# ALISOLS (AL)

The Reference Soil Group of the Alisols comprises strongly acid soils that have accumulation of high activity clays in the subsoil. They occur in humid (sub-)tropical and warm temperate regions, on parent materials that contain a substantial amount of unstable Al-bearing minerals. Ongoing hydrolysis of these minerals produces aluminium, which occupies more than half of the cation exchange sites. Hence, Alisols are unproductive soils under all but acid-tolerant crops. Internationally, Alisols correlate with 'Red Yellow Podzolic Soils' that have high-activity clays (Brazil), 'Ultisols' with high-activity clays (USA Soil Taxonomy) and with 'Fersialsols' and 'sols fersiallitiques très lessivés (France).

## Definition of Alisols

Soils having

1 an argic horizon, which has a cation exchange capacity (by 1 *M* $NH_4OAc$ at pH 7.0) of 24 cmol(+) $kg^{-1}$ clay or more, either starting within 100 cm from the soil surface, or within 200 cm from the soil surface if the argic horizon is overlain by loamy sand or coarser textures throughout, **and**

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

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

Common soil units:

Vertic, Gleyic, Andic, Plinthic, Nitic, Umbric, Arenic, Stagnic, Abruptic, Humic, Albic, Profondic, Lamellic, Ferric, Skeletic, Hyperdystric, Rhodic, Chromic, Haplic.

## Summary description of Alisols

*Connotation:* strongly acid soils with subsurface accumulation of high activity clays that have more than 50 percent $Al^{3+}$ saturation; from L. aluminium, alum.

*Parent material:* Alisols can form in a wide variety of parent materials having high-activity clay minerals such as vermiculite or smectite. Most occurrences of Alisols reported so far are on weathering products of basic rocks.

*Environment:* most common in old land surfaces with a hilly or undulating topography, in humid (sub-)tropical and monsoon climates.

*Profile development:* ABtC-profiles. Variations among Alisols are mostly related to truncation of A-horizons in eroded lands.

*Use:* Alisols contain low levels of plant nutrients (except for $Mg^{2+}$ in some cases) whereas soluble inorganic Al is present in toxic quantities. If liming and full fertilization is no option, use of these soils is generally restricted to crops, which accommodate with low nutrient contents and tolerate high levels of free Al. Alisols are traditionally used in shifting cultivation and for low volume production of undemanding crops. In the past decades, Alisols have increasingly been planted to Al-tolerant estate crops such as tea and rubber, and also to oil palm.

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## Regional distribution of Alisols

Major occurrences of Alisols are found in Latin America (Ecuador, Nicaragua, Venezuela, Colombia, Peru, Brazil), in the West Indies (Jamaica, Martinique, St. Lucia), in West Africa, the highlands of Eastern Africa, Madagascar and in southeast Asia and northern Australia. See Figure 1. Driessen and Dudal (1991) estimate that about 100 million ha of these soils are used for agriculture in the tropics. Alisols occur also in subtropical and Mediterranean regions: they are found in China, Japan and the South Eastern USA and minor occurrences have been reported from around the Mediterranean Sea (Italy, France, and Greece).

