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Major Soils of the World

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INTRODUCTION

This lecture note 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 summarized 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 generalization. It also demonstrates the continuity of the soil cover and illustrates the reasons for separating the classes.

The thirty reference groups are arranged in nine sets according to a common denominator, as follows:

Soils conditioned by topography/physiography (Fluvisols, Gleysols, Regosols, Leptosols)
Soils conditioned by parent material (Andosols, Arenosols, Vertisols)
Soils conditioned by climate in steppes and steppic regions (Chernozems, Kastanozems, Phaeozems)
Soils conditioned by climate in arid and semi-arid regions (Calcisols, Durisols, Gypsisols, Solonetz, Solonchaks)
Soils conditioned by climate in wet tropical and subtropical regions (Lixisols, Acrisols, Alisols, Nitisols, Ferralsols, Plinthosols)
Soils conditioned by climate in subhumid forest and grassland regions (Luvisols, Planosols, Albeluvisols, Podzols)
Soils conditioned by limited age and only weak to moderate soil development (Cambisols, Cryosols, Umbrisols)
Soils conditioned by organic soil materials (Histosols)
Soils conditioned by man (Anthrosols)

1. SOILS CONDITIONED BY TOPOGRAPHY/PHYSIOGRAPHY

1.1 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 and 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 (Austral.), Regosols (Can), Sols tropicaux récents (Za); Sols minéraux bruts d'apport alluvial ou colluvial, Sols peu évolués non climatiques d'apport alluvial ou colluvial (Fr.); Fluvents (USA); Auenböden (Germ); Alluvial soils (Russia), Fluvisols (FAO).

Concept and morphology. The environmental conditions during the process of sedimentation, invariably gives rise to/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 and therefore show little horizon differentiation. Chemically, Fluvisols usually are rich, with a near neutral pH, however soil salinity and high sodium levels may be a problem in coastal sediments. A special case is the Thionic Fluvisols, which contain large quantities of pyrite in the subsoil. Upon drainage pyrite is oxidized and in the process large quantities of sulphuric acid is released which in turn may lead to toxic levels of free aluminium in the soil solution. Physically, Fluvisols are wet in most cases due to stagnating groundwater or floodwater. Freshly deposited Fluvisols usually are unripe and little trafficable. 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 a host of organisms such as crayfish in river and coastal areas, worms, moles and worms in riverine lowlands.

Geography. By definition, Fluvisols occur on materials deposited in aqueous sedimentary environments. Driessen and Dudal (1991) suggest that there are three of these 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 saltings or brackish marsh environment, of which deltas are a special case. Fluvisols are found on all continents under all kinds of 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 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 northeastern coast of South America (Venezuela, the Guyana's).

Linkages. Soil forming processes, other than the formation of a surface horizon through accumulation of organic matter, have not left their marks in 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 coastal areas are normally under mangroves or other halophyte vegetation. Fluvisols are grown to 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 actual (oxidized) Thionic Fluvisols because they are highly acidic and usually contain toxic amounts of aluminium.

Many Fluvisols in the humid tropics in Southeast Asia are under highly productive rice cropping systems, whereby three crops per annum are possible. Important however is that the paddy land be left 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.

1.2 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 (Can.); Sols à gley peu profond peu humifères (Fr.); Gley (Germ.); Aquents, Aquepts, Aquolls (U.S.A.); Meadow soils (Russ.); Groundwater Rendzina (Austral.);Borowina (Germ.); Lacovisti (Romania).

Concept, morphology and definition. Gleysols or soils with gleyic properties are permanently 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 wet are evidenced by a characteristic gleyic 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 show black colours due to presence of iron sulphides. In sands colours are light grey to white due impoverishment of iron and manganese. The upper part of a reduced soil layer typically looks rusty, mainly around channels of burrowing animals or plant roots.

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 gleyic properties but have a different hydrology and morphology. Stagnic subunits normally have a slowly permeable dense layer in the solum on top of which groundwater stagnates. They are usually very wet at the top, well drained in the subsoil and commonly occur in plateau 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 better of than the surrounding uplands, due to the fact that they normally have a finer soil texture, 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 soil densification due to weakening of interparticle bonds during saturation and contraction of soil particles upon desaturation (Driessen and Dudal, 1991). This results in a poor aeration of the rooting environment and poor conditions for most fauna except for 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 occur in the boreal and cool parts of the world as well as in Zaire, Angola, Botswana, Mali and China.

Linkages. Soils in other major 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 are formed in alluvial sediments and are associated with Fluvisols near riverbeds and in coastal areas, and with Histosols. In moraine and loess landscapes they occupy depressions with a high groundwater table and are occur together with Histosols, while Luvisols and Cambisols occupy the higher landscape positions.

In the semihumid 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 Solonetz. Calcisols or Gypsisols besides Cambisols, Regosols, Arenosols and/or Leptosols normally occupies higher landscape positions with yermic surface properties.

Land use and management. Most Gleysols have natural swamp vegetation or are used for grazing. In the tropics and sub-tropics they are widely planted to rice. They can be used for arable cropping, dairy farming or horticulture provided the groundwater table is lowered or groundwater seepage intercepted. Special precautions must be taken in case of Thionic Gleysols, which may acidify irreversibly upon oxidation after drainage.

Trafficability usually is a burning issue with Gleysols. If the soil is cultivated in too wet a condition, soil structure is likely to deteriorate (Driessen and Dudal, 1991).

1.3 REGOSOLS

History, connotation and correlation. Regosols (from Gr. rhegos, blanket: mantle of loose material overlying the hard core of earth; 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) focussed 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 (Austral.), Sols peu évolués régosoliques d'érosion, Sols mineraux bruts d'apport éolien ou volcanique (Fr.) Rohböden (Germ.), Entisols (USA).

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 due to a limited time of exposure or as a consequence of soil erosion. On the other hand they may be exposed to conditions that retard soil formation such as dry and hot desert climate or permafrost. A special case of Regosols is the colluvial soils in undulating to rolling landscapes covered with loess. After deforestation severe historical soil erosion caused truncation of the soils in the upper slopes and deep (50-100cm) sedimentation in the low-laying landscape positions.

Properties. Most properties of Regosols are associated with the 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, if located on sloping terrain. Regosols in agricultural land of the loess belt in the northern hemisphere at footslopes continuously build up by sedimentation at a rate of several mm per annum, forming 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 portion of the weakly developed soils, occurring in the polar and boreal zones (278 million ha), formerly classified as Regosols are now separated as Cryosols. About 170 million ha in the arid zone, 52 million ha in the dry tropics, and 36 million ha in mountain areas comprise most of the Regosols.

Linkages. Some of the Regosols associated with, and interspersed with, adjacent soils in landscapes 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 calcaric or gypsiric soil material.

Regosols are found in all landscapes throughout the world, in relation with many other soils. In the terrain 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 gets more grip on the soil, Regosols may develop into many other soils depending of the most important soil forming factor(s).

Land use and management. Most Regosols are under natural vegetation. In the steppe regions they can be used for agricultural production, under irrigation. Regosols in mountain zones may be used for extensive grassland or left idle.

