SOIL MONOLITH PAPER 4

HUMIC NITOSOL
(OXIC PALEUSTALF)

KENYA

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INTRODUCTION

Subject of this paper is a humic nitosol in Kenya, collected as ISRIC soil monolith EAK 16 by Mr. H.J.A. van Baren in June 1980.

Nitosols are widespread in East-Africa and other parts of the world, notably South-Africa and the Far East. They belong to the relative fertile soils in the tropics and subtropics and are extensively used for the production of cash- and foodcrops.

On the basis of soil profile EAK 16 much attention will be paid to the nitosols in general. Information will be presented with respect to general setting (chapter 1), properties (chapter 2), genesis and classification (chapter 3) and to matters concerning the land evaluation (chapter 4).

CHAPTER 1: GENERAL INFORMATION AND SETTING

1.1 NITOSOLS

1.1.1 CONCEPT OF NITOSOLS

Nitosols are soils with a deep reddish brown argillic horizon that has a clayey texture that remains rather constant with increasing depth. Further on nitosols are characterized by diffuse horizon boundaries and strongly developed fine blocky structure as well as by a high porosity, a high stability, a good moisture storage capacity and a relative high CEC. The name is derived from the characteristic shiny pedfaces in the B and C horizons (nitidus [lat] = shiny). Because of their very favourable physical and chemical properties for agriculture, nitosols were separated in the FAO-Unesco Legend of the Soil Map of the World (FAO-Unesco, 1974) as a separate soil order. Unfortunately, in order to obtain conformity with the 'pale' great groups of the alfisols and ultisols of the USDA Soil Taxonomy (Soil Survey Staff, 1975), the nitosols were defined only in general terms: the order of nitosols comprises all soils that have an argillic horizon with a clay percentage that does not decrease from its maximum by more than 20% within 150 cm from the surface; they lack plinthite within 125 cm from the surface and a mollic horizon as well as vertic and ferric* properties. An aridic moisture regime must be absent. Because of this broad definition, soil scientists meet many problems, particularly in classifying soils with a deep argillic horizon (luvisols, nitosols or acrisols, see chapter 3). Profile EAK 16 may be considered as an example of a typical nitosol and shows all the properties of the original concept of nitosols.

In the FAO-Unesco legend (1974) humic nitosols are defined as nitosols having a base saturation of less than 50% in at least part of the B horizon within 125 cm of the surface and an umbric A horizon or a high organic matter content in the B horizon or both. Dystric nitosols have only a base saturation of less than 50% in at least part of the B horizon whereas all other nitosols have to be classified as eutric nitosols.

*ferric properties: see section 3.2.1.

1.1.2 GLOBAL EXTENSION

About 2.1 million sq km of the land surface of the world is covered with nitosols. Their occurrence is almost entirely restricted to the humid to
subhumid tropics and subtropics, where they occupy about 15% of the surface of the land. They occur predominantly on the African continent (55%), but their occurrence is also reported in Central America, South America (especially in Brazil, Surinam, Peru, Colombia), The Far East (India, The Philippines, Burma, Thailand) and in Australia (See fig. I)(FAO-UNESCO Soil Map of the World, vol. III, IV, VI to X, 1971-1979; EMBRAPA, 1981; CSIRO, 1983). The development of nitosols is commonly associated with intermediate or basic igneous or metamorphic rock and a humid to subhumid tropical climate. Dystric nitosols are most frequently found (about 56%), followed by the eutric nitosols (about 38%) and humic nitosols (about 6%).

The humic nitosol this paper is concerned with, is located at the premises of the Kenya Agricultural Research Institute (KARI) at Muguga in the Central Province of Kenya. It is representative for a large acreage of similar soils in Central and Western Kenya. The parent material in Kenya consist of tertiary basic volcanic rock or pre-cambrian rock (schist, gneiss, quartzite). According to the FAO-UNESCO Soil Map of the World, sheet VI-3 Africa (1973), the humic nitosols cover large areas in neighbouring countries, Zaire, Uganda, Tanzania, Nigeria, Cameroon, Burundi and Rwanda, as well. In most of these countries the humic nitosols are developed on pre-cambrian rock of the African shield (schist, gneiss, amphibolite, quartzite, charnockite), under humid or subhumid tropical climatic conditions.

Outside Africa the occurrence of humic nitosols is reported in Burma (vol. VII, North and Central Asia) and on Sumatra and Kalimantan (vol. IX, South and East Asia). In Burma they occur on gneisses and schists of the Indian Shield and the climate is described as cool humid. On Sumatra and Kalimantan the parent material consist of acid and intermediate volcanic tuff and lahar deposits. Here the climate is of an humid to everhumid semi-hot equatorial type.

1.1.3 GLOBAL AGRICULTURAL USE

Nitosols are highly suitable for agricultural land use at all levels of farming. This can be deduced from the volumes III, IV, VI to X of the FAO Soil Map of the World (FAO, 1971-1979) that report upon various kinds of landuse on nitosols all over the world. In East Africa nitosols are intensively used for the production of cashcrops (coffee, tea, pyretrum), but also for the production of foodcrops (maize, potatoes, pulses). On the nitosols of South America coffee, weath, oat, soyabean, corn, watermelon, rice, sugarcane and banana are cultivated. The soils are also used for grazing. In the more elevated parts of South America (Peru, Chile) nitosols are under cereals, potatoes and pasture. The nitosols in Venezuela and the Guianas (including Surinam) are still covered with tropical forests.

The production of coffee, cocoa and citrus on nitosols is reported from Central America, in the humid lowlands these crops are replaced by banana, rice and sugarcane.

In Asia (The Philippines, Kalimantan, Sumatra, Burma, Bangladesh) large areas with nitosols are covered with tropical rainforests with occasional shifting cultivation. In more densely populated areas cultivation of a wide variety of crops is practiced on nitosols. Under a high rainfall regime in India and Sumatra rice is the most important crop. Pulses, oilseeds, fruit, rubber, coconut, oilpalms, coffee and cocoa are other crops cultivated on
nitosols in Asia. Finelly, in Australia nitosols are used for the production of timber, groundnut, maize, sugarcane, coconut, flowers and vegetables. However the most important land use on nitosols in Australia is cattle breeding.

1.2 REGIONAL ENVIRONMENTAL SETTING

1.2.1 CLIMATE

According to the system of Köppen (Köppen, 1931) the climate of the Muguga area is classified as steppe climate with a mean annual temperature of less than 18 °C (BSk). Important characteristics of the climate are the alternating dry and wet seasons and the absence of large seasonal changes in temperature. The precipitation is bimodal with one rainy season from mid-March to May (the long rains) and a secondary rainy season from mid-October to December (the short rains). The prevailing wind direction is NE to E from October to April (NE monsoon) and E to SE from May to September (SE monsoon).

Climalic data of the Muguga area are obtained from the Muguga climatic station (no. 91.36/121) (2170 m asl) as reported by the East African Meteorological Department, nowadays the Kenya Meteorological Department (EAMD, 1975).

The rainfall (P) is recorded from 1951 to 1970, the air temperature (T) from 1933 to 1970, and the pan class A potential evaporation (Eo) is measured from 1963 to 1970. The evapotranspiration (PE) is calculated by the formula PE = 0.75 x Eo. (see table 1 and fig. 2). Observations at the National Agricultural Laboratories (NAL) near Nairobi (station no. 9140/025, 1740 m asl) lead to the estimation that the Muguga area receives an average of close to seven hours of sunshine per day and radiation in the order of 450 cal/sq cm/day. Especially the ultraviolet radiation is high. In Kenya two agro-climatic classification systems are in use. The Kenyan agro-climatic zone classification is based on water availability (P/Eo) and temperature (Somers, 1982). According to this system the Muguga area must be placed in the semi-humid water availability zone III (P/Eo = 60 %), and in the fairly cool temperature zone 5 (mean annual temperature = 15.9 °C) (see table 2 and 3).

