

## FERRALSOLS (FR)

The Reference Soil Group of the Ferralsols represents the 'classical', deeply weathered, red or yellow soils of the humid tropics. These soils have diffuse horizon boundaries, a clay assemblage dominated by low activity clays (mainly kaolinite) and a high content of sesquioxides. Local names usually refer to the colour of the soil. Internationally, Ferralsols are known as Oxisols (Soil Taxonomy, USA), Latosols (Brazil), Sols ferralitiques (France), Lateritic soils, Ferralitic soils (Russia) and Ferralsols (FAO).

### Definition of Ferralsols

#### Soils

- 1 having a [ferralic](#) horizon at some depth between 25 and 200 cm from the soil surface, **and**
- 2 lacking a [nitic](#) horizon within 100 cm from the soil surface, **and**
- 3 lacking an [argic](#) horizon that has 10 percent or more water-dispersible clay within 30 cm from its upper boundary **unless** the soil material has [geric](#) properties or contains more than 1.4 percent organic carbon.

#### *Common soil units:*

[Gibbsic](#), [Geric](#), [Posic](#), [Histic](#), [Gleyic](#), [Andic](#), [Plinthic](#), [Mollic](#), [Acric](#), [Lixic](#), [Umbric](#), [Arenic](#), [Endostagnic](#), [Humic](#), [Ferric](#), [Vetic](#), [Alumic](#), [Hyperdystric](#), [Hypereutric](#), [Rhodic](#), [Xanthic](#), [Haplic](#).

## Summary description of Ferralsols

*Connotation:* red and yellow tropical soils with a high content of sesquioxides; from L. ferrum, iron and aluminium, alum.

*Parent material:* strongly weathered material on old, stable geomorphic surfaces; more in weathering material from basic rock than in siliceous material.

*Environment:* typically in level to undulating land of Pleistocene age or older; less common on younger, easily weathering rocks. Perhumid or humid tropics; minor occurrences elsewhere are considered to be relics from past eras with a wetter climate than today.

*Profile development:* ABC-profiles. Deep and intensive weathering has resulted in a residual concentration of resistant primary minerals alongside sesquioxides and well-crystallized kaolinite. This mineralogy and the low pH explain the stable microstructure (pseudo-sand) and yellowish (goethite) or reddish (hematite) soil colours.

*Use:* Ferralsols have good physical properties but are chemically poor. Their low natural fertility and tendency to 'fix' phosphates are serious limitations. In natural systems, the limited stock of plant nutrients is in a constant process of 'cycling' with most nutrients contained in the biomass. Many Ferralsols are (still) used for shifting cultivation. Liming and full fertilization are required for sustainable sedentary agriculture.

## Regional distribution of Ferralsols

The worldwide extent of Ferralsols is estimated at some 750 million hectares, almost exclusively in the humid tropics on the continental shields of South America (Brazil) and Africa (Zaire, southern Central African Republic, Angola, Guinea and eastern Madagascar). Outside the continental shields, Ferralsols are restricted to regions with easily weathering basic rock and a hot and humid climate, e.g. in southeast Asia. See Figure 1.



 Dominant  Associated  Inclusions  Miscellaneous lands

**Figure 1.** Ferralsols worldwide.



## Associations with other Reference Soil Groups

Ferralsols tend to occupy the upper portions of stable land surfaces in the humid tropics where they occur alongside [Acrisols](#) (in lower positions or on more acidic parent rock such as gneiss) or [Nitisols](#) that evolved on top of more basic rock such as dolerite. Clear zonality of Ferralsols and Acrisols exists on a continental scale. Ferralsols are dominant in (humid) Central Africa with Acrisols occurring in the sub-humid periphery of the Ferralsol area, extending into West and East Africa. In South America, Ferralsols are prevalent in the more humid eastern Amazon Basin and Acrisols in the western Amazon.

## Genesis of Ferralsols

Water affects primary minerals through the processes of 'hydration' and 'hydrolysis'.

- *hydration* is water absorption by solid particles.
- *hydrolysis* is the process of H<sup>+</sup>-ions penetrating minerals such as feldspars, which then release bases (K, Na, Ca, Mg). Hydrolysis weakens the structure of the minerals because the hydrogen ion is much smaller than the cations it replaces. Dissolution of Si and Al are accelerated in the process.