The Regosols of colluvial origin in the Loess belt of northern Europe and North America are among the best soils for agriculture. Most of them are under intensive agriculture and planted to wheat, barley and sugar beet or are used for apple or peer growing.

When freshly deposited the colluvial strata may form a surface seal which may hamper germination of young seedlings. At the bottom of the micro-valleys ravine Regosols are vulnerable to ravine erosion and need special protection through grassed waterways.

1.4 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 to Entisols, Lithic subgroups, Rendolls (USA), Lithosols (FAO, 1974), Renzina (FAO, 1974), Rendzines (Fr.), Derncarbonate soils (USSR), Rankers (Fr., Germ.), Humuskarbonatböden (Switzerland).

Concept and morphology. Leptosols are soils, which either are limited in depth by continuous hard rock within 30 cm of the soil surface, or contain or overlie within the same depth material with a very high calcium carbonate content, or are very gravely 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 soil units. So the maximum development in Leptosols will often be the minimum criteria required for one of the other soil groups. The concept of Leptosols is to comprise 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 group of soils.

Properties. Leptosols have a range of chemical, physical and biological characteristics. These characteristics are strongly conditioned by the nature of the parent material. Calcareous Leptosols are chemically 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 inactive due to drought.

Geography. Leptosols are the most widespread major 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 extensive soil unit and form the most important soils of mountain regions. Their greatest concentration is 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.

Linkages. Much steeply sloping land in the mountainous parts of the world carries 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 ones than on the acid types. The main physical constraint of Leptosols in their low water holding capacity, which makes them very susceptible to drought stress. Chemical fertility of most Leptosols usually compares more favourable than other soils developed from the same parent material. Leptosols have severe physical limitations for arable cropping, but have a certain potential for trees and for extensive grazing. The better types are the ones developed on limestone under a humid climate. Tree roots find anchorage by entering fissures. In mountain 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 taken up into a slash and burn system they degrade after a few years due to severe soil erosion. They can be stabilized by terracing, under permanent grassland or by means of strip cropping.

2. SOILS CONDITIONED BY PARENT MATERIAL

2.1 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 in the Référentiel pédologique français (AFES, 1990).

Concept and morphology. Andosols are soils developed in volcanic ash, tuff, pumice and other volcanic ejecta of various compositions. The rapid weathering of the porous parent material results in an accumulation of amorphous complexes such as allophane and imogolite. The andic horizon concept thus covers a number of soil horizons, which have in common the dominant presence of short-range-order minerals. There are, however, distinct differences in expression amongst the various kinds of andic horizons and each subtype possesses a unique set of properties: (1) an andic horizon dominated by volcanic glass, (2) an andic horizon constituting mainly of allophane and similar minerals and (3) an andic horizon 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 smeary 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 hardly taking place. The subsurface horizons, if present, still 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 (lavas, tuffs) or gradual in soft materials. Rooting in Andosols is dense and roots penetrate deeply in the soil. Mesofaunal activity is intense. Recent pyroclastic materials may be heterogeneous because of superposition. In such cases horizonation does not only result from pedogenesis, it may also be 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.

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, while there is only little macroporosity in the subsurface horizons. Andosols have a high permeability and a generally a large moisture storage capacity.

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

Geography. The 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, and 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 prominent on many islands in the Pacific: Fiji, Vanuata, New Hebrides, New Caledonia, Samoa and Hawaii. 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.

Linkages. Andosols, being a group of soils occurring worldwide in a large variety of environmental conditions, have linkages with almost all other major 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 toposequences occur with Andosols prevailing at higher elevations and Cambisols, Luvisols and Vertisols developing downslope towards the inter-andine 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 rainwater infiltration and to restrain erosion risks. Deep cultivation, such as deep tillage, can modify the physical properties of Andosols and may produce too drastic soil dehydration. The soil then becomes very friable and looses a large part of its water retention capacity, transforming itself into a loose sandy loam, which is easily erodible.

However, some Andosols have a rather poor fertility, owing to their high phosphorus retention, their acidity and aluminium toxicity, and 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 rather sandy texture, giving rise to a large macroporosity, low water retention capacity and low cation exchange capacity. Other types of Andosols have excessive humidity, 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 the climatic conditions and 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.

2.2 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 Psamments or Psammaquents. Other names for Arenosols in other soil classification systems include the following: sols mineraux 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 as well as sandy soils with Neocarbonate B horizons in the South African system and raw sands (Britain and Germany), Arenosols (FAO).

Concept and morphology. Fundamental to the concept of Arenosols is the sandy nature of these soils, which dominates their characteristics and properties. The texture of Arenosols is loamy sand and coarser. There is no restriction as to the minimum degree of soil development required. The limits of Arenosols with other major soil groups are determined by the maximum degree of soil development permitted.

Properties. Arenosols do not have other diagnostic horizons than an ochric or an albic horizon. Structures are normally massive or only weakly developed. Arenosols are very permeable and have rapid infiltration, high hydraulic conductivity and low water holding capacity. Chemically there may be quite large variations in contents of organic matter and nutrients. CEC ranges from very low to moderate levels. The pH and base saturation are very variable.

Geography. Arenosols are widely distributed and form one of the most extensive major soil groups in the world. Arenosols cover about 900 million ha or 7 percent of the land surface. If shifting sands and active dunes are included, the coverage will 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 known as Kalahari sand, it is bordered by the Zaire 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 dunes or flats, but have also formed on marine, littoral and lacustrine sands of beach ridges, lagoons, deltas, lakes, etc. In addition Arenosols are found on coarse-grained weathering rock, mainly sandstone, quartzite, granite, etc. 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.

Linkages. Spatial linkages between Arenosols and other major soil groups are found in basically two major environments:

Areas where sand is the overall predominant parent material (mainly Aeolian depositional environments); and

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. In arid and semi-arid environments stabilized or shifting dunes with Arenosols may be found in association with playas and other depression 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. As of 400 - 500 mm rainfall 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 the 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 Highvelt 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 highly 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 due to an increased tendency to cultivate soils while 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 should 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.

2.3 VERTISOLS

History, connotation and correlation. As early as 1898 the black 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 grouped into the order of 'Pedocals' (Marbut, 1928). The Russian school of pedologists named such soils Chernozems.

Further field studies indicated however that the cracking clays of the Black earths were much unlike the Russian Chernozems because of the low organic matter content, the very typical structural profile and the deep cracks developing during the dry season. Because of the process of constant turnover of soil material in Vertisols, 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 smectite that expand upon wetting and shrink upon drying. They form large cracks down to 50 cm from the soil surface 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 slickensides, or wedge-shaped or parallepiped structural aggregates with shiny and grooved curved surfaces ('slickensides'), shear planes, show a linear frequency of micro knolls and depressions, collectively known as 'gilgai' microrelief. Gilgai is a consequence of churning of soil material as a result of swelling and shrinking.

The parent material conditions Vertisols. They are mainly derived from fine-grained rocks, such as basalts, tuffs, basic metamorphic rocks, limestone, marls, and from fluvial, lacustrine or marine alluvium.