The second agro-ecological classification system is made by the FAO (FAO, vol. 1, 1978). This system pays more attention to the length of the growing period, that is defined as the the period (in days) during a year when precipitation (P) exceeds half of the potential evapotranspiration (PE, according to the Penmann formula) plus a period required for the evapotranspiration of 100 mm water from excess precipitation (or less if not available) stored in the soil profile. A normal growing period must enclose a humid period, i.e. a period with an excess of precipitation over potential evapotranspiration. According to the FAO publication the Muguga area has a growing period of 90 to 150 days. This number corresponds with the length of 120 days for the growing period and of 100 days for the humid period of the LAK 16 site, deduced from the ombro-thermic diagram (see fig. 2, the PE is in this case calculated from the Eo, that is determined by pan class A measurements).

During the short rains another period occurs with the precipitation exceeding half of the potential evapotranspiration. This second period is not taken into account in the FAO system, although it is actually used by the farmers in the Muguga area for a second harvest of crops with a short
growing season. The short rains also benefit the growth of perennial crops (coffee). Both the agro-climatic zone classification systems of Kenya and of the FAO are based upon yearly resp. monthly averages of the rainfall, potential evapo(transpiration) and temperature. Temperature and potential evapo(transpiration) data are fairly constant without large deviations from the average. The data of precipitation however are more variable. This variability can be expressed in probability figures of the rainfall (see table 4). The probability to receive more than the average rainfall during the long rains in Central Kenya is less than about 44% and to receive more rainfall than half of the potential evapotranspiration is 100%. During the short rains these changes are less than about 39% and 68% respectively. The probability that the short rains are humid \((P > PE)\) is less than about 16%, for the long rains this probability is much higher (about 95%) (Braun, 1977).

1.2.2 GEOLOGY

The geology of the Muguga area is closely associated with the African rift valleys, the large rift system that intersects the African continent. In Kenya the rift system consists of the Gregory or main (central) rift traversing the country from north to south, and the Kavirondo rift, a branch rift trending east-west into Lake Victoria. The development of the central rift valley in Kenya with accompanying volcanic events is schematically illustrated in fig 3. The Muguga area is situated at the eastern shoulder of the central rift valley. It is underlain by Limuru Quarz trachyte of Early Pleistocene age (Saggerson, 1971). The eruption of the Limuru Quarz Trachyte must probably be placed at the end of the fourth event and the beginning of the fifth event of figure 3. The basaltic volcanicity in the rift floor ended with trachytic fissure volcanicity that locally overflowed the eastern wall of the rift. Later on, this shoulder has been lifted up and fractured by faulting (event 5 of fig. 3) (Baker, 1965 a and b).

A quarz trachyte is an intermediate extrusive rock. The elemental and normative mineralogical composition of a quarz trachyte is given in table 5 (Baker, 1954).

1.2.3 PHYSIOGRAPHY AND HYDROLOGY

The humic nitosols in central Kenya are mainly found at elevations of 1500 to 2500 m asl in a volcanic ridge landscape, the so called 'broad ridge topography' (Scott, 1963). This landscape consists of dissected footslopes associated with old volcanos and volcanic hills and exhibits a radial or semi-radial drainage pattern. In the Muguga area the major landscape elements are broad flat to slightly convex interfluvies, steep convex or straight valley slopes and narrow flat valley bottoms (see fig. 6, pag.x). In areas close to the Central Rift Valley humic nitosols may be encountered on flat to almost flat platforms, induced by faulting. The humic nitosols are well drained and no groundwater is observed within the solum during the year. The Muguga area is drained by a tributary of the Nairobby river.

1.2.4 VEGETATION AND LANDUSE

The natural vegetation of the Muguga area is described as dry forest and
moist woodland (see table 2). The monolith EAK 16 is collected in a forest reserve with a secondary forest cover. Outside the reserve the original vegetation has disappeared completely and is replaced by tree plantations and agricultural crops. The tree plantations produce timber and charcoal. Examples of planted trees are Croton megalocarpus, Croton macrostachyus, Erithrina abyssinica, Combretum molle and Acacia hockii. Most of the nitosols in central Kenya, including the humic nitosols, are however used for intensive cultivation of crops in small holdings or in larger estates. Frequently cultivated crops are coffee, tea, pyrethrum, maize, pulses, sunflowers, potatoes, vegetables and flowers. Irrigation is not applied and intercropping is common practice. The large estates produce coffee (Coffea arabica) and tea. Here fertilizers and pesticides are used.
CHAPTER 2: SOIL PROFILE EAK 16

2.1 DESCRIPTION OF THE SITE AND GENERAL INFORMATION ON THE SOIL.

The site where the monolith has been collected is located at approximately 1°13'S/36°38'E at the premises of the Kenya Agricultural Research institute (KARI) at Muguga (about 20 km NW of Nairobi) in the Central province of Kenya (see location map, fig 4). The altitude is 2170 m (7000 ft).

The physiographic position of the profile can be described as the upper part of a slightly convex slope, exposed to the south west. The slope gradient is 4%. The site is well drained with no evidence of impeded drainage. From the water balance of the soil with assumed 200 mm storage capacity (see fig. 7 and table 7, pag.x) it can be deduced that the soil moisture control section (which extends from 15 to 45 cm depth) is dry in most years in some or all parts for 90 or more cumulative days but moist in some part for more than 180 cumulative days. The soil therefore has an ustic moisture regime (Soil Survey Staff, 1975).

Soil temperature data are not available. Taken into account the mean annual air temperature of 15.9 °C, the soil temperature regime is considered as isothermic, with a mean annual soil temperature at a depth of 50 cm between 15 and 22 °C and a difference between mean summer and winter temperature less than 5 °C.

The soil has developed in weathered Limuru Quarz Trachyte (see section 1.2.2). The mineral composition of the sand fraction (see appendix 1) is in line with the composition of the parent rock. The sand fraction (50 to 500 µ l) largely (about 95%) consists of light minerals, predominantly K-feltspar and to a minor extent of quartz. The bulk of the heavy minerals, more than 95% of the total amount of grains, is opaque. Most of the transparant heavy minerals consist of zircon and amphibolites (green and brown hornblende). The composition of the sand fraction is rather uniform throughout the profile, indicating in situ soil formation. Although not expressed in the sand mineralogy, an admixture with volcanic ash cannot be excluded.

2.2 SOIL CHARACTERISTICS

2.2.1 BRIEF DESCRIPTION OF THE SOIL

The soil has a well developed deep solum with a A, AB, Bt profile (see profile description, appendix 1). Moist undisturbed soil colours range from dark reddish brown in the topsoil to dusky red in the subsoil. The texture is clay throughout the profile. However in the field the clay percentage is easily underestimated due to aggradation, which explains the local name of the soil: Kikuyu Red Loam. The very fine and fine crumb structure of the topsoil gives way to a moderate to strong, coarse angular blocky structure in the Bt horizon. The peds, especially in the lower part of the Bt horizon show conspicuous shiny surfaces, that at least partly are described as argillans. Pores are common and the soil is deeply rooted. In the lower part of the Bt horizon some soft sesquioxidic accumulations are observed. The boundary to the AB horizon is clear, all other horizon boundaries are gradual to diffuse.

2.2.2 PHYSICAL AND BIOLOGICAL SOIL PROPERTIES

The particle size distribution of soil profile EAK 16 shows a very high
amount of clay which increases with depth to values of 90% clay in the Bt2 horizon (all analytic data are presented in appendix 1). The amount of waterdispersable clay decreases with depth. In the A horizon 15.5% waterdispersable clay is present, which corresponds to a flocculation index (total clay – waterdispersable clay/total clay x 100) of 72.3%. The Bt2 horizon has only one percent waterdispersable clay resulting in a very high flocculation index (98.9%).

