil moisture. With improved surface drainage two sequential crops such as barley followed by chickpeas became possible. Yield increases reported with broad bed and furrow technology ranged from 50% for wheat to 150% for faba beans in the Ethiopian highlands.

Contour cultivation and bunding are used to improve infiltration. Irrigated dry season use of Vertisols has to take into account the infiltration and hydraulic conductivity characteristics as well as effects of irrigation water quality. A beneficial side-effect of contour bunding is a check on soil erosion which usually is a severe problem of Vertisols on slopes. Vertical mulching is sometimes practised to enhance infiltration in the subsoil. Stubble of crops are placed upright in trenches along contours, protruding 10 cm above the soil surface. Distance between the trenches is normally 4 to 5 m. Sorghum yields reportedly increased up to 50% by vertical mulching (Driessen and Dudal, 1991).

Vertisols are usually N-deficient due to the generally low amount of organic matter. Nitrogen fertilizers have to be applied carefully in order to avoid losses through volatilization, throughflow in the cracks or denitrification during inundation. Other nutrients which may need correction are phosphorus and, occasionally, sulphur and zinc.

Cotton is known to perform well on Vertisols because cotton has a vertical rooting system which is not damaged too much by cracking. Other common crops grown on Vertisols are sugar cane, wheat, sorghum, barley, chickpeas, flax and noug.
Glossary

Aeolian: referring to wind; aeolian erosion: wind erosion; aeolian sand: wind-blown sand
Albeluvic tonguing: penetrations of white material of an overlying horizon into the horizon below
Albic horizon: light coloured horizon from which clay and free iron have been removed
Alkalization: growing ionic imbalance in the soil with bicarbonates and carbonate salts dominating the soil solution, measurable by high pH of >8.5
Allophane: co-precipitate of silica and aluminium which contains water, exchangeable ions and frequently iron and organic matter as impurities
Anthropedogenic horizon: a variety of surface horizons that result from long continued cultivation
Anthropogenic: caused by continued use by man
Argic horizon: clay accumulation horizon
Azonal soil: see zonal soil
Base saturation: sum of exchangeable cations Ca, Mg, Na and K expressed as percentage of the total cation exchange capacity at a specified pH
Bulk density: apparent density or volume weight of the soil: mass of dry soil per unit bulk volume
Calcic horizon: horizon with distinct calcium carbonate enrichment
Cambic horizon: horizon showing evidence of alteration: modified colour, removal of carbonates or presence of soil structure
Cation exchange capacity (CEC): sum of exchangeable bases (calcium, magnesium, potassium, sodium) plus total soil acidity (hydrogen and aluminium) at a specific pH
Cheluviation: geochemical process through which soil minerals are weathered and decomposed by organic acids, enabling them to leach
Chilluviation: geochemical process through which iron/aluminium-humus complexes are accumulated and reversibly bound in the subsoil
C/N ratio: carbon/nitrogen ratio: indication of the quality of organic matter
Cryogenic processes: processes triggered by freeze-thaw phenomena
Cutan: fine textured accumulations on ped faces of clay, organic matter, iron/manganese or lime
Duripan: compact mineral soil horizon cemented by silica
**Efflorescence**: fluffy crystalline powder on a surface, produced by evaporation

**Eluvial horizon**: a soil horizon which is depleted of clay and/or iron through leaching

**Eutrophic**: having an neutral to slightly alkaline soil pH, indicating a high base status, a nutrient-rich soil

**Ferralic horizon**: highly weathered fine textured horizon

**Ferric horizon**: horizon with prominent iron-enriched mottles or nodules

**Ferrihydrite**: hydrated iron hydroxide mineral

**Gelisol order**: partial equivalent of Cryosols in USDA Soil Taxonomy

**Gilgai microrelief**: topographic feature typical for Vertisols: succession of microbasins microknolls in nearly level areas, or microvalleys and microridges parallel to the direction of the slope

**Gleyic properties**: properties of soil materials that are completely saturated with groundwater for a period that allows reducing conditions to occur and show a gleyic colour pattern

**Great Group**: third categoric level of USDA Soil Taxonomy

**Gypsic horizon**: horizon with distinct calcium sulphate enrichment

**Histic horizon**: organic surface horizon

**Hydrolysis**: process of chemical weathering, a reaction in which salt combines with water to form acid and a base

**Igneous rocks**: rocks formed from cooling and solidification of magma

**ILRI**: International Livestock Research Institute, Addis Ababa, Ethiopia

**Imogolite**: gel-like hydrous aluminium silicate, the genesis and properties of which are closely related to those of allophane