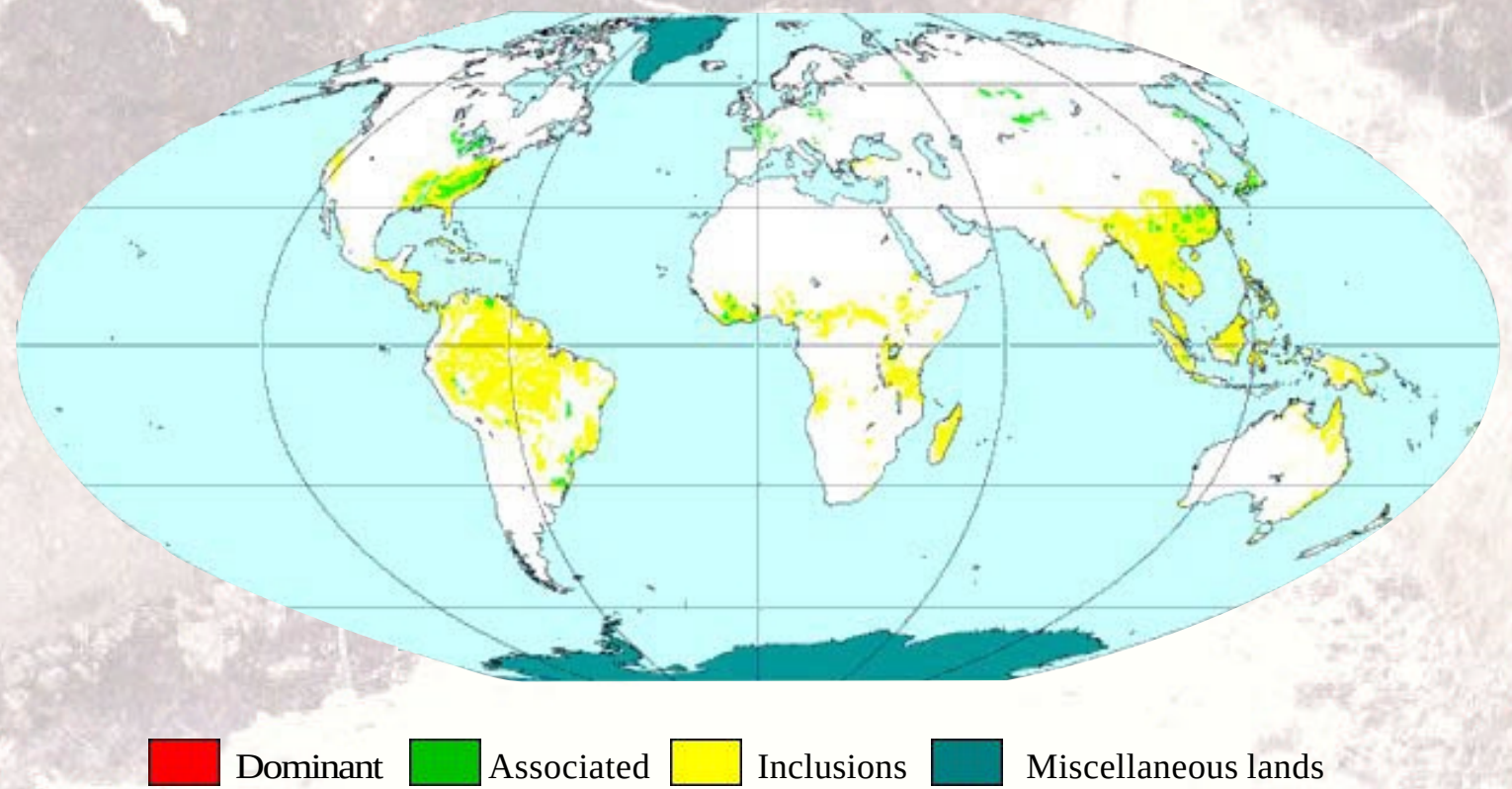


**Figure 1**. Alisols worldwide.

## Associations with other Reference Soil Groups

Alisols have their argic horizon in common with Acrisols, Lixisols, Luvisols and Albeluvisols. They differ from Acrisols and Lixisols because these soils lack high activity clays and from Luvisols because Luvisols lack 'alic' soil properties. Alisols are less weathered than 'typical red tropical soils' such as Ferralsols and Nitisols. In the landscape, Alisols can be associated with Gleysols and all the major soil groupings mentioned above, except Albeluvisols.

*In the humid tropics*, Alisols can be found on slopes where smectitic saprolithes outcrop; Acrisols or Lixisols and possibly Nitisols or Ferralsols are dominant on plateaus (West Africa, West Indies). Alisols in sloping land can also be see alongside Cambisols (e.g. in the foothills of the Andes). In flat and level terrain, Alisol-Acrisol patterns reflect the lithological nature of the dominant parent material (Amazon region, Colombia).

*In tropical and subtropical regions* with distinct wet and dry seasons, Alisols occur alongside Luvisols in sloping areas and together with Vertisols (Kenya, Somalia) or Gleysols (Southeast USA) in depression areas. Alisols in regions with warm, wet summers and cold, dry winters are associated with Cambisols, notably on eroding steep slopes in hilly areas (South Eastern China).

*In Mediterranean areas*, Alisols have been found in old river terraces; their occurrence is probably associated with wetter climate conditions in a distant past. Alisols may also occur on slopes that are exposed to frequent rain bearing winds.