The specific surface area of the soil reaches very high values. This signifies that the clay fraction must be composed either of a fairly high amount of 2:1 clay minerals, particularly vermiculite or smectite (which is improbable, see section 2.2.1), or of other components with a high specific surface area, such as free sesquioxides.

The field as well as the thin section observations point at a very high porosity. Total pore space is not determined. Pereira (1957) measured the porosity of a comparable humic nitosol at Ruiru (Kenya) and found values ranging from 52 to 61%. It is therefore not surprising that the bulkdensity of the soil is rather low (1.0 to 1.15 g.cm\(^{-3}\)). In the topsoil this low bulkdensity is also related to the high organic matter content. Some indications about the size of the pores can be deduced from the pH data (see appendix 1). The clear drop in the water content from pH 1.5 to pH 2.0 demonstrates that large macro-pores (> 50 \(\mu\)m) contribute in a considerable way to the porosity of the soil. The water content at pH 4.2 is still high (27-31 wt%) which points to the abundance of micro-pores (< 0.2 \(\mu\)m), correlated with the high clay content. The available water content is therefore not very high.

Typic, strong birefringent, thin clay skins are present in the thin sections of the AB, Bt1 and Bt2 horizons (for the micro-morphological descriptions one is referred to appendix 2). Their amount is rather low and increases slightly with depth. Part of the clay skins are incorporated in the soil matrix. Small iron nodules are observed in the thin sections of all horizons. At least part of these nodules possibly originates from papules enriched with iron or manganese. The colour of the groundmass in the thin sections changes from reddish brown in the A horizon to red in the Bt2 horizon. In all horizons the colour is homogeneous and evidence of temporary reducing conditions is nowhere observed. Stress features are only weakly present in the thin section of the Bt2 horizon, which implies that the clay most probably is of the 1:1 type.

Features of biological activity are observed in the thin sections of all horizons. In particular the abundance of (partly infilled) channels, the absence of stress features in the topsoil and the presence of papules point at strong faunal activity in this soil. Subterranean termites (Odontotermes sp.) make up most of the soil micro- and mesofauna.

### 2.2.3 Chemical Soil Properties

The pH(H\(_2\)O) of the soil decreases with depth from 6.4 in the A horizon to 3.4 in the Bt2 horizon. In the A, AB and Bt1 horizon the difference between pH(H\(_2\)O) and pH(KCL), \(\Delta pH\), is one pH unit or more; in the Bt2 horizon \(\Delta pH\) is less than one pH unit.

The organic matter content of the topsoil is high and decreases gradually with depth. Taken into account the clear relationship \(y=3.94+0.29x, r=0.998\) between the % C per 100 g clay \((% C/\% \text{ clay}) \times 100 = x)\) and the CEC \(((\text{CEC}/\% \text{ clay}) \times 100 = y)\), it is evident that the organic matter content is largely responsible for the increased CEC values of the Bt1, AB and A
horizons. The CECc of all horizons, corrected for organic matter (method: 
Rodinam et al., 1980) is about 12 meq/100 g clay. 
Ca, Mg and K make up most of the exchangeable cations. The exchange 
complex is in all horizons unsaturated; the base saturation ranges from 74 
% in the A horizon to values slightly above (Bl1, Bl2) and below 50 % (AB). 
The X-ray analyses indicate that the clay fraction consists of predominant 
kaolinitic clay minerals, of felspar and of iron(hydr)oxides. 
The 'free' iron(hydr)oxides (i.e. not bound to silicates) occur mostly in 
crystalline form, considering the much higher values of extractions with 
DCB (Fe_d) compared to the extractions with NH_4Ox (Fe_o) and NaP (Fe_p). 
Cristallinity increases with depth. The 'activity ratio' (Fe_o/Fe_d) 
(Andriessse, 1979) is relatively high in the topsoil (0.08) but drops to low 
values in the Bl2 (0.02). Although a part of the 'active' (oxalate extractable 
iron) iron in the topsoil will be organically complexed (see Fe_p) the bulk 
seems to be amorphous inorganic iron. The figures of free Al are very 
low. 
Available P (method Olsen) is very low in this profile. Highest values are 
observed in the A horizon, lowest values in the AB horizon.

2.3 SOIL PATTERN

In the Muguga area the humic nitosols are developed on very gently sloping 
to undulating interfluves. A subdivision can be made on the basis of the 
thickness of the humic topsoil and of the topographic site. In real level 
position the soil has a very deep (xx cm) dark reddish brown humic topsoil 
that gradually changes to a dark red subsoil (Kikuyu Chocolate). On the 
upper slopes and the gently sloping to undulating terrain of the interfluves 
soils with a somewhat shallower (xx cm) humic topsoil occur (Kikuyu Dark 
Red). In small depressions and on concave slopes some eroded topsoil 
material has accumulated. Here the soils also have a very deep humic 
topsoil, that however partly consists of transported material (Kikuyu 
Creep). 
The humic nitosols on the interfluves have a toposequential relation with 
humic acrisols and with a complex of pellic vertisols and humic gleysols. 
The humic acrisols are situated on the lower slopes of the broad incisions 
bordering the valley bottoms and have slightly impeded drainage conditions. 
Sometimes they show an accumulation of Fe/Mn concretions. The pellic 
vertisols and humic gleysols are developed on the valley bottoms, which are 
Somewhat badly to badly drained (see figure 5 and 6). 
On the Exploratory Soil Map of Kenya (Sombroek, 1982), scale 1:1.000.000, 
humic nitosols in Central Kenya occur mainly in large zones around high 
volcanic areas or single volcanos, passing into humic andosols at higher 
alitudes (xx m) and into eutric nitosols with nito-chromic* cambisols and 
chromic acrisols, partly with a pisoferric* or petroferric fase at lower 
alitudes (xx m).

* according to the KSS classification (Sombroek, 1982) 
nitochromic cambisol: FAO chromic cambisol 
chronic acrisol: FAO orthic acrisol 
pisoferric fase: 40 % or more oxidic concretions or hardened plinthite or 
ironstone with a thickness of at least 25 cm, the upper part of which occurs 
within 100 cm of the surface.
CHAPTER 3: GENESIS AND CLASSIFICATION OF NITOSOLS

3.1 SOIL GENESIS

3.1.1 INTRODUCTION

Although much is available on tropical soil in general, specific literature about nitosols is rather scarce and mainly deals with the occurrence and recognition of nitosols (FAO, 1977; Isbell, 1980; reports on soil surveys in several countries, see section 3.2). The genesis of nitosols is only marginally discussed in these papers. Recently Sombroek and Siderius called for better diagnostic criteria for the classification of nitosols (Sombroek et al., 1982). They drew up an inventory of the existing knowledge and listed some major conditions essential to the genesis of nitosols. Nitosols are almost exclusively developed on basic or intermediate volcanic or metamorphic rock, on their sedimentary products or on other sediments with admixture of non volcanic ash (see section 1.1.2). These easy weatherable and base-rich parent materials are in a twofold way important for the formation of nitosols.

Firstly, the rapid and easy weathering of the parent materials promotes the loss of soil material by leaching. In this way a considerable soil volume is created that helps maintaining good drainage conditions in a well aerated soil profile. Secondly, despite this easy and rapid weathering, the total depletion of bases is prevented by the continuous supply of new bases from the rich parent material. Thus, acidification as well as processes like ferrolyse, or segregation of iron and aluminium, are inhibited in nitosols due to both the high supply of basis and the maintenance of well aerated and well drained soil profiles.