Properties. Vertisols become very hard and develop deep and wide cracks during the dry season. During the rainy season the cracks disappear while the land becomes fairly inaccessible due to a very slippery surface. They become sticky and plastic (often untrafficable) 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 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 (H_2O) is neutral or slightly alkaline in most cases. Base saturation is usually high, also because many Vertisols show 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 and Ethiopia, eastern Australia and 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.

Linkages. 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 more lustrous vegetation, giving raise 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 semiarid tropics still remain unused. Agricultural use ranges from very extensive (rough grazing, fire wood production, charcoal burning) through smallholder post-rainy season crop production (millet, sorghum, cotton, chick peas) to smallscale (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 done 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, growing vegetables etc. ILCA 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 to thrive on residual soil moisture. With improved surface drainage two sequential crops become possible such as barley followed by chickpeas. Yield increases reported with broadbed and furrow technology ranged from 50 % for wheat to 150 % for fababeans 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 practiced to encourage infiltration in the subsoil. Stubble of crops is therefore placed vertically in contour trenches with the stubble protruding 10 cm above the soil surface. Trenches are 4 to 5 m apart. 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 volatilisation, 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 too much damaged by cracking. Other common crops grown on Vertisols are sugar cane, wheat, sorghum, barley, chickpeas, flax and noug.

3. SOILS CONDITIONED BY CLIMATE IN STEPPES AND STEPPIC REGIONS

3.1 CHERNOZEMS

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. Dokuchaev identified the soil 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 Chernozem (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. Calcareous loess or loess-like sediments largely cover these areas. 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 downwards and lime accumulates in the subsoil, which shows up as soft whitish powder, mycelium-like streaks or small concretions. In the wetter (colder) areas at the boundary of steppe and deciduous forest, clay may also accumulate in the subsoil. The soils are neutral pH and 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.

Linkages. 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.

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.

3.2 KASTANOZEMS

History, connotation and correlation. Kastanozems (from L. castaneo, chestnut and Russian zemlja, earth) or "dark chestnut" soil, were considered the "normal" or "zonal" soils in Docuchaev's (1883) last classification (Basinski, 1959) 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 substratum. 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 layer, particularly in the lighter Kastanozems, is associated with a lower degree of microaggregation, 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.

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 down to Texas and throughout Mexico). In South America, they occur in the pampas northern Argentina and in the Gran Chako of Paraguay.

Linkages. 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 Calcisols and Gypsisols. Here they also form associations with Solonchaks and Solonetz.

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.

3.3 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 Grey 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 loess and loess-like sediments or glacial till. Because of their more humid environment weathering and leaching is more pronounced 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. Especially earthworms (Lumbricides and Enchytraeides) 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.

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 farmland. Many Phaeozems show a clay accumulation in the subsoil, which increases its water holding capacity. Yet 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.

Linkages. Phaeozems occur in steppe to forest-steppe or forest-prairie areas including the drier parts of broad-leaf forests, as far as the potential natural vegetation can be reconstructed. Consequently, these soils border towards the more humid side 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 edge of the Chernozem areas of Eurasia and North America. In the area bordering the Albeluvisols, Phaeozems occur which show uncoated silt and sand grains on structural ped surfaces ("white powder" or "salt and pepper". In South America, Phaeozems link up 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 forms a limiting factor. Most of it is derived from fossil groundwater, the shortage of which is increasing. In the cold temperate climate belt wheat and barley besides vegetables are the principal crops because of shorter growing periods. 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.

4. SOILS CONDITIONED BY CLIMATE IN ARID AND SEMI-ARID REGIONS

4.1 CALCISOLS

History, connotation and correlation. The name Calcisols is connotative of L. calcis, or soils with substantial accumulation of calcium carbonate. It has first been 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 français (AFES, 1990). They correspond more or less to the Calciorthid 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.

Concept and morphology. The central concept of Calcisols is that of soils in which accumulation of calcium carbonate is or has been the most dominant soil forming process. 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 precipitate deeper in the solum, or originate from lateral enrichment along toposequences. They can also be derived from carbonate-rich groundwater or airborne dust. The accumulation of lime can occur in different forms; as diffuse distributions, impregnated in the soil matrix, as localized concentrations, or as continuous layers, which may be cemented. Calcisols usually show little horizon differentiation apart from the calcic horizon(s) present. A calcic horizon is a horizon in which calcium carbonate has accumulated either in a diffuse distribution or as discontinuous concentrations as pseudomycelia, cutans, soft powdery lime, nodules (soft or hard) or veins.

Properties. The morphology of Calcisols is largely determined by the dominant presence of large accumulations 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 segregations. These horizons therefore act as a barrier through which roots hardly penetrate. A crusty surface may occur especially when the soils are silty. Calcisols invariably have a high base saturation. The exchange complex is usually dominated by clay minerals with a high cation exchange capacity. The pH (H_2O) is neutral or slightly alkaline, while many of them are low inorganic matter.

Geography. Calcisols are fairly extensive, mainly occurring in arid and semi-arid regions. It is estimated that the total area of Calcisols is about 800 million ha. Main occurrences of Calcisols are located in Mediterranean climates and in the semi-arid subtropics of both hemispheres.

Linkages. The limits of Calcisols and the lateral transition to other soils are largely determined by a change in expression of the surface layers and the appearance of other horizons between the surface layer and the calcic horizon. The lateral transitions are a function of the relief (at local level) and of climatical 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 unlayered calcrete to layered or platy calcrete or compact calcrete. The distribution of calcic horizon in space and time shows that both vertical and lateral redistribution movements, as well as airborne additions play a role in the formation of calcic and hypercalcic horizons. Of these three lateral movements are probably more important than vertical redistributions.

Land use and management. Being mostly related to arid and semi-arid environments, Calcisols usually carry sparse vegetation. They are frequently used for extensive grazing. Under rainfed conditions some drought resistant crops may be grown. When irrigated, crops grown should be tolerant to the high calcium levels and care should be taken to prevent the land from crusting and salinization.

4.2 DURISOLS

History. The name Durisols derive 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 WRB. 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" as well as "Wiluna hardpan", or soils with 'silcrete'. 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 recognized 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 (continuous compact soil layer) or durinodes (discontinuous nodules) are cemented by silica so that dry fragments do not slake during prolonged soaking in water or in hydrochloric acid.

A typical Durisol profile consists of a red coloured, non-calcareous topsoil on top of the duripan. Two main morphological types of duripans are distinguished, i.e. massive or those with a platy or laminated structure. The durinodules (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 durinodules do not slake in water although some softening can take place after prolonged soaking. Horizons containing durinodules are not very common and they are considered to be the predecessor for duripan formation. Durisols occur extensively in level to slightly sloping terrain mainly along footslope positions.

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 of their compact cemented duripan at shallow depth, which 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 and decrease 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 climates. They were extensively reported in Australia, South Africa and the USA.

Linkages. As Durisols are typical for dry ecological zones, they are bound to occur in association with Gypsisols, Calcisols, Vertisols, Arenosols and Cambisols.