## Genesis of Alisols

Alisols may form where ongoing hydrolysis of secondary high-activity clay minerals such as vermiculite and smectite, produces much inorganic Al. In practice, Alisol formation is confined to environments where most weatherable primary minerals have disappeared and secondary high-activity clays dominate the clay complex. Where these materials outcrop, for instance in hilly topography, the secondary high-activity minerals weather under humid conditions with intense leaching of silica and alkaline and alkaline-earth cations.

The genesis of Alisols involves three distinct steps:

1 The first step involves transformation and/or hydrolysis of primary weatherable minerals in the parent rock and moderate leaching of silica. These processes produce a saprolith with little weatherable primary minerals and a dominance of secondary high-activity clays formed by transformation of micas. The high-activity clays are predominantly smectites in basic and intermediate rocks such as basalt and andesite and of the vermiculite type in more siliceous rocks such as granite, gneiss and schist.

2 The second step involves redistribution of clay in the soil and accumulation in an argic horizon. Such redistribution can be vertical migration of clay particles (clay illuviation) and/or lateral clay transport. Note that fine clay particles can move only under mild acid conditions, say in the pH range from pH 5 to pH 6.5. At lower pH, $Al^{3+}$ ions become dominant on the exchange complex because $Al^{3+}$ is preferentially adsorbed over divalent and monovalent cations. Al-saturation may then keep the clay flocculated and impede dispersion. This prompted some authors to suggest that argic horizons in strongly weathered soils in the wet tropics are relics from earlier soil genesis involving clay illuviation. Textural differentiation could also have been brought about by lateral transport of clay and/or by weathering of clay in the topsoil; this latter process seems to be prominent in most Alisols. Note also that many Alisols on slopes in (sub)tropical areas became truncated; former subsoil horizons with clay illuviation now outcrop at the soil surface.

3 The third step involves weathering of secondary high-activity clay; this step may overlap with clay redistribution as suggested above. High-activity clays are unstable in environments depleted of silica and alkaline and alkaline-earth cations. Their weathering liberates soluble inorganic aluminium and - on basic parent materials - iron and magnesium from the octahedral inner layers of the (2:1) clay minerals. Iron oxides explain the reddish colour of some Alisols, e.g. the Rhodic Alisols in the Caribbean region. Figure 2 shows the relation between KCl-extractable Al and the cation exchange capacity (CEC), both expressed in cmol(+) $kg^{-1}$ clay. The data were collected from ferralic and argic subsurface horizons in acid ($pH_{KCl} < 4.0$) Ferralsols, Acrisols and Alisols from Indonesia, the Caribbean region, Rwanda, Cameroon, Peru and Colombia.