Apart from the particular characteristics of the parent material, the environment must allow the undisturbed evolution of the soil. This implies a stable well drained position of the soils without much erosion nor sedimentation. Finally, the climate must produce a moisture regime in which leaching is possible (thus a (peri)udic, ustic or xeric moisture regime) and must also produce sufficiently high temperatures to allow a high speed of weathering (thus a mesic or warmer temperature regime). In this respect Duchaufour (1982) states that nitosols, belonging to the group of ferruginous soils (see section 3.2.1), do not further develop to ferralsols in a climate that has either a marked dry season (dry tropics) or that is colder than a real tropical climate (humid subtropics).

Under the above described conditions the genesis of nitosols is controlled by the formation of low activity clays (ferrallitic weathering), clay migration, formation of the well developed structure with the conspicuous shiny faces and homogenisation by soil fauna.

In the following sections attention is paid to these soil forming processes. Because of the high impact of free sesquioxides on soil properties and processes, a separate section is assigned to these oxides. Further on, as soil profile EAK 16 belongs to the humic nitosols, another section will deal with the formation of the humic topsoil.

3.1.2 WEATHERING

In a warm humid climate weathering in well drained soils has a geochemical nature and is often referred to as ferralsitisation or ferrallitic weathering (Duchaufour, 1982). Under neutral to slightly acid conditions the bases as
well as Fe, Al and Si are rapidly liberated from the crystal lattices of the primary minerals by hydrolysis. The bases and Si are leached (desilication). Fe and Al are less mobile and remain in the soil. Fe precipitates as iron(hydr)oxides and Al recombines with Si to form secondary kaolinite clay minerals (neof ormation of clay). Comparison of the SiO₂/Al₂O₃ ratio of the quartzrock of table 5 (5.2) with the SiO₂/Al₂O₃ ratio of the soil material of profile EAK 16 (between 3.1 and 2.3) reveals that desilication indeed has taken place. The SiO₂/Al₂O₃ ratio of the soil material <2 mm shows values between 2.3 and 2.1; weathering thus has almost reached the stage of monosialisiation (Pedro, 1977). Further indications of the strong degree of weathering of soil profile EAK 16 are the low silt/clay ratio (see appendix 1), the rather high values of the Fe₉/Fe₇ ratio, ranging between 0.57 (A horizon) and 0.54 (Bt2 horizon) (Duchaufour, 1982 and Torrent et al., 1982), and the high amount of titanium (Mohr et al., 1972).

The question how much time has been necessary to reach the stage of weathering of profile EAK 16 is difficult to answer. Geochemical weathering cycles require a long time to develop fully. Duchaufour (1982) mentions a timespan of 10,000 to one million years for the ferrallitic weathering process. Sombroek et al. (1982) have reported that most nitosols are developed on surfaces of early to middle Pleistocene age. The parent material of soil profile EAK 16 dates from the early Pleistocene (see section 1.2.2).

3.1.3 CLAY MIGRATION

Nitosols are characterized by the presence of an argillic horizon without a clear clay bulge. The particle size distribution in soil profile EAK 16 indeed does not show a marked maximum of clay in the B horizon. In the thin sections thin clayskins are observed in the B horizon of profile EAK 16 but their amount is rather low. This points to only a moderate significance of clay migration processes in this soil, although, particularly in the upper part of the profile, part of the clayskins might be destroyed by faunal activity. Taken into account the flocculation index of the clay in profile EAK 16, peptisation of the clay is probably restricted to the minor easily dispersable part of the clay in the topsoil. It is not very likely that the observed thin clayskins originate from translocations in the subsoil itself (see also section 3.1.5). The abundancy of shiny pedfaces in profile EAK 16, observed in the field, is contradictory to the low amount of clayskins in the thin sections. Therefore, the conclusion is made that the shiny pedfaces in the field can only be partly attributed to clay illuviation. A decrease of the SiO₂/R₂O₃ ratio of the soil material with depth is usually conceived as an indication of clay migration (Mohr et al., 1972). However, in profile EAK 16 addition of fresh material, notably volcanic ash, might have increased the SiO₂/R₂O₃ ratio in the topsoil.

3.1.4 STRUCTURE

One of the outstanding features of nitosols is the well developed angular blocky structure, especially in the subsoil. In the Australian as well as in the Brazilian soil classification systems this structure is used as an
important differentiating soil property of nitosols in comparison with
forralsols (see section 3.2.3). In general, the formation of structure is
believed to be a result of flocculation of clay and of cementation. 
Cementation not only implies coherence by means of cementing agents as
organic matter, calcium carbonate or iron- and aluminium oxides but also
coherence as a consequence of pressure. In the subsoil the most important
pressing forces are the swelling and shrinking of the clay related to
alternating wetting and drying cycles. Shape and size of peds are largely
dependent on the nature of the clay and on the frequency of wetting and
drying. Peds tend to be larger as this frequency lowers. (Hillel, 1982).
Considering the climate at the Muguga area, with alternating wet and dry
seasons (see section 1.2.1), swelling and shrinking may very well have
contributed to the development of the medium to coarse angular blocky
structure of soil profile EAK 16. As the clay fraction largely consists of
kaolinite, that does not have a large COLE (coefficient of linear expansion),
the effects of swelling and shrinking are not as pronounced as in soils
dominated by 2:1 clay minerals. The abundantly occurring shiny pedfaces
may therefore very well be referred to as micro-slickensides (Sombroek et
al., 1982).
In soils with a high content of free iron the iron(hydr)oxides are often
considered as structure stabilizers. Pedro et al. (1976), in an attempt to
explain the genesis of a terra roxa estruturada in Brazil, described that the
structure in the Bt of this soil is initiated by swelling and shrinking of the
clay, by which peds and fissures are formed that permit the entrance of
water and air. The clay bordering the fissures graduallylooses basic
ations that are replaced by acid ironhydroxides (FeOH^{2+}) moving from the
 interiors of the peds outwards. The adsorption of positively charged
ironoxide particles at the surface of negatively charged kaolinitis reported
by several other authors as well (schwertmann, 1977). In this way,
 according to Pedro et al., a sort of crust, or 'cortex' is formed, made up
by iron bound to clay, that stabilizes the peds. This face in structure
formation is called 'grains de mais'. The 'cortex', made up of
ironhydroxides, could very well be responsible for the shiny appearance of
the pedfaces, characteristic for the nitosols. Sombroek et al. (1977) have
tenatively named this process 'metalлизation'.
When time progresses, the crust is separated from the interiors of the
 peds forming stable micro-aggregates. This process continues untill all the
plasma is transformed into micro-aggregates and the ferbalsol stage is
reached. The structure is than called 'poudre de cafe'.
The existence of well developed structure elements with shiny faces in the C
horizon and even in the saprolite of nitosols, as is reported by several
authors (Sleeman et al., 19??, Sombroek et al., 1982), suggests that
inheritance of structure from the parent material is also a possible source
of the structure elements in nitosols.

3.1.5 BIOLOGICAL ACTIVITY

The activity of soil fauna has a great contribution to the genesis of the
studied profile. Particularly the activity of the abundantly occurring
subterranean termites (Odontotermes sp.) is reported to have important
consequences on soil formation (Wiemaker, 1964). The homogeneity of
the soil, the gradual horizon boundaries, the high amount of macro-pores
and the absence of differences in sand mineralogy are to a large extent a
result of their activity.
Termites may also have contributed to the high base saturation of the soil by having transported fresh material (including bases) from the C horizon upwards (Duchaufour, 1982).