4.3 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 were called 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 ($CaSO_4.2H_2O$). Primary gypsum, such as gypsum rock and mobile gypsum sand, are excluded from the definition of gypsic horizons. Sources of secondary gypsum are weathering, gypsum-bearing rocks, gypsum dust, run-off and 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 accumulations 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 gypsum 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, amas, etc., distributed throughout the solum without a clear formation of a gypsic horizon. In sofar these soils do not qualify for Solonchaks, they are grouped with the Gypsisols rather than Gleysols, as gleyic 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 due to the sedimentary environment in which they occur. Especially on river terraces the gravel component can be important. Soil structure is usually weakly developed and 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 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 Namibian deserts, Yemen, Somalia, northern Iraq and Syria. They often occur in association with Calcisols in southern USSR, southeast and central Australia and southwestern USA. They form a large portion of the rangelands. 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 (Ilaiwi, 1983). Gypsisols in Iraq occupy a major part of the Mesopotamian plains between and adjacent to the Tigris and Euphrates rivers.

Linkages. The gypsic horizons as defined above 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, Solonetz 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 layers 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 plays a key role in transporting and redistributing gypsum. For example, where gypsiferous rocks are exposed in semi-arid hilly or mountainous regions, gypsum is transported by run-off and deposited in lower lying areas over quite far distances.

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 are have 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 hypergypsic horizon.

If the gypsum content in the upper 30 cm is not more than a few %, they 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, caving in canal walls and corrosion of concrete structures.

4.4 SOLONETZ

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-, differ not only in their chemical character, but also in geographical and in their morphological, physical and physico-chemical properties. Reclamation methods of these soils are different as well. Solonetz are therefore separated at high categoric level in many national soil classification systems: Solonetz (Canada), Sols sodiques à horizon B et Solonetz solodisés (France), Natrustalfs, Natrustolls, Natrixeralfs, Natrargids, Nadurargids (USA), Solonetz (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 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 neutral sodium salts, mainly sodium chlorides and sodium sulphate, affect soils Solonchaks are formed, while Solonetz are developed more under the influence of such salts as $NaHCO_3$, Na_2CO_3, Na_2SiO_3 and $MgCO_3$. Characteristic for Solonetz is the natric horizon associated with often humus-rich surface horizons and saline subsoil. A bleached layer (albic horizon) may be present between the surface and the natric horizon. The natric horizon is a dense subsurface horizon which has a higher 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. It shows often thick and dark coloured clay cutans, especially in the upper part of the horizon. Soil reaction is strongly alkaline with a pH (H_2O) of more than 8.5. A surface layer usually rich in organic matter 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 surface layer and the natric horizon ('solodized soils').

Properties. Solonetz generally show differentiation within the profile with respect to colour, structure, and bulk density and particle size distribution. Low-lying Solonetz may have thick and well-structured surface horizons. On terraces of saline lakes thin surface layers dominate frequently 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 hardness 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 (H_2O), which are frequently more than 9.0.

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

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

> Histosols, which may be saline, occurring on terraces of lakes and old stream beds within the steppe landscape with loess deposits, impeded drainage and some salt accumulation;
>
> Chernozems, mainly on loess-like loams in a landscape with poor surface drainage and some microrelief;

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

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

Vertisols in the 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 grass vegetation and are used as pastures. Predominant among the grasses *are Festuca sulcata*, *Pyrethrum achilleifolium* and *Artemisia maritima incana*, in association with *Parmelia vagans* lichen and *Nostoc commune* algae.

When the thickness of the humus horizon decreases up 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*, *Statica gmelini*, *Camphorosma monspeliacum* and *Kochia prostata*. In the case of a high groundwater table some halophytes such as *Salicornia herbacea* and *Saueda corniculata* appear.

Solonetz are problem soils 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 lifting of the carbonate or gypsum containing humus 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. In many parts of the world Solonetz are in use for extensive grazing or left idle.

4.5 SOLONCHAKS

History, connotation and correlation. The name Solonchak is derived from Russian sol: salt, and chak: salty area. Solonchaks have always been distinguished at highest categorical 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).

Concept and morphology. Solonchaks are soils with high concentrations of salts at some time of the year in the topsoil. This may be caused 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. 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 in 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 expressed by 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 pression of the soil solution, or the toxicity of a given ion leads to special landscapes, either occupied by a 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 these sodium is very 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):

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 desalinisation. A slight increase in pH may take place.

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 alkalinisation occurs after desalinisation. Subsequently, the structure tends to degrade.

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 desalinisation hydrolysis of the magnesium complex results in a strong alkalinisation followed by structural degradation. From the above it is clear that sodium and magnesium may have an adverse effect on the soil structure, depending on the presence or absence of calcium.

Properties. The only common characteristic in 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. This process is more or less continuous in space and evolutive in time (white efflorescences, salt crusts, non-aggregated brown powder, black salt deposits, evaporative salt crystals, etc.) (Loyer et al., 1989). 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 senso 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 (alkalinisation). The aggregates remain stable and flocculated and the hydrodynamic properties of the soil are unchanged. After desalinisation cations from the soil solution may be absorbed at the exchange complex and only then degradation of the soil structure will be enhanced. A typical structural expression in Solonchaks, however, does not exist, contrary to Solonetz.

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 Middle East, North and South Africa, Namibia and Chad. In Paraguay and Uruguay they are often associated with Solonetz.

Linkages. 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. Gypsisols and Calcisols are excluded.

In the landscape natural Solonchaks occupy the lower parts where through runoff, seepage and shallow groundwater salts can accumulate. In central parts of closed basins in arid regions salts accumulate at the surface, forming a saltpan, 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. The agricultural use of these soils is delicate. 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 under these climatic conditions 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 conservation, the chemical degradation and the regeneration of salt-affected soils are presently of prime importance in irrigated areas, especially in the light of the expansion of irrigated land in developing countries.

5. SOILS CONDITIONED BY CLIMATE IN WET TROPICAL AND SUBTROPICAL REGIONS

5.1 LIXISOLS

History, connotation and correlation. Lixisols (from L. lixivia, washed out substances) are strongly weathered soils in which clay has been washed out from the surface down to an argic horizon of low activity clays 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) in which they cover soils with an argic B horizon dominated by low activity clays and a base saturation less than 50%. Lixisols soils have been named red yellow podzolic soils (Br.), Podzólicos vermelho-amarelo eutróficos a argila de atividade baixa (Br.), sols ferrugineux tropicaux lessivés and sols ferrallitiques faiblement désaturés appauvris (CPCS, 1967), red and yellow earths, Latosols and oxic subgroups of Alfisols (Soil Taxonomy).

Concept and morphology. Lixisols are characterized by a clay accumulation in the 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. The argic horizon is further elaborated upon under the Luvisols.

Properties. The higher base saturation tends to give Lixisols somewhat better developed structures than the weak ones normally encountered in Acrisols. Often an eluvic horizon is present which is massive. When dry, the eluvic 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 ferric properties in the subsoil may impede root growth however. The absolute amount of exchangeable bases is generally not more than 2 cmol (+)/kg 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. Only under fairly humid conditions and/or low temperatures as occurring in tropical highlands, accumulation of organic matter may be considerable.