'*Ferralitization*' is hydrolysis in an advanced stage. If the soil temperature is high and percolation intense (humid climate!), all weatherable primary minerals will ultimately dissolve and be removed from the soil mass. Less soluble compounds such as iron and aluminium oxides and hydroxides and coarse quartz grains remain behind. Ferralitization (or '*desilication*' as it is also called) is furthered by the following conditions:

- 1 *Low soil-pH and low concentrations of dissolved weathering products* in the soil solution promote desilication and build-up of high levels of (residual) Fe and Al. CO<sub>2</sub> in the soil (from respiration by roots and soil organisms feeding on organic matter) and percolating rainwater depress the pH of the soil and lower the concentrations of weathering products.
- 2 *Geomorphic stability* over prolonged periods of time is essential. Ferralitization is a very slow process, even in the tropics where high temperatures increase reaction rates and solubility limits. *Note that* old erosion surfaces are more common in the tropics than in temperate regions where recent glacial processes shaped the landscape.
- 3 *Basic parent material* contains relatively much iron and aluminium in easily weatherable minerals, and little silica. Ferralitization proceeds much slower in acidic material that contains more quartz. Even though most silica is leached from the soil (hence '*desilication*'), the silica content of the soil solution remains higher than in soils in basic material. This silica combines with aluminium to the 1:1 clay mineral kaolinite ('*kaolinitization*'), in particular where internal drainage is impeded and dissolved silica is less quickly removed (see [Table 1](#)).

**Table 1.** Schematic occurrence of gibbsite ( $\text{Al}(\text{OH})_3$ ) and kaolinite in strongly weathered soils with various drainage conditions.

Parent Material	Internal drainage			
	very good	good	moderate	poor
Mafic ('basic') rock	gibbsite	gibbsite	kaolinite	2:1 clays
Felsic ('acidic') rock	gibbsite	kaolinite	kaolinite	kaolinite

Ferrihydrite ( $\text{Fe}(\text{OH})_3$ ; see also the chapter on Andosols) is a common weathering product of iron-rich parent material. Hematite ( $\text{Fe}_2\text{O}_3$ , the mineral that gives many tropical soils their bright red colour) forms out of ferrihydrite if:

- 1 the iron concentration is high, **and**
- 2 the organic matter content is low (Fe-humus complexes inactivate Fe !), **and**
- 3 the temperature is high (accelerates dehydration of ferrihydrite and decomposition of organic matter), **and**
- 4 the soil-pH is above 4.0 (else  $\text{Fe}(\text{OH})_2^+$ -monomers are formed).

Goethite ( $\text{FeOOH}$ , more orange in colour than bright red hematite) is formed when one or more of the above conditions are not (fully) met.

## Characteristics of Ferralsols

### *Morphological characteristics*

Ferralsols are deep, intensely weathered soils. By and large, Ferralsols have the following characteristic features:

- 1 a deep solum (usually several meters thick) with diffuse or gradual horizon boundaries.
- 2 a '[ferralic](#)' subsurface horizon, reddish (hematite) or yellowish (goethite) in colour, with weak macro-structure and strong microstructure ('pseudo-silt' and 'pseudo-sand') and friable consistency. Soils with 60 percent or more clay 'feel loamy' and have similar pore volume and mechanical properties as medium or even light-textured soils.
- 3 deep internal drainage and absence of conspicuous mottles.

### *Mineralogical characteristics*

Ferralsols are characterized by relative accumulation of stable primary and secondary minerals; easily weathering primary minerals such as glasses and ferro-magnesian minerals and even the more resistant feldspars and micas have disappeared completely. Quartz is the main primary mineral (if originally present in the parent rock). The clay assemblage is dominated by kaolinite, goethite, hematite and gibbsite in varying amounts, in line with the kind of parent material and the drainage conditions (see also [Table 1](#)).

### *Hydrological characteristics*

Most Ferralsols are clayey (a consequence of advanced weathering) and have strong water retention at permanent wilting point while the presence of micro-aggregates reduces moisture storage at field capacity. This explains their rather limited capacity to hold 'available' water (i.e. available to most crops); some 10 mm of 'available' water per 10 cm soil depth is a rule of thumb. Ferralsols are poorly equipped to supply crops with moisture during periods of drought, particularly those in elevated positions.

### ***Physical characteristics***

Stable micro-aggregates explain the excellent porosity, good permeability and favourable infiltration rates measured on Ferralsols. Soils with high contents of (positively charged) iron oxides and (negatively charged) kaolinite have stable soil structure due to bonding of opposite elements. Ferralsols with low contents of iron and/or organic matter as occur in Surinam and Brazil ([Xanthic](#) Ferralsols) have less stable structure elements, especially the sandy ones. Surface sealing and compaction become serious limitations if such soils are taken into cultivation.