3.1.6 SESQUIOXIDES

Highly weathered tropical soils usually contain a considerable amount of free sesquioxides. In profile EAK 16 the total amount of free sesquioxides is determined by extraction with DCB (see appendix 1). It appears the free sesquioxides are almost totally made up of free iron. Therefore the attention is focussed on the free iron(hydr)oxides. According to the X-ray analysis the crystalline free iron in profile EAK 16 consists of goethite. This observation does not strike with the general accepted opinion that red colour of soils is caused by haematite, that even in low concentrations changes soil colours to hues redder than 5 YR (Schwertmann, 1977; Torrent, 1982; Bigham, 1978). Evidently the X-ray analyses failed to indicate haematite. The low amount of haematite in the topsoil is possibly related to the high concentration of organic components, that may prevent the formation of ferrhydrite, a necessary precursor of haematite (Schwertmann, 1977).

The high specific surface areas of soil profile EAK 16 (about 220 m²/g clay) can only be attributed, with respect to the subsoil, to the high content of free iron. The specific surface area of kaolinite and of illite, that is present in very low amounts, reach values of no more than 30 m²/g respectively 100 m²/g (Hillel, 1982; Scheffer et al., 1979). Bigham et al. (1978) indeed observed that the high specific surface area of well drained ultisols and oxisols is correlated to the content of free iron in the soil material: deferrated clays (by DCB) showed a much smaller surface area than natural clays. Further on these authors found that the specific surface area of oxalate extracted clays did not differ significantly from the natural clays, which indicates that the crystalline iron oxides were responsible for the high specific surface areas. Values of specific surface area for oxisol iron oxides were lower than those obtained for ultisol iron oxides, which has also been reported by Sombroek et al. (1982). Bigham et al suggest that this blockage of iron oxide surfaces in oxisols is caused by aggradation of the iron oxides or intimate association with silicate surfaces. Due to the chemical nature of their surface area, the iron(hydr)oxides are efficient sinks for anions as well as cations by non-specific and specific adsorption. Non-specific adsorption comprises the balancing of the pH dependent charge of the hydroxylated surface of the iron oxides by an equivalent amount of cations or anions. The ZPC (zero point of charge) of synthetic goethite and haematite lies in the range of pH 7.5 to 9.5 (Schwertmann, 1977), ZPC values of natural samples being generally lower. At the pH = 5 value of EAK 16, the surface of the iron oxides is probably somewhat positively charged.

In the case of specific adsorption some ions, particularly phosphate, are incorporated into the oxide structure and are bound much stronger than ions adsorbed by non-specific adsorption. Fixed in this way, ions are not or only slightly available for plants. According to Schwertmann (1977; see also Pope, 1976 and Juo, 1977) the variations in the amount of ions specifically adsorbed originate mainly from the differences in specific surface area of the iron oxides involved rather than from structural or compositional differences. This is in line with the observations of Bigham et al. (1978) who found that soils with iron oxides showing the highest values of specific
surface area absorbed most phosphate. A link with the composition of the iron oxides could however not be ruled out, as according to the observations of these authors, soil goethite had a higher specific surface area than soil hematite. As the available P (Olsen) in soil profile EAK 16 is very low, it must be reckoned with that in this profile a considerable amount of phosphate might be bound by specific adsorption (see also section 4.6).

Another soil property related to the presence of free iron is the high flocculation index of the clay. Eswaran (1979) pointed out that in soils with low activity clays and a high amount of free iron the clays are often immobilized by iron coatings. According to this author, in well drained soils clays can only be dispersed after removal of iron by reduction with organic material. Lepsch et al. (19??) suggest however that in well drained soils temporary reducing conditions due to stagnation may very well occur in the macropores in the top of the soils. A higher Fe_d/clay ratio in the topsoil compared with the subsoil should prove the occurrence of clay mobilization by means of reduction of the iron coatings, according to these authors. In profile EAK 16 the Fe_d/clay ratio in the subsoil is indeed somewhat lower than in the topsoil. According to Eswaran (1979) the illuviated clayskins in that case must have a paler colour than the surrounding Fe(III) rich plasma. This is not observed in profile EAK 16.

3.1.7 ACCUMULATION OF ORGANIC MATTER

In a constantly humid equatorial climate with a high production of organic matter the amount of humus in the soil generally remains low as the rates of the simultaneously occurring processes of biodegradation and mineralization are high. In equatorial climates with a dry season slow maturation of humus (by means of polymerization of certain humic compounds in the dry season) is favoured and accumulation of humus may become important (Duchaufour, 1982). The accumulation of matured humus has important effects on soil pH and on the base status of the soil. The matured humus retains bases freed by weathering, particularly Ca^{2+} and Mg^{2+}, thus inhibiting the acidification and the lowering of the base status of the humus rich horizons (Duchaufour, 1982, quoting Perraud 1971). This may offer an explanation to the frequently observed high base saturation of the humic topsoils of many nitosols in Central Kenya (see section 3.2.1).
3.2 SOIL CLASSIFICATION

3.2.1 FAO-UNESCO LEGEND

diagnostic horizons
Soil profile EAK 16 has an ochric A horizon because the A horizon does not meet the colour requirements for the mollic or umbric horizons; the chroma is too high and the difference in colour value with the underlying horizon is not darker than one unit or more.
The Bt1 and Bt2 horizons together qualify for an argillic B horizon:
- There is no eluvial horizon present; the soil therefore cannot fulfil the required textural differences between the eluvial horizon and the Bt.
- The thickness of the horizons, more than 140 cm, is more than 15 cm.
- The horizons show more than 1 % orientated clay on horizontal and vertical pedfaces and in pores.
- The B horizons consist of kaolinitic clay and contain more than 40 % clay.
- The lower part of the B horizon, the Bt2, shows clayskins on peds and in pores and has a blocky structure. Clayskins are also present in the upper part of the B, the Bt1 and even in the AB horizon, but their frequency is higher in the lower part of the Bt horizon.
- The horizon lacks the set of properties which characterizes the natric B horizon.

diagnostic properties
Because the $\text{CEC(NH}_4\text{Cl)}$ of the studied profile is less than 24 meq/100 g clay the soil would have ferric properties. According to Dudal (pers. comm., see Sombroek et al, 1982) however, the ferralic part of the ferric properties, i.e. CEC less than 24 meq/100 g clay, is allowed in nitosols. Therefore, in spite of the low CEC values, soil profile EAK 16 does not have ferric properties.
The organic matter content of profile EAK 16 meets the requirements for the diagnostic property 'high organic matter content in the B'. The weighted average content of organic matter of the fine earth fraction of the soil to a depth 100 cm is 3.2 % and thus more than 1.35 %.

classification
The soil keys out as a humic nitosol because:
- The soil has an argillic horizon with a clay distribution where the percentage of clay does not decrease from its maximal amount by as much as 20 % within 150 cm of the surface. Actually, the amount of clay increases with depth within 150 cm of the surface.
- The soil lacks plinthite within 125 cm of the surface.
- The soil lacks vertic and ferric properties as well as an aridic moisture regime and a mollic horizon.
- The base saturation (by NH$_4$OAC) is 45 % and thus less than 50 % in at least part of the B horizon within 125 cm of the surface; i.e. 45 % in the AB horizon.
- The soil has a high organic matter content in the B horizon.

Among the soils that are related to the humic nitosols are of course the dystric nitosols, lacking an umbric A horizon or a high organic matter content in the B horizon, and the eutric nitosols, having a base saturation higher than 50 %. 'Nitosols' with a mollic A horizon have to classified as luvic phaeozems. If clayskins are lacking the soils most probably must be
classified as humic or rhodic ferralsols. In general the depth criterium for 
the argillic horizon is easily met. However, when this is not the case, for 
instance after erosion of top of the profile, the soils are classified as 
humic or ferric acrisols, or ferric or chromic luvisols, dependent on the 
base saturation level.

3.2.2 USDA SOIL TAXONOMY

diagnostic horizons

Because soil profile EAK 16 does not have the required colour for a mollic 
or umbric epipedon (chroma lower than 3.5 and one unit darker than the C 
or overlying horizon) the soil has an ochric epipedon.