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 is found in Africa and about one-quarter in South and Central America.

Linkages. 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 dominantly 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 these kinds of soils have cation exchange capacities close to this value, 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 in weatherable minerals than Acrisols. These criteria, together with the pH, may be used as field indicators. However, awaiting better criteria for use in the field, 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 the 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 where in Pleistocene times arid and humid periods have alternated. On old erosion or depositional surfaces or in piedmont areas of the humid regions they are often a major soil group, associated with

Nitisols when on basic rocks, and with Vertisols, Planosols, Plinthosols and Gleysols in depressions and flatlands. 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 savannah and open woodland. Such areas with Lixisols are often used for extensive grazing. 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 at a regular basis. The low cation exchange capacity often dictates split-level applications to prevent fertilizer loss. Continuous cultivation is quite well possible but needs to take into account recurrent input in terms 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 decrease due to adverse surface soil characteristics is regularly recorded on these kinds of soils. Rotation of annual crops with improved pastures should be recommended to maintain or improve the organic matter content. Soil erosion control is very important, 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 if occurring in the drier parts of the tropics and subtropics or in case stonelines occur at shallow depth.

5.2 ACRISOLS

History connotation and correlation. Acrisols (from L. acris, very acid) are characterized by a subsurface accumulation of low activity clays, a distinct clay increase with depth, and a low base saturation. These soils have been named red-yellow podzolic soils, Podzólicos vermelho-amarelo distróficos 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 covered 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 (+)/kg clay) was added, separating Acrisols from Alisols.

Concept and morphology. Acrisols are diagnosed by a clay accumulation in the B-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 with depth of the clay content or morphological characteristics related to clay translocation are used to define the argic horizon, which has to be present in the Acrisols.

Properties. The argic horizon in Acrisols often lacks clear illuviation features and most Acrisols are therefore characterized by a sharp clay increase occurring over a short distance. Due to the low cation exchange capacity and base saturation Acrisols tend to have weakly developed structures. Often an eluvic horizon is present, which is massive.

Root penetration is usually poor because of the strongly acid subsoil. Many Acrisols have high aluminium saturation with values exceeding often 70 percent. The absolute amount of exchangeable aluminium, however, is generally not more than 2 cmol (+)/kg fine earth due to 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 occurring in tropical highlands, accumulation of organic matter may be 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 South-eastern Asia.

Linkages. Acrisols are common in tropical, subtropical and warm temperate climates and where in Pleistocene times arid and humid periods have alternated. On old erosion 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, and with Vertisols, Planosols, Plinthosols and Gleysols in depressions and flatlands. On ancient shield landscapes in tropical regions Ferralsols and Acrisols are dominant. 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 often found in these landscapes on slopes and on surfaces subject to erosion. For example, they are found on low hills covered by quartz and ironstone gravel, surrounded by pediments with Ferralsols, or on lower surfaces cutting in on stable uplands with Ferralsols. In case the sandy topsoil becomes thicker than 1 m Acrisols fade into the 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, while 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 canopy dense rain forest to open woodland. A large part of the roots (probably more than 80%) is concentrated in the surface layer with only a few taproots going deep down. 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 input in terms 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 subsoil layers will be exposed at the surface. Perennial crops like oil palm, rubber, cashew, mango and plantation 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 should be recommended to maintain or improve the organic matter content.

5.3 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 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, and 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, contrary to the Lixisols and Acrisols. Driessen and Dudal (1991) estimate that in the tropics about 100 million ha of these soils is being used for agriculture.

Alisols correlate partly with high activity Aquults, Humults and Udults in Soil Taxonomy (Soil Survey Staff, 1996), the Fersialsols of the Référentiel pédologique français (AFES, 1990) or sols fersiallitiques très lessivés of the CPCS (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 layer 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 in these soils at a stage where 2:2 and 2:1 clay minerals are being degraded, releasing large amounts of aluminium and magnesium, thus creating a very acid environment. Most primary minerals have disappeared. 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 with 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. 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 show poorly expressed soil structures. 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 (gneisses, etc.).

Geography. Alisols are reported from the southeastern USA, Latin America (Ecuador, Nicaragua, Venezuela, Colombia, Peru (foothills of the Andes), Brazil), West Indies (Jamaica, Martinique), West Africa, the highlands of Eastern Africa (Rwanda), India, Indonesia (Kalimantan and Sumatra) and China. Their total extent is difficult to assess, as they were only recently introduced in FAO's Revised Legend.

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). Forestation requires planting tolerant species.

The major problem in managing cultivated Alisols are (1) the instability of surface horizons and their susceptibility to erosion, and (2) Al toxicity at shallow depth. 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 very productive after heavy fertilization and liming.

5.4 NITISOLS

History, connotation and correlation. During the early soil surveys in the in the Kivu Region, Nitisols were already recognized under the name of 'Sols Fersialitiques' or 'Ferrisols'. They usually were developed on strongly weathered basaltic volcanic deposits. The Nitisol concept was elaborated upon by Sombroek et al. (1981). In the FAO/Unesco legend special provision was made for these soils under the name "Nitosols", from L. nitidus, shiny, connotative of shiny ped faces in the subsoil. In the revised Legend of the FAO soil map of the world the name Nitosols was changed into Nitisols, and 'nitic properties' were specified more precisely. The reason for their distinction at the highest level of classification was that though they are strongly weathered and look like Ferralsols at first glance, Nitisols proved to be far more productive soils. In Soil Taxonomy (Soil Survey Staff, 1996) Nitisols keyed out under the Alfisols and the Ultisols. Later on the importance of the Nitic properties were accredited by the introduction of the Kandic horizon in Soil Taxonomy, which occurs in the Oxisols, Ultisols and Alfisol Orders. Other international correlations are: E: Red earths, Br: Latosol, Fr. Ferrisol Krasnozems (Austral. and Russia), Terra Roxa estruturada (Br.)

Concept and morphology. Nitisols are deep, well-drained soils with a typical nutty or polyhedral blocky structure and shiny ped faces. They are dusky red or dark red and have a clayey or fine clayey texture. The 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 is the nitic horizon, which has '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 (polyhedral 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 those 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 abruptic erosion features are involved. Nitisols are formed in intermediate to basic parent materials under a vegetation type ranging from wooded grassland to (mountain) rain forest (Driessen & Dudal, 1991). Nitic properties come into existence as a consequence of different processes. Firstly there is very strong weathering, which is called ferralitisation. This process is comparable to what happens in Ferralsols, but it is still in an early stage. Secondly the shiny peds are formed by a micro-swelling and shrinking. Manganese and ferrihydrite, which move in between the microcracks, form microcoatings on the ped faces. Thirdly there is the process of biological homogenisation 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.

Nitisols have only a fair effectively available water holding capacity per unit of volume (5-15%) 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.

Water permeability is moderately rapid to moderate (about 50 mm per hour) and tillage operations can be carried out easily a day after moistening without damage to the soil structure. Usually no gravel or stone sized concretions are present, but some fine Fe/Mn 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).