**Krotovina**: a former burrow in a soil horizon that has been filled with organic matter or soil material

**Lacustrine**: refers to old lake bed deposits in the landscape

**Löss**: a sediment, commonly non-stratified and unconsolidated, composed dominantly by silt-size (2-50 microns) particles deposited primarily by wind

**Mollis horizon**: surface horizon with dark colour due to organic matter, rich in plant nutrients

**Moraine**: accumulation of glacial debris

**Natric horizon**: clay accumulation horizon with high level of exchangeable sodium, usually with a columnar or prismatic structure

**Nitic horizon**: horizon with a moderate to strong angular blocky soil structure, easily falling apart into smaller blocky elements, showing shiny ped faces

**Oligotrophic**: having an acid soil pH, indicating a low base status, a nutrient-poor soil

**Order**: highest categoric level in USDA Soil Taxonomy

**Organic soil materials**: soil material that contains more than 20% organic matter

**Oxymorphic properties**: colour pattern in the soil indicating alternating oxidized (drained) and reduced (waterlogged) conditions

**Permafrost**: perennially frozen soil layer

**pH**: see reaction

**Piedmont**: laying or formed at the base of a mountain

**Plaggen**: manure composed of earthy grass sods and cattle dung
Plinthite: iron-rich, humus-poor mixture of clay with quartz and other diluents that hardens irreversibly on drying

Pseudomycelia: lime in the soil matrix in the shape of fungus filaments

Pyritic soil material: soil material containing pyrite: FeS₂

Pyroclastic: originating from volcanic eruption

Reaction: soil reaction refers to soil pH, which indirectly measures the base status. The pH of the soil solution is the negative logarithm to the base ten of the hydrogen ion activity in the solution

Reduced soil materials: see reduction

Reduction: a chemical reaction in which an element gains an electron, that is the positive valence is reduced, e.g. Fe³⁺ + e⁻ = Fe²⁺

Regolith: unconsolidated mantle of weathered rock and soil material on the earth’s surface

Salinisation: accumulation of soluble salts in the solum

Slickensides: polished grooved ped surface in the soil, resulting from soil mass sliding against adjacent material along a plane

Smeary consistence: a consistence which changes under pressure and returns to the original state after pressure is removed

Smeectite: group of swelling-type of clay minerals made up of 2:1 unit layers, each consisting of two silicon-oxygen tetrahedral sheets enclosing one aluminium-oxygen octahedral sheet

Soil structure: the combination or arrangement of primary soil particles into secondary units or peds

Spodic horizon: sub-surface horizon, containing illuvial humus and/or amorphous iron or aluminium oxides

Stagnic properties: refers to soil materials that are at least temporarily completely saturated with surface water to allow reducing conditions to occur and show a stagnic colour pattern

Structure: see: soil structure

Taiga: vegetation zone of cold continental climatic belt, dominated by conifer forests

Thermokarst: type of topography formed over permafrost which is characterized by closed depressions and sinkholes due to melting of ground ice

Thixotrophy: a reversible property of soil material the consistency of which changes to a highly viscous fluid on agitation or repeated moulding

Tuff: rock formed of compacted volcanic fragments

Umbric horizon: surface horizon with dark colour due to organic matter, poor in nutrient reserves

Variable charge: charge (negative or positive CEC) of soil colloids which is variable (due to eg. pH)

Vertic horizon: horizon with cracks (when dry), slickensides, wedge-shaped structural aggregates

Water holding capacity: quantity of water which can be stored in a soil profile and which can become available for plant growth
Yermic surface properties: soil surface indicative of arid climatic conditions; typical are varnished wind-shaped gravel or stones, a pavement and a vesicular crust

Zonal soil: soil which is in equilibrium with the soil forming factors climate and vegetation
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Since 1980, the International Soil Science Society has been working to develop a vital common language for naming the soils of the world, a universally accepted system of soil classification: the World Reference Base for Soil Resources (WRB). WRB is designed as an easy means of communication amongst scientists interested in or dealing with soils and land, to identify, characterise and name major types of soils. WRB will serve as a common denominator through which national soil classification systems can be compared and correlated. WRB is edited in a series of three publications: the Introduction to the Reference Soil Groups, the Atlas (both editions published by Acco, 1998), and the Technical Key (published by FAO: World Soil Resources Reports nr. 84, 1998).

The introduction to the WRB aims to serve as a first entry into the knowledge of soil diversity and soil distribution, accessible to disciplines other than Soil Science sensu strictu and to a wider public. The salient features of the 30 Reference Soil Groups are discussed by briefly highlighting history, connotation, correlation with other systems of soil classification, concept and morphology, properties, geography, linkages, land use and management. The link to the real world is made by providing for each Reference Soil Group, typical colour pictures as well as typical landscapes in which these soils are commonly occurring.

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