The (AB?), Bt1 and Bt2 together form an argillic horizon. They fulfill the 
required:
- thickness: more than 15 cm
- presence of orientated clay: clayskins on horizontal and vertical pedfaces 
  and in pores, and more than 1 % orientated clay in thin sections

other diagnostic soil characteristics

The particle size class of the soil is clayey. This means that in the control 
section (between 25 cm and 100 cm) the weighted clay % of the fine earth 
fraction (< 2 µm) is more than 35 % and rock fragments are less than 35 % 
by volume. From the quantitative X-reay analysis it is anticipated that the 
mineral composition of the control section consists of more than 50 % by 
weight of kaolinite. The soil therefore is placed in the kaolinitic mineralogy 
class.

The soil moisture regime and temperature regime are already briefly 
discussed in section 2.1. The soil moisture regime turns out to be ustic 
according to the definition in Soil Taxonomy (Soil Survey Staff, 1975) that 
comprises the following: The control section (between 15 and 45 cm) is dry 
in some or all part for 90 or more cumulative days, but moist in some part 
for more than 160 cumulative days or it is continuously moist in some part 
for at least 90 consecutive days. Van Wambke (1982) states that Nairobi, 
situated at an altitude of about 400 m below Muguga (see fig. 4) has a typic 
udic soil moisture regime, but this author used other definitions for the soil 
moisture regimes than Soil Taxonomy. The Kenya Soil Survey Department 
also applies an ustic soil moisture regime at Muguga, because a P/Eo ratio 
of 60 % corresponds to a an ustic soil moisture regime according to Sombroek et al (1982). The soil temperature regime is isothermic, i.e. the soil 
temperature lies between 15 and 22 °C at a depth of 50 cm with a yearly 
variation of less than 5 °C.

Classification

Base saturation by sum of cations never reaches a value below 35 % in soil 
profile EAK 16 (38 % in the AB). The soil therefore has to be classified as an 
alftisol, due to the presence of an argillic horizon. Because of the ustic soil 
moisture regime the soil keys out at the suborder of the ustalfs.

Considering the clay distribution (the percentage of clay does not decrease 
by as much as 20 % of the maximum within a depth of 1.5 m from the soil 
surface) and the soil colour (hue redder than 10 YR and chroma of more 
than 4 in the matrix of at least the lower part of the argillic horizon) the 
soil is put in the great group of the paleustalfs. The soil meets also the 
requirements for the rhodustalfs but the paleustalfs key out first. On 
account of the low (< 24 meq/100 g clay) CEC of the argillic horizon, of the
absence of a calcic horizon or soft powdery lime as well as of the absence
of a base saturation of 75% or more in any part of the argillic horizon, the
classification of the soil up to the subgroup level turns out to be oxic
paleustalf. The complete classification of soil profile EAK 16, including the
family level, reads oxic paleustalf, clayey, kaolinitic, non calcareous,
isothermic.
Profile descriptions and analytic data of a number of soil profiles, all
humic nitosols according to the FAO-Unesco Legend (1974), are collected to
compare important soil properties. This comparison is used in chapter 4.
The classification of these soils according to the USDA Soil Taxonomy (1975)
is given below. In most cases the classification is tentative since diagnostic
data are either determined by methods different from those applied in Soil
taxonomy or they are incomplete.

EAK 16: oxic paleustalf, ustic, isothermic, clayey, kaolinitic
(this paper)
CK 19: orthoxic palehumult, udic, isothermic, clayey, -
CK 28: orthoxic (ustic) palehumult, ustic, isothermic, clayey, -
CK 51: ustic palehumult, ustic, isothermic, clayey, -
CK 54: oxic paleustult/orthoxic (ustic) palehumult, ustic,
isothermic, clayey, -
CK 56: orthoxic (ustic) palehumult, ustic, isothermic, clayey, -
(profiles are taken from Siderius et al., 1977)
excursion 5: ustic palehumult, ustic, - , clayey, kaolinitic
(profile is taken from KSS, 1977)
WK 13: typic paleudoll, udic, - , clayey, -
WK 14: orthoxic palehumult/typic paleudoll, udic, - , clayey, -
WK 16: orthoxic palehumult, udic?, -, clayey, -
WK 18: orthoxic palehumult, udic?, -, clayey, -
WK 20: orthoxic palehumult, -, -, clayey, -
(profiles are taken from Wielemaker et al., 1982)
Kibirigwe 92: orthoxic palehumult, -, -, - , -
(profile is taken from Alphen, 1980)
ZA 21: typic palehumult, udic, thermic, clayey, mixed
(profile is taken from the ISRIC collection)
Passo Fundo: orthoxic palehumult, -, -, clayey, -
(profile is taken from FAO, 1977)
BR 8: orthoxic palehumult/tropeptic haplorthox, udic, thermic,
clayey, oxidic
BR 25: rhodic paleudult, perudic, isohyperthermic, clayey,
oxidic
(profile is taken from Camargo et al., 1978)
KB 3: typic paleudult, perudic, isohyperthermic, clayey,
kaolinitic
(profile is taken from Buurman, 1980)
M 1: orthoxic palehumult/typic paleudult, udic,
isohyperthermic, clayey, kaolinitic
(profile is taken from Beinroth et al., 1979)

Soil profile EAK 16 is the only soil profile that must be classified as an
alfsol. This is due to the fact that the requirement of a base saturation of <
50% by pH 7 is not completely identical to the requirement of a base.
saturation <35 % by sum of cations. Obviously profile EAK 16 represents
the more saturated humic nitosols, although the base saturation of humic
nitosols in general is relatively high.
The humic acrisol, that is discussed in Soil Monolith Paper 5 (Scholten et
al., 1982) must also be classified as orthoxic paleuhumult, as most of the
humic nitosols presented above. An important difference between the
humic acrisol of Soil Monolith Paper 5 and the humic nitosols is the
presence of a BtG horizon with ferric mottling in the acrisol.
With respect to the proposals of the introduction of the kandic horizon
(Moorman et al., 1982), it might be stated that most nitosols will not meet
the requirements for this horizon, considering their high clay percentage
in the B. In fine textured soils, e.g. nitosols, the textural differentiation,
on which the kandic horizon is based, loses much of its genetic and
practical significance, according to these authors. Moreover, textural
differentiation is only slightly present in nitosols. The discussion of the
ICOMLAC on the significance of of an argillic horizon in low activity clay
soils on the basis of the presence of a rather low amount of clayskins or
of a textural increase (see for instance Isbell, 1980) is of course also
applicable to the nitosols. The introduction of the kandic horizon in the
USDA classification system may give a solution for part of these
problematic soils but not for the nitosols (see also section 3.2.4).

3.2.3 OTHER CLASSIFICATION SYSTEMS

In the French classification system of 1967 (CPCS, 1967) two classes
deal with the soils developed under warm climatological conditions
(subtropical, tropical, equatorial) and subjected to a geochemical
weathering cycle: the 'sols a sesquioixides de fer' and the 'sols
ferrallitiques'. According to this system soil profile EAK 16 belongs to
the classe sols ferrallitique, sous classe faiblement desaturées en (B) (base
saturation between 40 and 70/80 %), groupe humique, at least when
emphasis is laid on the amount of exchangeable bases (2–8 meq/100 g soil
in the sols ferrallitiques faiblement desaturés; in profile EAK 16 the weighted
average in the B between 10 and 150 cm is 7.6 meq/100 g soil).
After modifications of this system, described in Duchaufour (1977, 1982),
a third class is introduced by upgrading the two subclasses of the 'sols a
sesquioixides de fer' to two substantive classes. The three classes formed
in this way, fersiallitic, ferruginous and ferrallitic soils, represent the
phases in the same weathering process, the ferrallitic soils being the final
stage. This final stage is not always reached; the most limiting factors are
climate and topographic site. The three phases are described as follows
(Duchaufour, 1982):
Phase 1: fersiallitisation. There is a dominane of 2 : 1 clays
rich in silica, partially inherited and partially of neoformation
(or of a special kind of transformation). Considerable amounts
of free iron oxides are formed that are generally more or less
rubified. The absorbent complex is saturated or almost
saturated by the movement of the towards the surface of
calcium in the dry season. An argillic horizon occurs as a
result of fine clay perversion, often complicated by an
impoverishment in clay of the surface horizons. The exchange capacity is higher than 25 meq/100 g clay.