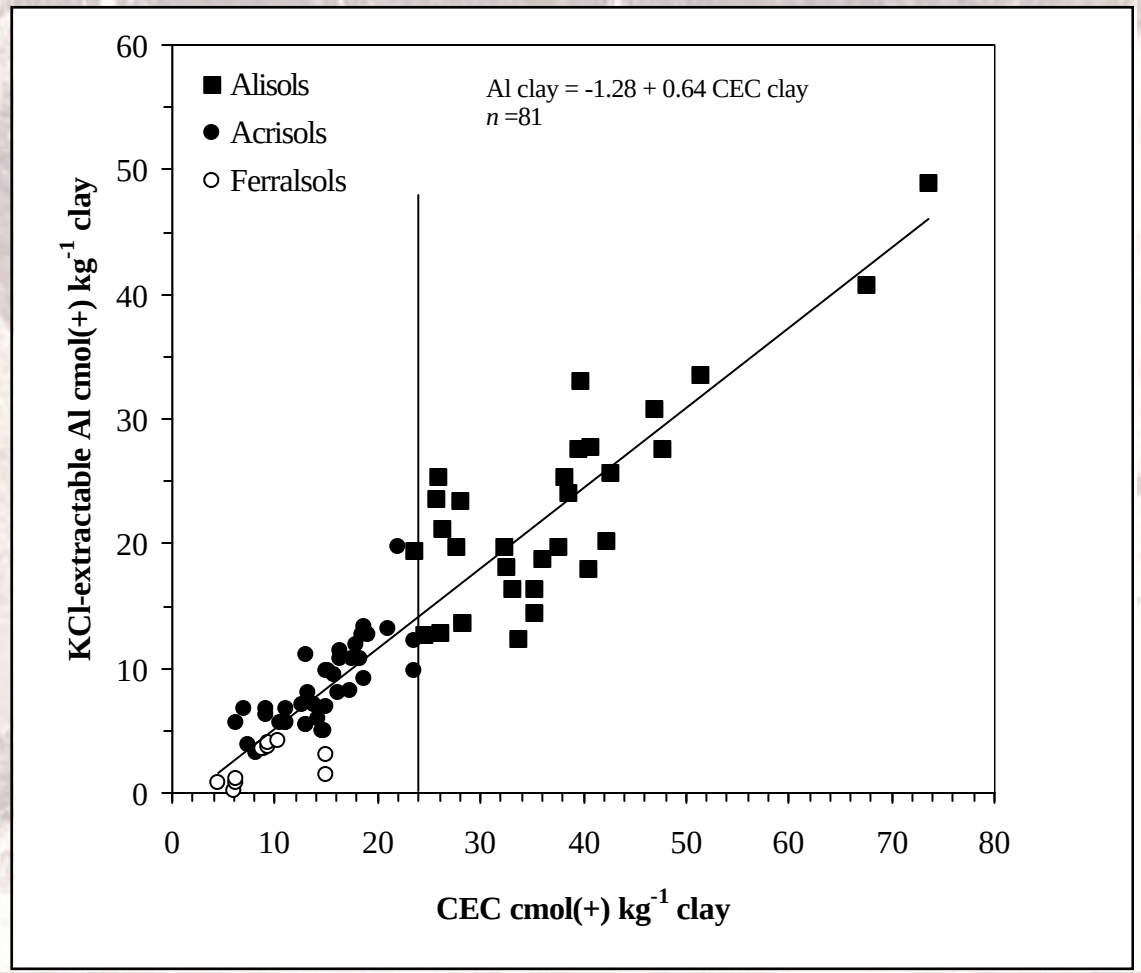


**Figure 2.** Consistent, strong and positive correlation of KCl-extractable Al and CEC-clay is found in acid Ferralsols, Acrisols and Alisols from all over the world.

The correlation of KCl-extractable Al and CEC-clay documented by Figure 2 supports the following statements.

1 Weathering clay minerals determine the content of KCl-extractable aluminium in strongly weathered acid soils in the (sub-)tropics. Consequently the hazard of Al-toxicity increases from acid Ferralsols to Acrisols and Alisols. Low pH-KCl values have implications in terms of Al-saturation that differ by soil type.

2 The exchange properties of the clay fraction (CEC-clay) reflect the content of high-activity clays and are a useful indicator of the degree of soil weathering.

3 Exceptionally high levels of KCl-extractable Al ($\geq$ 12 cmol(+) $kg^{-1}$ clay) occur in Alisols; this sets them apart from strongly acid Ferralsols and Acrisols.

Weathering processes affect the clay mineralogy of soils; the mineral assemblage of Alisols appears to be in a state of transition from 'bisiallitic' high-activity clays to 'fermonosiallitic' material that is rich in iron oxides and kaolinite. The content of iron oxides is largely dictated by the composition of the parent rock, notably its content of primary ferromagnesium silicates. The transitional character of Alisol clay mineralogy is further evidenced by:

- kaolinite-smectite mixed-layer clay minerals found in some Rhodic Alisols (West Indies, Kalimantan);
- Al-hydroxy-interlayered smectite and vermiculite found in some Haplic Alisols (China) and in Rhodic Alisols (West Indies).

Al-hydroxy-interlayered 2:1 clay minerals resemble the mineralogical structure of 1:1 clay minerals in the sense that their structural layer is of the 1:1:1:1 type, with alternating octahedral and tetrahedral sheets. Their stability in soil environments is indeed similar to that of kaolinite.