The strong cohesion of (micro-)aggregates and rapid (re)flocculation of suspended particles complicate measurements of the particle size distribution in Ferralsol material. The clay content found after the removal of iron and addition of a peptising agent is known as the 'total clay' content. The clay content found after shaking an aliquot of soil with distilled water (without removal of iron or addition of dispersion agents) is the 'natural clay' content. The high degree of aggregation in ferralic subsurface horizons explains the low content of natural clay (< 10 percent).

### ***Chemical characteristics***

Ferralsols are chemically poor soils. The types and quantities of clay minerals, oxides and organic matter condition the exchange properties of soils. The total exchange capacity is composed of a permanent and a variable component:

- The '*permanent charge*' component is the result of isomorphic substitution, e.g. of  $\text{Si}^{4+}$  by  $\text{Al}^{3+}$  or  $\text{Al}^{3+}$  by  $\text{Mg}^{2+}$ , in the crystal lattices of clay minerals. The *negative* permanent charge is independent of soil-pH or ion concentrations of the soil solution. Kaolinite, the main clay mineral in Ferralsols, has only a very small permanent charge.
- The 'variable charge' component is caused by:
  - 1 '*dissociation of  $\text{H}^+$ -ions*' from molecules at the periphery of the exchange complex. Dissociation of  $\text{H}^+$ -ions creates negative exchange sites and is strongest at high concentrations of  $\text{OH}^-$  in the soil solution. It accounts for the '*pH-dependent*' component of the overall Cation Exchange Capacity (CEC).



- 2 'protonation', i.e. release of protons ( $H^+$ ) by acid groups at the edges of clay particles, or by carboxylic or phenolic groups in organic matter, or by aluminium and iron hydroxides. Protonation contributes to positive charge component.

The CEC of a ferrallic horizon may, by definition, not exceed 16 cmol(+)/kg clay. Note that CEC is determined in a 1M  $NH_4OAc$  solution buffered to pH 7; the field-pH of Ferralsols is normally much less than 7.

The net negative charge of the exchange complex is neutralized by exchangeable bases ( $Na^+$ ,  $K^+$ ,  $Ca^{2+}$ ,  $Mg^{2+}$ ) **plus** 'exchangeable acidity' ( $Al^{3+} + H^+$ ). The 'Effective CEC' (ECEC), i.e. the sum of bases and exchangeable acidity, is thought to represent the cation exchange capacity at field conditions.

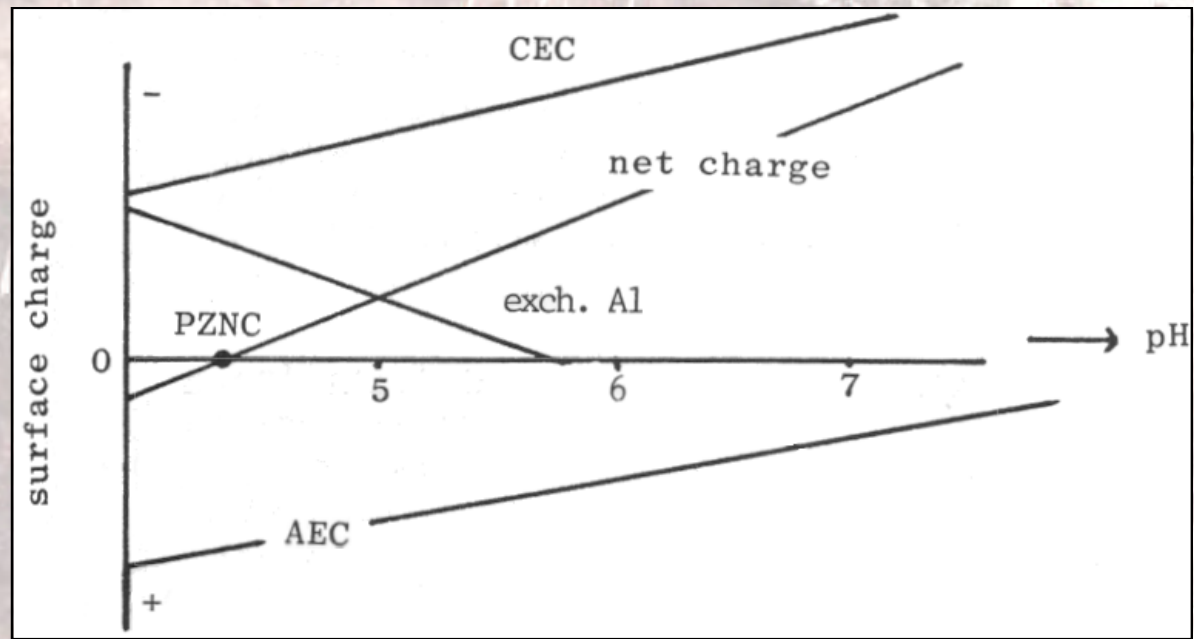
Note that the ECEC of Ferralsols is much less than the CEC; actual cation adsorption is often a mere 3 or 4 cmol(+) per kg soil.