Linkages. Nitisols occur frequently associated with other soils having an argic horizon, with Ferralsols, Vertisols and Cambisols, and with Andosols. They are set apart from the group of soils with an argic horizon (Luvisols, Lixisols, Acrisols, Alisols, Albeluvisols) by the presence of a nitic horizon, which is unique for the Nitisols.

Nitisols are frequently 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 relations may be observed as described below. 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:

> In undulating landscapes on basic and ultrabasic rocks, Nitisols often occupy the upper and middle slopes, merging into soils with Vertisols or vertic units of other major soil groups on the lower slopes and in valleys.
>
> On volcanic landscapes Andosols are found on the upper slopes while Nitisols occur on the lower slopes.

On uplifted and re-modelled plateau landscapes on old land surfaces Nitisols occupy the slope positions while Ferralsols occur on the flatter plateau parts.

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

Vegetation, uses and management. Nitisols are much sought after for sustained smallholders' farming and plantation crops such as cocoa and coffee despite the low CEC and frequently low base saturation. The good tilth, easy workability of the soil and other physical attributes has contributed to sustainable low-input agriculture on these soils.

Micronutrients and potassium are likely to be supplied by 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).

5.5 FERRALSOLS

History. The name Ferralsols comes from L. ferrum and aluminium; 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 Zaire 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 (Br.), Oxisols (USA), Sols ferralitiques (Fr.), Lateritic soils, Ferralitic soils (Russia).

Concept, morphology and definition. 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, 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 measured by 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 having 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 as if 'the soil material flows 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 high ambient temperatures and rainfall - 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; because of their depth, high permeability and stable microstructure 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 disrupted by agricultural practices, while inactivation of phosphorus is a major problem (>85 % phosphate fixation 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 depending 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 Zaire, southern Central African Republic, Western Angola, Congo, Guinea and western 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 (Driessen and Dudal, 1991). The total area is estimated as 750 million ha.

Linkages. As mentioned before Ferralsols occupy geomorphologically old land surfaces. They are associated with Cambisols where rock comes 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 rock (e.g. dolerite) they occur associated with Nitisols. Near valleys Ferralsols merge into Gleysols and Plinthosols.

On continental scale of Africa, a clear zonality has evolved due to 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. the tops of table mountains). 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 permanently 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 insulation so that organic matter is preserved. This organic rich surface horizon in Ferralsols contains nearly all fertility and is therefore of primordial importance for sustainable land use on Ferralsols.

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 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 this does not result in accelerated mineralization of organic matter or create micronutrient 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 to other soils with comparable clay content. Ferralsols are stable and resistant to soil erosion.

5.6 PLINTHOSOLS

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). The Plinthosols with plinthite are known as Plinthosols (FAO-Unesco-ISRIC, 1990), "Groundwater Laterite soils", "low-level Laterite", "Lateritas hidromórficas" (Br.), "Sols gris lateritiques" (Fr.) or "Plinthaquox" (Soil Survey Staff, 1996).

Concept and morphology. The concept of Plinthosols is one of soils affected, at present or in the past, by groundwater or stagnating surface water in which iron has been segregated to such an extent that a mottled layer has been formed which irreversibly hardens when exposed to the air and sunshine. Included in the concept are those soils that have such a hardened layer at shallow depth. Two types of iron components are important in Plinthosols:

> Plinthite. An iron-rich, humus-poor mixture of kaolinitic clay with quartz and other diluents; 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;
>
> 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 and generally show a low base saturation.

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 eluvic 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.

Linkages. Plinthosols dominantly occur in intertropical regions and, as such, have linkages with Ferralsols, Alisols, Acrisols and Lixisols. Apart from stony units, they exhibit both gleyic and stagnic properties, and are linked to Gleysols as well. Well-drained soils with loose ironstone concretions are frequent nearly everywhere in the tropics and subtropics, in many landscape situations; the material is the result of former plinthite formation, subsequent hardening, and transport or re-weathering. The soils concerned are geomorphologically related to Plinthosols, but pedo-morphometrically belongs to other soil classes. 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 and are usually freely drained.

The other Plinthosols, on the contrary, 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. Petric Plinthosols occur often 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.

Land use and management. The imperfectly drained soils with a plinthic horizon have poorer natural vegetation than geographically associated well-drained soils, for instance tree savanna or grassy savanna instead of closed-canopy high forest. Also, 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, including mining (for iron ore, manganese, bauxite) and building material (building block making, road building, terracing). Also 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 much welcomed by construction engineers.

6. SOILS CONDITIONED BY CLIMATE IN SUBHUMID FOREST AND GRASSLAND REGIONS

6.1 LUVISOLS

History, connotation and correlation. The name Luvisols was coined from the Latin 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. Moderate to high activity clays and low aluminium saturation further characterizes these soils. They are known as 'sols lessivés' in France, Parabraunerde in Germany, pseudo-podzolic soils in Russia, brown-brown podzolic soils in earlier USA terminology or as Alfisols (proparte) in USDA Soil Taxonomy. In the FAO legend they are called Luvisols (FAO).

The term 'podzolic' used for these soils, on account of the lighter coloured surface horizon, was particularly confusing, as the formation of these soils has no relationship to the process of podzolisation.

Concept and morphology. The characteristics used to define Luvisols are essentially the textural differentiation (presence of an argic horizon), the cation exchange capacity of the clay and the aluminium saturation. The genesis of an argic horizon in Luvisols is ascribed to eluviation and illuviation of clay occurring in the surface and subsurface horizons respectively.

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. Sedimentation 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 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 of more humid conditions.

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

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

Linkages. The argic horizon as described above is diagnostic for Luvisols but is not exclusive to them. Argic horizons are also diagnostic for the major soil groupings of Lixisols, Acrisols, Nitisols and Albeluvisols and occur in some Chernozems, Kastanozems, Phaeozems, Gypsisols, Calcisols and Arenosols. In these soils, however, other diagnostic horizons or properties occur which separate 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 as such and by itself a sufficiently diagnostic feature to characterize soils at the highest level of generalization.

Being a mineral soil having an argic horizon with a high cation exchange capacity and a relatively low aluminium saturation percentage in the B horizon, Luvisols differ from other soils in terms of texture, amount of clay increase, nature and thickness of the illuvial horizon and exchange characteristics. The differences between the Luvisols and most other major soil units can be deducted from the key to the units.

Luvisols are linked to a number of major soil groupings with which they share common properties or show characteristics less pronounced than in the major soil grouping to which the linkage exist.

The limit with Vertisols is determined 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 gley 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 argic horizon are not been met. 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. Typical examples in the Belgian loess 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 eluvic 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 volume percent. Chemically, most Luvisols do contain reserves of weatherable minerals; hence with balanced fertilizer applications good yields can be expected. Dystric Luvisols can give good crop yields provided the low pH is adjusted by liming.

6.2 PLANOSOLS

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, level 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 that of soils with a silty or loamy brown surface or shallow subsurface horizon showing signs of periodic wetness and overlying a dense subsoil horizon with 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 eluvic 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.