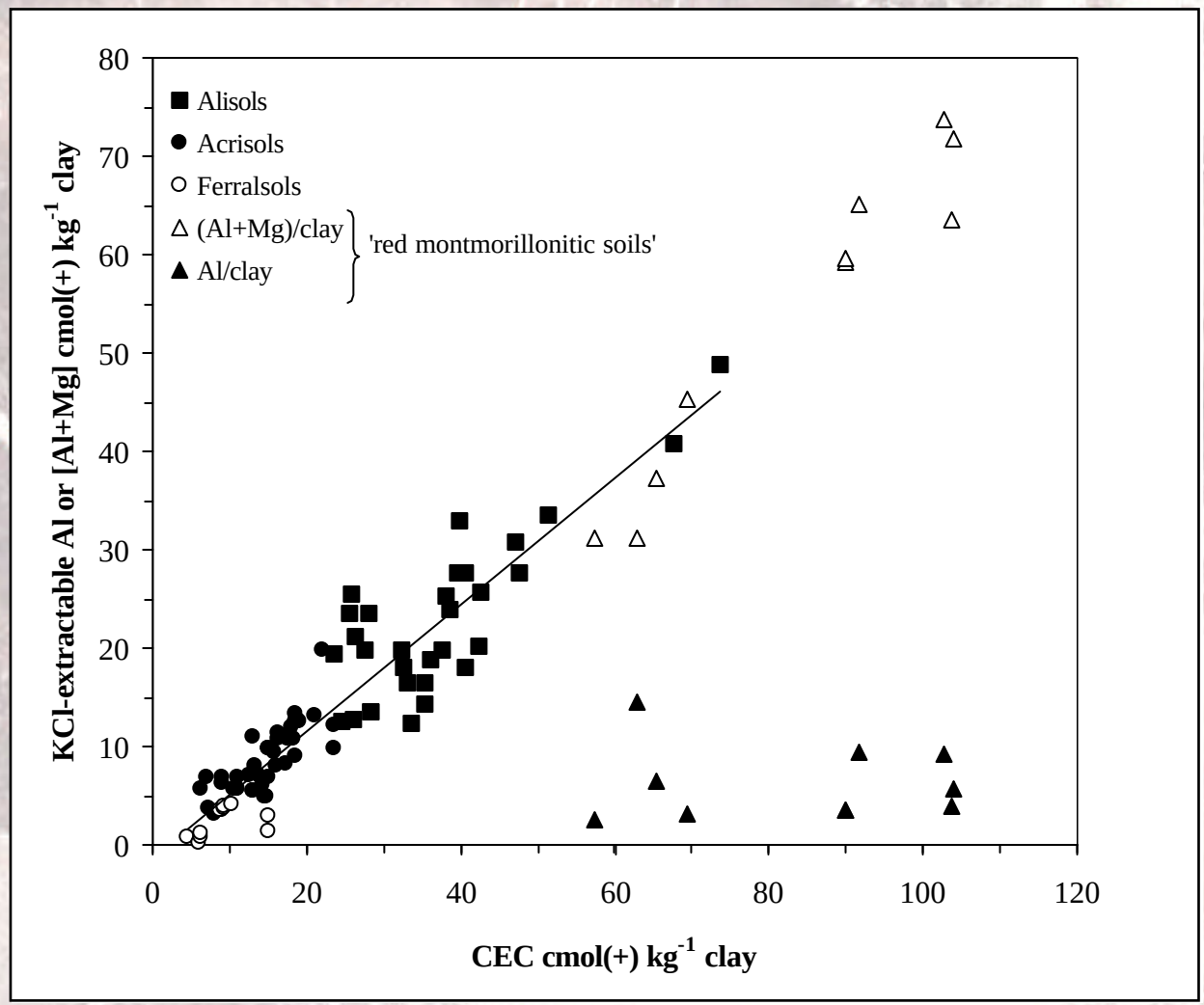


**Figure 3.** KCl-extractable Al and/or [KCl-extractable Al + exchangeable Mg] correlate with CEC-clay in tropical soils with pH-KCl values less than 4.0.

Figure 3 further illustrates how release of octahedral Al from 2:1 layer silicates contributes to the development of alic soil properties. Figure 3 is an extended version of Figure 2; it considers additional data from strongly acid soils with smectite. These acid soils developed in weathering material of basic rock and are rich in octahedral Mg. These 'red montmorillonitic soils' (from Martinique) contain much smectite clay and free iron oxides (hematite) and are red indeed: Munsell hues of 2.5 YR and 10R are common. They contain less than 12 cmol(+) KCl-extractable Al per kg clay even though the CEC-clay exceeds 55 cmol(+) $kg^{-1}$. However, considering the relation between (Al + Mg) and CEC-clay produced the strong positive correlation of Figure 2. This suggests that release of octahedral Al and Mg from weathering high-activity clay conditions saturation of the exchange complex in these soils. Note that these strongly acid soils with considerable Mg-saturation are not Alisols; they would rather key out as Eutric Cambisols.