Protonation of hydroxylic groups at low pH-values may boost the soil's '*Anion Exchange Capacity*' (AEC) to the extent that the AEC equals or exceeds the CEC. This can be detected by comparing pH-values of two samples of the same soil, one in suspension in  $H_2O$  and the other in 1M KCl.  $pH_{(KCl)}$  is less than  $pH_{(H_2O)}$  in soils with net negative charge (the 'normal' situation); the reverse is true in soils with net positive charge.

The following terminology is used in publications on the exchange properties of strongly weathered tropical soils:

- The pH value at which AEC fully compensates CEC (permanent plus variable charges) is called the '*point of zero net charge*' (PZNC).
- The difference between  $pH_{(KCl)}$  and  $pH_{(H_2O)}$  is known as '*delta pH*'.

[Figure 2](#) presents the exchange characteristics of strongly weathered tropical soils at different pH levels in a schematic way.



**Figure 2.** Schematic relation between exchangeable aluminium level, AEC, CEC, net surface charge and soil-pH<sub>(H<sub>2</sub>O)</sub>.

### ***Biological characteristics***

Intense termite activity is, according to some, at least partly accountable for the typical diffuse horizon boundaries of Ferralsols. Termites destroy (remnants of) stratification/rock structure; they increase the depth of the solum and their nests, tunnels and ventilation shafts increase the permeability of the soil. As termites preferentially move fine and medium sized particles and leave coarse sand, gravel and stones behind, they are thought to contribute to 'stoneline' formation. The depth of the stoneline is thought to indicate the depth of termite activity.

Note that stonelines may also occur where termites are absent, e.g. formed by soil creep in sloping terrain.