Properties. The soil structure of the eluvic 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. This explains waterlogging in the upper layers due to the slow permeability in the subsoil. Chemically Planosols are degraded: the cation exchange capacities of the clay fraction in the surface layers and eluvic horizons of Planosols are significantly lower than in the underlying horizons.

Geography. The main extents 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.

Linkages. 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 hill slopes adjoining river plains, 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 kinds, 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 brown or light brown, silty upper soil horizons of variable thickness abruptly overlying heavy clay, with silty material "etched in" along cracks into the underlying clayey material. Clay removal or clay destruction, or both, in former Vertisols when seasonal wetness of the climate increased, may thus have formed Planosols. 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 natural vegetation, which is adapted to seasonal waterlogging conditions such as herbaceous plants, or shallow rooting trees and shrubs.

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 to wetland rice. The dense layer 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 mineralised N for the crops; other plant nutrients, including K and Ca, are generally low as well. S deficiency has been observed in wetland rice on some Planosols. Plant nutrient management is more difficult than on better 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. Extremely developed Planosols may carry a very sparse savanna vegetation with scattered small trees, leaving much of the soil surface bare even where adjacent better (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 on mostly rainfed, bunded fields 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.

6.3 ALBELUVISOLS

History, connotation and correlation. Albeluvisols (from L. albus, white, and eluere, to wash out). The term is connotative of penetrations of clay and iron-depleted material into the underlying horizon. In the Legend and Revised Legend of the World Soil Resources Map (FAO, 1974) they are named Podzoluvisols. They correlate with the sols lessivés glossiques (CPCS, 1967) or Luvisols dégradés glossiques (AFES, 1990) 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, Ortho-Podzolic in Russia.

Concept and morphology. The central concept of Albeluvisols is that of soils with brown or bleached topsoil and an argic horizon whose upper boundary is irregular because of deep penetrations of a contrasting lighter coloured and coarser textured eluvic horizon. They develop mostly in unconsolidated quartz rich glacial till, or materials of glaciolacustrine, fluvial origin, or of aeolian origin. Most of these soils have a perched water table related to the period of snowmelt, or to a season with precipitation exceeding evapotranspiration. Albeluvic tongues have the colour of an albic horizon and the coarser texture of the related eluvic 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. In the forest areas of Western Europe, which have experienced little or no cattle grazing activities, root penetration and water percolation is limited to the albeluvic 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.

Properties. The litter layer on Albeluvisols under a forest cover is slowly to very slowly decaying. Burrowing animals of the macro- and mesofauna are scarce or completely absent. As a result there is very little mixing of the organic matter with the mineral soil and the humiferous surface horizon is often only a few centimetres thick. Wind-thrown trees may be the major bioturbation agent in these soils. When reduction through temporary saturation with groundwater is lacking, the eluvic horizon has pale brown to yellowish brown colours and a relatively large amount of roots. This horizon is also known as the "biologically active B horizon". Where the periodic saturation lasts for long periods, the eluvic horizon becomes bleached and discrete iron enriched nodules may form in the subsoil. When Albeluvisols are not cultivated they are acid to very acid (pH (H_2O) 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 area of the Albeluvisols can be split into two parts, each having a particular range of climatic conditions and presenting soils with a particular morphology.

Albeluvisols of the cold continental regions cover by far the largest area of Albeluvisols. 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 through the East European Plain until the footslopes of the Ural and then further 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 loess 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 Aquitaine and Paris Basin, respectively), central Belgium, south-eastern Netherlands and the western part of Germany. Albeluvisols here occur on loess 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 loess and coversand deposits and alluvial 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).

Linkages. The Albeluvisols have direct spatial links with Luvisols, Gleysols and Podzols. In the cold continental areas Albeluvisols border to the north and east with Podzols. In the transition zone between both soil types, a Podzol may develop in the strongly clay and iron depleted eluvic horizon overlying the argic horizon. Also 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 with Albeluvisols are now replaced by Luvisols as a direct and indirect result of anthropogenic activities. A direct impact is the erosion of the upper decimetres of the soil and the ploughing activity, 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 evolution also explains why Albeluvisols are mainly observed in forested areas.

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 springtime. This is why the Albeluvisols of the northern taiga zone are 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 is possible with summer wheat/barley, potatoes, sugar beets and forage maize.

6.4 PODZOLS

History, connotation and correlation. The name Podzols means 'soils with a subsurface horizon that has the appearance of ash due to strong bleaching by aggressive organic acids: from R. 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 B-horizons that are underlying the ash-brown eluvial horizon. The name 'Podzol' is therefore readily recognizable in many soil classification systems: Podzol in the European and Russian classification systems and Spodosol in USDA Soil Taxonomy, Podzol (FAO).

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 aluminium, 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 -, by quartzitic parent materials - quartzitic sands in western Europe or in the tropics - 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 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 cementation of the spodic horizon are adequate criteria to accurately identify cheluviation and to distinguish between more and less strongly expressed Podzols. In other materials, the morphology is less expressed (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 analytical characteristics of Podzols. The spodic horizon gets diffuse and fades out towards the groundwater table. Surface waters often get a black colour due to presence of mobile fulvic acids.

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. Clay percentage is often less than 10 percent. Accordingly, water retention capacity is low, less than 50 mm and, although podzols develop in 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 up to 5.5 in the lower horizons. The cation exchange capacity is mostly due to the organic compounds present 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 (C/N=20 or more), indicative of low biological activity and a slow process of 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 the USSR and in Canada south of Baffin Bay. Tropical Podzols occur extensively along the Rio Negro and in the Guyana's 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 were reported in western Zambia.

Linkages. 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. Cambisol-Podzol sequences are found on slopes developed in acid crystalline rock (granite) areas (old mountain areas). Podzols may be associated with Andosols in regions with volcanic ash covers.

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. Aluminium 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 practiced. However, more often Podzols are used for forestry, extensive (sheep) grazing or are left fallow.

7. SOILS CONDITIONED BY LIMITED AGE AND ONLY WEAK TO MODERATE SOIL DEVELOPMENT

7.1 CAMBISOLS

History, connotation and correlation. The name Cambisol comes from L. cambiare, to change, thus soils with beginning 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 the USDA Soil Taxonomy they were classified under the Inceptisols.

Concept and morphology. Cambisols represent soils, which show a minimum degree of soil development characterized by a certain development of their structure or by colours indicating moderately pronounced alteration and development features. Marks of alteration are evidenced by a recognizable soil structure, absence of rock structure, stronger chroma, redder hue or higher clay content with respect to the underlying layer(s). They do not have appreciable quantities of illuviated clay, organic matter, aluminium and/or iron compounds. Cambisols are generally considered as soils conditioned by a 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 major soil groups but there it is not a differentiating characteristic because other properties are given higher priority for example gleyic 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 not well possible to sum up all mineralogical, physical and chemical characteristics of Cambisols in one generalized account because Cambisols occur in such widely differing environments. However, most Cambisols contain at least some weatherable minerals in the silt and sand fractions. They occur in regions with a precipitation surplus but in terrain positions that permit surface discharge of excess water. Cambisols are medium textured and have good structural stability, high porosity, and good water holding capacity and good internal drainage. 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 the second largest major soil grouping of FAO's Revised Legend. Cambisols are particularly common in temperate and boreal regions, which were under the influence of ice during recent glacial periods, partly because the soil parent's 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), while moderate weathering and absence of clay migration due to 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. They are further widespread in areas with active geologic erosion. Cambisols are also quite frequent in arid climates.