Phase 2: Ferrugination. Weathering is stronger, but certain primary minerals still persist (orthoclase, muscovite). De-silication is more marked and there are more neoformed 1:1 clays (kaolinite) than 2:1 transformed clays, but free gibbsite does not generally occur (except in certain transitional soils). Iron oxides may or may not be rubified (red or ochreous colour). Base saturation is very variable, depending on the humidity of the climate and the importance of the dry season. The processes of pervection, preferentially affecting the the 2:1 clays, are still active, even though to a lesser extent than in the ferrallitic soils. The exchange complex lies between 25 and 16 meq/100 g clay.

Phase 3: Ferrallitisation. There is a complete weathering of primary minerals (except for quartz) and clays are all neoformed, consisting solely of kaolinite. Free gibbsite occurs frequently, although its presence is not absolutely essential. Clay pervection decreases as clay is increasingly resistant to dispersion by water and no true argillic horizon is formed. However, more or less marked lateral impoverishment can occur at the surface. The exchange capacity is lower than 16 meq/100 g clay.

The studied profile seems to fit best in the second class, the ferruginous soils. This class is further subdivided into ferruginous soils sensu stricto and ferrisols. The ferrisols are close to the ferrallitic soils in having a very deep solum (often more than 3 m) and a dominance of kaolinitic clayminerals, but they still contain some weatherable minerals, especially in the lower part of the profile. These soils may have either an argillic horizon or not and the decrease in the amount of clay going from the B(t) towards the A and C horizon is very gradual. Profile EAK 16 must be placed in the soil group ferrisols with an argillic B horizon on the basis of the above mentioned descriptions of ferruginous soils and ferrisols, although the CEC of the studied profile is less than 16 meq/100 g soil. If this CEC criterium however is striktly applied, profile EAK 16 must be classified as a ferrallitic soil.

In 1979 a number of pedologists of the Ostrom proposed to replace the entire French system by a totally new classification scheme (Project de Classification des Sols, 1979; ISRIC, 1984). In this system the differentiation of soil classes and subclasses is based upon the mineral and organic constituents of the soil, because, according to the OSTROM co-operators, they represent the primordial reflection of the formation processes of the soil and control the main soil properties. The second level comprises the morphology (horizonation) of the soil: in the great group the humus horizons are nominated, the group and subgroup account for the characteristics of the mineral horizons and the family describes the parent material. At the third level the physical and chemical properties of the soil are taken into account. the genus specifies the absorption complex by means of base saturation and pH, the type gives the texture and the available water volume and the variety accounts for the thickness of both the pedon and the horizons.

According to this system the classification of soil profile EAK 16 includes
the following:

level I  **class:** Fermonosialsoil. The mineral horizon below the humus horizon (mineralolon) has: less than 10% 2:1 type clay minerals (monosial); more than 3% free iron oxides but less than 50% total free sesquioxides and a ratio free Al/total Al of 50% or less; an amount of weatherable minerals of 10% or less in the 20-200 um fraction.

**subclass:** kaol- and goethl-. Kaol- means that more than half of the clay minerals of the mineralolon consist of kaolinite. Goethl- means that more than half of the free iron oxides of the mineralolon consist of goethite.

level II  **great group:** pachidyspallid. The humus horizon (humon) has more than 0.5% organic matter and a moist chroma of 4 or more or a dry value of 6 or more (pallid); it is more than 18 cm thick (pachi); base saturation is more than 50% (dys).

**group:** argillanlic. The mineralolon contains more than 5% argillans (when this is not the case the soil belongs to the orthic group).

**subgroup:** red, prismatic, shiny

**family:** alterlite of quartz trachyte

level III  **genus:** eutric, acidic. Base saturation of the mineralolon is higher than 50% and the pH(water) lies between 5 and 6.6.

**type:** clay, medium available water volume in the topsoil, low available water volume in the subsoil.

**variety:** thick (pedon more than 2 m thick).

A fourth level gives data concerning the possibilities of soil utilization: the soil moisture regime, the soil temperature regime, the drainage conditions, rock outcrop, stoniness, slope and other environmental data like geomorphology, vegetation, present land use, agronomy etc.

In the Brazilian system of soil classification (Klatt et al., 1985) soil profile EAK 16 is called a terra roxa estructurada, which forms a subclass of the mineral soils with textural B horizon, low activity clay, low textural gradient between A and B horizon, moderate to strong prismatic or blocky structure and clayskins on peds. A textural B horizon is comparable to the argillic B horizon of Soil Taxonomy (1975) apart from the somewhat differently defined ratio of clay content between the A and the B horizon and from the absence of the requirement of a textural from the A to the B horizon when the B horizon has a well developed blocky or prismatic structure or clayskins. The subclass terra roxa estructurada must be developed on basic rock and must have dusky red to dark red colours, a high Fe$_2$O$_3$ content, high magnetic susceptibility and effervescence with H$_2$O$_2$ in the B horizon.

On the soil map of Brazil (EMBRAPA, 1981) a subdivision of the terra roxa estructurada is made on the basis of base saturation levels (dystrophic: BS < 50%, eutrophic: BS > 50%). A humic subtype is not distinguished.

In Kenya the Kenya Soil Survey uses the FAO-Unesco Legend (1974) for the classification of soils, adapted however to Kenyan conditions. The definition of the nitosols in the Kenyan concept of the FAO-Unesco Legend is narrowed to obtain more conformity in the soil order of the nitosols and to exclude
of the nitosols in the Kenyan concept of the FAO-Unesco Legend is narrowed to obtain more conformity in the soil order of the nitosols and to exclude those soils that do not show the favourable physical and chemical properties characteristic for nitosols according to the original concept of the FAO-Unesco Legend (see section 1.1.1 and 3.2.4). To avoid confusion the newly described nitosols in the Kenyan system are called nitisols. Nitisols are defined as having the following characteristics (Sombroek et al., 1982):

1. An argillic B horizon with a high clay content (more than 40%) and a moderate to low silt percentage (silt/clay ratio less than 35%); The requirement of sufficient clay increase within a vertical distance of 30 cm may be waved if all of the following characteristics are present;
2. a gentle clay bulge extending beyond 150 cm depth and only a gradual increase in clay % from the A to the B horizon (clay % ratio B/A horizon usually between 1.0 and 1.2);
3. many shiny pedfaces, especially in the deeper B horizon (more than 10% of the surface area), which cannot or can only partly be ascribed to argillans;
4. moderately to strongly developed, very fine to medium, angular blocky structure (polyhedral);
5. very friable when moist;
6. high aggregate stability (practically no water dispersable clay in horizons with low organic matter content);
7. clay activity (excluding organic matter content) of less than 24 me/100g.