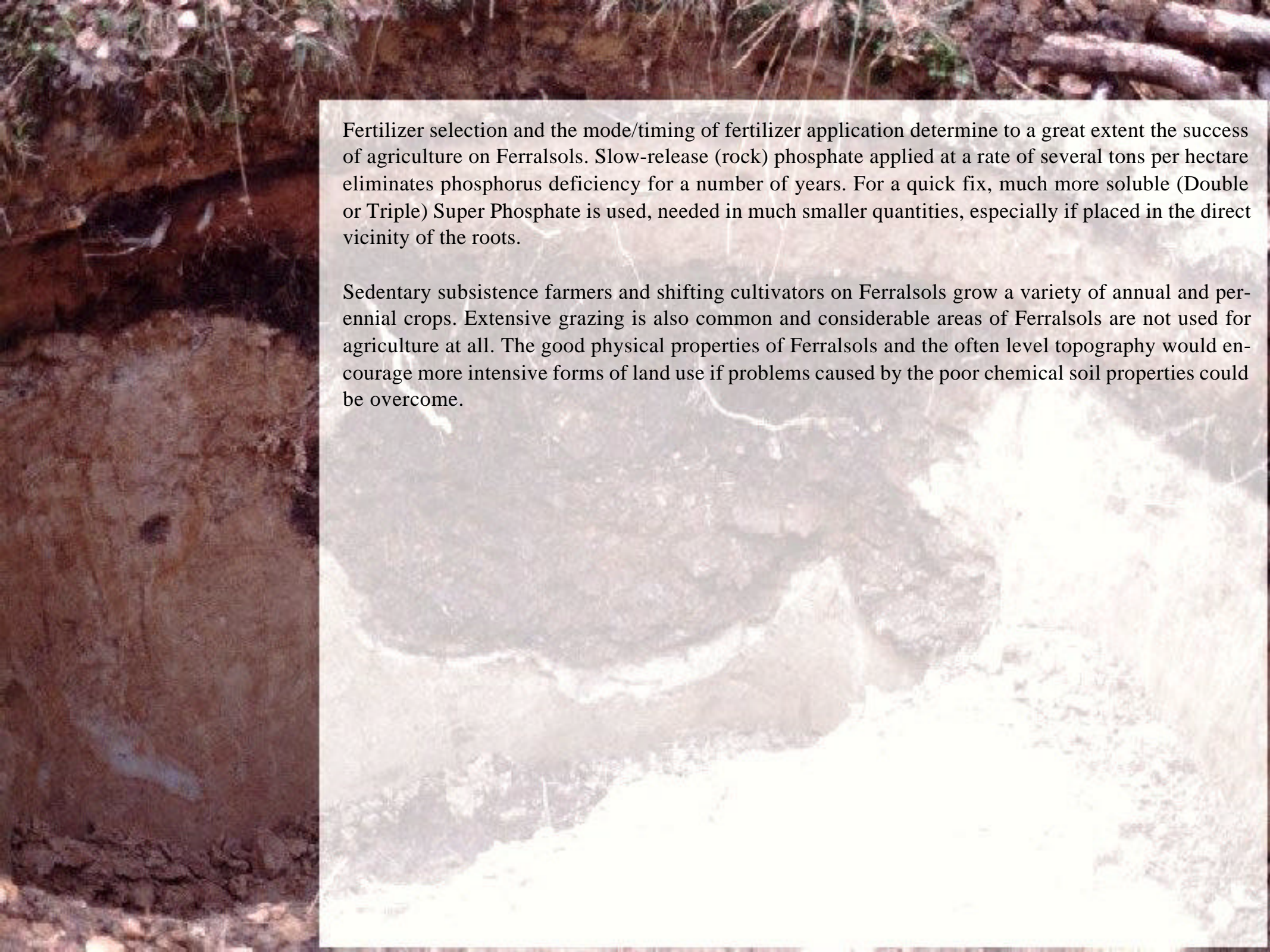
## Management and use of Ferralsols

Most Ferralsols have good physical properties. Great soil depth, good permeability and stable micro-structure make Ferralsols less susceptible to erosion than most other intensely weathered red tropical soils. Moist Ferralsols are friable and easy to work. They are well drained but may in times be droughty because of their low 'available' water storage capacity.

The chemical fertility of Ferralsols is poor; weatherable minerals are absent and cation retention by the mineral soil fraction is weak. Under natural vegetation, nutrient elements that are taken up by the roots are eventually returned to the surface soil with falling leaves and other plant debris. The bulk of all cycling plant nutrients is contained in the biomass; 'available' plant nutrients in the soil (and all living plant roots) are concentrated in the upper 10 to 50 cm soil layer. If the process of '*nutrient cycling*' is interrupted, e.g. upon introduction of low input sedentary subsistence farming, the root zone will rapidly become depleted of plant nutrients. Maintaining soil fertility by manuring, mulching and/or adequate (i.e. long enough) fallow periods and prevention of surface soil erosion are important management requirements.

Strong retention ('*fixing*') of phosphorus is a problem of Ferralsols (and several other soils, e.g. Andosols). Ferralsols are normally also low in nitrogen, potassium, secondary nutrients (calcium, magnesium, sulphur) and a score of micro-nutrients. Even silica deficiency is possible if silica-demanding crops (e.g. grasses) are grown. Manganese and zinc, which are very soluble at low pH, may at some time reach toxic levels in the soil or become deficient after intense leaching of the soil.

Liming is a means to raise the pH-value of the rooted surface soil. Liming combats aluminium toxicity and raises the CEC. On the other hand, it lowers the AEC, which might lead to collapse of structure elements and slaking at the soil surface. Frequent small doses of lime or basic slag are therefore preferable over one massive application; 0.5 – 2 ton/ha of lime, or dolomite, are normally enough to supply calcium as a nutrient and to buffer the low soil-pH of Ferralsols.



Fertilizer selection and the mode/timing of fertilizer application determine to a great extent the success of agriculture on Ferralsols. Slow-release (rock) phosphate applied at a rate of several tons per hectare eliminates phosphorus deficiency for a number of years. For a quick fix, much more soluble (Double or Triple) Super Phosphate is used, needed in much smaller quantities, especially if placed in the direct vicinity of the roots.

Sedentary subsistence farmers and shifting cultivators on Ferralsols grow a variety of annual and perennial crops. Extensive grazing is also common and considerable areas of Ferralsols are not used for agriculture at all. The good physical properties of Ferralsols and the often level topography would encourage more intensive forms of land use if problems caused by the poor chemical soil properties could be overcome.