Linkages. The wide variation among Cambisols is perhaps best illustrated by mentioning 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 at all, 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 that do no 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 Cambisols 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 withLuvisols, Acrisols and Plinthosols.

Land use and management. Management of Cambisols largely depends on climate. Since they occur in areas of rather contrasting endowment (permafrost, arid zones, humid tropics) it is difficult to give a general assessment. On the whole, 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 and forestland. 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 and they have a higher cation exchange capacity. The Cambisols of the alluvial plains under paddy rice are highly productive soils.

7.2 CRYOSOLS

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-Duff) 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 Gelisol Order will encompass the Cryosols. In the FAO/Unesco legend they came at second level as gelic subgroups of other Reference Soil Groups. Only recently the importance Cryosols was recognized for their role in global climate equilibrium 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, which consist of repeated cycles 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 freeze-back, the freezing portion 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 also responsible for the development of blocky structures in these soils, while the 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 merge results in soil compaction. Cryoturbation (frost churning) is the process which mixes soil matrix within the soil, resulting in broken 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 soil materials from fine 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 Cryosol platy and blocky macrostructures 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 alkalinisation occur due to accumulation of soluble salts 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 broken soil horizons and oriented stones in the soil and sorted and nonsorted 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 higher ice content than do coarse- textured soils. Cryosols soils 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 meters. Soil texture is one of the factors controlling ice content in mineral soils. Fine textured Cryosols have 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 lies above the permafrost table that is subject to annual thawing and refreezing. 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 17.7x 106 km2 and occur in the Arctic, Antarctic, Subantartic and Boreal regions under cold continental, subhumid 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 mountainous regions such as the Rockies (North America), Andes (South America), Himalayas (Asia) and Alps (Europe).

Linkages. 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 north-facing slopes, while on south-facing slopes Cryosols may be associated with non-permafrost soils (Tarnocai et al., 1993).

Land use and management. Cryosols support unvegetated 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). Cryosolic soils not only support the biological life 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 off or removed and, in most cases, the damage is confined to the loss of a small amount of topsoil or reduction in the soil carbon. For Cryosolic soils, however, removal of the surface peaty layer or vegetation and disturbance of soil materials often leads to drastic and rapid environmental change, with possible resultant damage to 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 both the vast northern areas of Asia and in northern Europe. In some of these areas, especially in 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 drastic thermokarsting on land cleared for agriculture. Improper management of pipelines and mining can cause both serious damage to the soil and very serious and long-lasting pollution.

7.3 UMBRISOLS

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 categorical levels within both the 1988 Revised Legend (FAO-Unesco-ISRIC, 1990) (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, 1990).

The objective in separating a major 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 125 cm below the surface). The main characteristic used to recognize and define Umbrisols is the presence of an umbric 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 artefacts, 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.

Linkages. 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 conditions and depend on the interaction between the age of the landscape and local conditions.

In the coolest and/or wettest areas, the youngest land surfaces will have Regosols and Leptosols, sloping surfaces of intermediate age will haveUmbrisols 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.

Probably the most problematic set of linkages results from human activities. 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 125 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 anthric plaggen or terric horizons. Thus in 'marginal' agricultural landscapes, a complex mosaic of linkages between Umbrisols, Phaeozems and Anthrosols are likely to exist, along with the other linkages previously described.

8. SOILS CONDITIONED BY ORGANIC SOIL MATERIALS

8.1 HISTOSOLS

History, connotation and correlation. The major 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), Bog soils (former USSR).

Concept and morphology. Histosols are unlike all other soils in that they are 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. Among the mechanical, physical and chemical properties of Histosols, specific density and volume density of the material are of particular importance. 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 retains 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), while extremely acid Histosols with a pH of less than 2 may occur where peat containing pyritic material have been drained for agricultural use. Generally eutrophic basin peat is 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 mountain areas, and one-sixth in the tropical lowlands. Histosols dominate in Northern Finland, Western Scotland, central Canada and south Baffin Bay, and east of the Ural Mountains, and occur in association with other ill-drained soils, mainly Gleysols in Alaska and the whole northern part of the former USSR. Some 20 million hectares of acid forest peat border the Sunda Flat in Southeast Asia.

Linkages. Histosols over permafrost occur mainly in boreal regions. Their high organic matter content results from the slow decay of organic debris, in the cold season caused by frost and in the summer because of waterlogging of the thawed surface soil. 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 unless artificially drained ('low moor peat') 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 of which the water regime is conditioned by high precipitation unless artificially drained ('high moor peat') 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 Flat), 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 soil groups, including Andosols, Podzols, Fluvisols, Gleysols, Cambisols and Regosols.

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 matrix 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. These reclamative 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. In addition to this 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 when sulfidic materials occur at shallow depth. They offer some potential for arable cropping or for horticulture, subject to judicious plant nutrition management including liming, NPK fertilizers and micronutrients. Peat lands are used for various forms of extensive forestry and/or grazing or lay idle. Deep peat formations are best left untouched.

9. SOILS CONDITIONED BY MAN

9.1 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, 1990), 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 to develop a genetic classification for the former USSR recognize several types of anthropogenic soils (agrozems, 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 anthropedogenic processes to the extent that the original soil is no longer recognizable or remains only as a buried soil. Several distinct anthropedogenic processes have been recognized, including deep working, application of plaggen manure, additions of extraneous materials, irrigation with sediment-rich waters, and longstanding paddy cultivation. Anthrosols are usually found in areas of old cultivation. The human influence is mostly restricted to the surface horizons. A buried soil can still be intact at some depth and testify of soil conditions as existed before the land was modified.

A special case of Anthrosols is the Fimic Anthrosols or the Plaggen soils. They consist of a thick humus-rich man-made 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 high phosphate content. Calculations indicate that the thickest plaggensoils 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 anthric 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 favorable physical properties (well structured, high porosity, high water retention capacity).

Geography. They 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 Southeast Asia. Minor areas occur in every country of the world, e.g. the 'Terra Preta do Indio' in the Amazon.

Linkages. Anthrosols are likely to border most of reference major soil groups where soils have been strongly influenced by man. Linkages between other major soil groups and Anthrosols are likely to reveal the genesis of these anthropogenic soils and their place in the soil cover.

Land use and management. Since characteristics of Anthrosols are very variable in properties and requirements, no generalized account of their management can be given. The so-called plaggen soils of Western Europe are among the more favourable ones, where with the good drainage and dark colour of the surface soil it is possible to till and sow early in the season. Traditionally European Anthrosols were grown to winter rye, oats, barley and tobacco. Now they are used for forage maize, potatoes, horticultural crops, and tree nurseries and for pastureland.

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