Alic soil properties may have an impact on the transformation of humus. It was observed in forest areas with Alisols in Kalimantan (Indonesia) that humus readily accumulates, possibly because biological activity is retarded by Al having a toxic effect on soil organisms.

# Characteristics of Alisols

***Morphological characteristics***

Most Alisols have an ochric surface horizon but darker umbric horizons can be expected under forest. Soil structure is rather weak in the surface horizon because biological activity is hindered by strong acidity. The surface horizon overlies a dense argic subsurface horizon that may hinder deep percolation of water. The structure of the argic horizon is clearly more stable than that of the surface soil. The expression of soil structure varies between soils with the relative contents of high-activity clays and free iron.

***Mineralogical characteristics***

Secondary clay minerals dominate the mineral assemblage of Alisols. Note however that the proportions of low- and high-activity clays vary between soils or between soil horizons because the clay is in a state of transition. Weathering high-activity clays release considerable quantities of Al; at the same time the content of kaolinite increases and CEC decreases. Strong adsorption of $Al^{3+}$ by high-activity clays counteracts formation of gibbsite ($Al_2O_3.3H_2O$). The content of free iron oxides varies between Alisols depending on the nature and weathering stage of the parent material. The sand fraction is made up of (weathering-resistant) quartz and the silt content is small.

***Physical characteristics***

The physical characteristics of Alisols are directly related to the relative contents of high-activity clays, low-activity clays and iron oxides. Where swelling and shrinking clays dominate the mineral assemblage, specific physical features may develop that resemble elements of ‘vertic’ horizons. Telltale signs are: distinct cracks, rapid bypass flow of water in dry soil and slow infiltration of water in wet soil, shining faces on peds, prismatic structure of the subsurface horizon and generally few macro-pores. Such Alisols have CEC-clay values in excess of above 50 cmol(+) $kg^{-1}$. Alisols in weathering materials from basic rock tend to have higher contents of iron oxides and stable structures, particularly in the subsurface horizon.

In many Alisols, textural differentiation between surface and subsurface horizons imparts different physical properties. Surface horizons tend to have an unstable structure (slaking!) and reduced permeability, in particular where the subsurface horizon is dense and massive as is the case in Alisols that have relatively low contents of high activity clays and iron oxides. This restricts internal soil drainage and increases the danger of erosion in sloping lands. In cropped lands, the low level of biological activity, a direct consequence of the acid and nutrient-poor environment, further enhances the adverse physical properties of the surface horizon.

***Chemical characteristics***

Ongoing weathering of high-activity Al-bearing clay leads to severe chemical infertility: Al and possibly Mn are present in toxic quantities whereas levels of other plant nutrients are low and unbalanced. However, the fact that Alisols have favourable cation exchange properties makes some Alisols productive under intensive management with adequate liming and application of manure and fertilizers. The mineral reserves of Alisols are conditioned by the clay fraction and depend largely on the composition of high-activity clays that act as weatherable minerals in the system. In most Alisols, these reserves are particularly low in Ca and K. Low pH and presence of large quantities of iron oxide may induce P-immobilization, but much less than in Acrisols and Ferralsols. The organic matter content of cultivated Alisols is usually modest, in contrast with Alisols under natural forest.

## Management and use of Alisols

Alisols occur predominantly on old land surfaces with hilly or undulating topography. The generally unstable surface soil of cultivated Alisols makes them susceptible to erosion; truncated soils are quite common. Toxic levels of aluminium at shallow depth and poor natural soil fertility are added constraints. As a consequence, many Alisols allow only cultivation of shallow-rooting crops and these suffer from drought stress during the dry season. By and large, Alisols are unproductive soils. Their use is generally restricted to acidity-tolerant crops or low volume grazing. The productivity of Alisols in subsistence agriculture is generally low as these soils have a limited capacity to recover from chemical exhaustion. If fully limed and fertilized, crops on Alisols may benefit from the considerable cation exchange capacity and rather good water holding capacity. Alisols are increasingly planted to aluminium-tolerant estate crops such tea and rubber but also to oil palm and in places to coffee and sugar cane.