3.2.4 REVISION OF THE CLASSIFICATION OF NITOSOLS IN THE FAO-UNESCO LEGEND

Considering the different classification schemes it appears the FAO-Unesco Legend is the most specific with respect to nitosols (they are placed on the highest level), although the description of the nitosols in this system is very brief. In the FAO as well as in the USDA system the main differentiating criterium for the classification of nitosols is the presence of an argillic horizon with a particular clay distribution. In the Brazilian system (Klamt et al, 1985) the structure is added as another criterium. In the old French system (CPCS, 1967; Duchaufour, 1982) emphasis is laid on the on the stage in the ferralitic weathering process and here the presence of an argillic horizon is downgraded as a differentiating criterium. In the newly proposed French system (Project de Classification des Sols, 1979) the constituents of the soil are differentiating at the highest level. Sombroek et al. (1982) put forward a proposal for a revision of the differentiating criteria for the classification of nitosols in the FAO system based on the Kenyan concept of nitosols. In this proposal a combination of differentiating criteria is used by defining the B horizon of the nitosols as a diagnostic horizon. The proposals includes the following:

1. a clay content above 35 percent, with a silt/clay ratio of less than 0.40;
2. a gentle clay bulge extending beyond 150 cm depth with only a gradual increase in clay percentage from the A to the B horizon (clay ratio B/A horizon is usually between 1.0 and 1.3); and none or only a very gradual decrease in clay percentage from the B to the C horizon;
3. shiny pedfaces, especially in the deeper part (below 100 cm
from the surface) of the B horizon that constitute more than 25 percent of the surface area, and which can only partly be ascribed to illuviation argillans:

4. dominantly (more than 50 % of the area) moderately to strongly developed, very fine to medium angular blocky structure (polyhedral);

5. very friable to friable consistence when moist;

6. high aggregate stability (practically no water dispersable clay in horizons with low organic matter content), resulting in a flocculation index of more than 90;

7. CEC-clay less than 24 meq/100 g clay, corrected for organic matter where necessary;

8. a specific surface area by EGME method of more than 150 m²/g clay in the main part of the B horizon, associated with more than 5 % free iron oxides by dithionite extraction.

The subdivision in humic, dystric and eutric nitosols remains the same, although the introduction of a mollic nitosol is considered in addition.
CHAPTER 4: LAND EVALUATION

4.1 LAND EVALUATION IN KENYA

In Kenya the Kenya Soil Survey department (KSS) is concerned with land evaluation (Nyandat et al., 1978). Reconnaissance soil surveys are carried out at scale 1:100,000 in the high and medium potential areas of the country and at scale 1:250,000 in the low rainfall areas, to achieve a systematic inventory of the soil and land resources for multi purpose land use planning.

Land evaluation is practiced according to the methods described in the FAO Framework for land evaluation (FAO, 1976). In an early stage relevant land utilization types (LUT's) are defined for the area concerned. The LUT's are characterised by the attributes produce, capital investment, labour intensity, land tenure, technical knowledge of the land user and infrastructural requirements. The defined LUT's are based on the current situation but can also be described for a future development of the area after the realization of major improvements.

In assessing the soil and land resources the KSS makes use of the concept of land qualities. A land quality is defined as (Beek, 1878) 'a (complex) attribute of the land which acts largely as a separate factor on the performance of a certain use. The expression of each land quality is determined by a set of interacting simple or compound land characteristics.' The land qualities used for land evaluations published by the KSS are listed in table 6 together with the measurable land characteristics. The land qualities are rated according to standards developed by the KSS. Five grades are distinguished ranging from 1 (very high) to 5 (very low).

The final suitability for a certain land utilization type of the various tracks of land, the mapping units of the soil maps, is obtained by a comparison between the physical demands of the land utilization types and the opportunities the land is offering, i.e. the land qualities. This step in land evaluation is the most difficult one and cannot be standardized because the land utilization types are based on the local/regional environmental and socio-economical situation. Suitability is expressed in two orders Suitable (S) and Non Suitable (N), the suitable order is divided in three classes Highly Suitable (S1), Moderately Suitable (S2) and Marginally Suitable (S3). A designation conditionally suitable is added for those tracks of land that are not only marginally suitable for a particular kind of land use but where this suitability can be improved after the fulfillment of certain conditions. The required input level is given by means of a symbol. Four classes are distinguished ranging from low technical requirements and costs involved to special skills and equipment needed with very high costs involved.

In the Muguga area no systematic soil survey has been carried out yet. Likewise no detailed land evaluation has taken place. The area belongs to the highly productive and densely populated parts of the country. Important current land utilization types on the humic nitosols in the Central Province of Kenya may be described as A smallholder rainfed arable farming; crops: coffee, tea, maize, sunflowers, flowers, pulses, potatoes and other vegetables; low technology (no mechanization, no fertilizers); average farmsize ?? ha; B idem but with intermediate technology (no mechanization, but some fertilizers and pesticides); average farmsize ?? ha; C large scale rainfed (sometimes with additional irrigation) coffee and tea farms; high
technology (mechanization, fertilizers and pesticides); average farm size: ?? ha.
The few land qualities that may be limiting to these land utilization types are
moisture availability and inherent fertility with regard to available phosphor. These and other important land qualities are dealt with in the
following sections. The rating of these land qualities according to the
Kenyan approach to land evaluation will also be discussed, at least as far
as data are available.

4.2 MOISTURE AVAILABILITY

Moisture availability is best expressed by the waterbalance of the soil and
depends upon climate (rainfall and evaporation), soil properties (storage
capacity and infiltration capacity) and of losses due to runoff. The crop
affects the evaporation by its water consumption and transpiration which is
expressed by the crop factor (Doornbos et al., 1979).
The average rainfall, the probability of the rain and the average
evaporation at Muguga are given in section 1.2.1 (table 1 and 4). The
storage capacity of the studied soil can be calculated from the pF data of
the soil (appendix 1). Taking the available water as the water between pF 2
and 4.2 the storage capacity of the soil is about 50 mm in the fist 50 cm.
Over 1 meter (shallow rooting crops) the storage is about 85 mm and over
2 m (deep rooting crops) about 150 mm. Dagg (1965) found a storage
capacity of 220 mm over 180 cm in a humic nitosol at Muguga. To get a
general picture about the water availability for a deep rooting crop like
maize or coffee the waterbalance with a storage capacity (Sto) of 200 mm
will be satisfactory, providing that no considerable runoff takes place.
Runoff is, among other factors, dependent on the infiltration capacity of the
soil, which will be discussed in section 4.4. Pereira et al. (1967) found
that on terraced grassed and arable fields on the humic nitosols at Muguga
(initial slope 12 %) only five storms out of six recorded years gave runoff.
The runoff occurred only on newly grazed-trampled grass lays.
From the calculated waterbalance (according to Thornthwaite, 1955, fig. 7
and table 7) it can be seen that only in May a surplus of water exists. The
short rains do not bring enough rain to replenish the soil to the full storage
capacity of 200 mm. This is in line with experiments of Semb et al. (1969)
who found that in maize fields on the humic nitosols at Muguga the soil
moisture content increased only in the top 40 cm of the profile during the
short rains. Only at the end of March the soil is dry in all parts according
to the definitions in the Soil Taxonomy (Soil Survey Staff, 1975).
Dagg (1965) set up calculated waterbalances for two maize varieties (a
variety with a growing season of 180 days and a local variety with a growing
season of 210 days) at Muguga during the long rains. He concluded that at
the end of August both varieties will suffer from drought stress but the
short term variety is by that time rapidly approaching harvest. The yields
of the local variety however may be severely suppressed from this late
drought. During the short rains only crops with a short growing season
and with low susceptibility to drought can be grown.
In the Kenyan land evaluation system (Braun et al., 1977) soil moisture
storage capacity and climate are considered as two separate land qualities.
The agro climatic zone classification (rainfall divided by evaporation)
makes up the rating of the land quality climate (see table 8). The Muguga
area must be placed in zone III. Soil moisture storage capacity is
determined by the amount of readily available moisture (i.e. the
moisture content between pF 2.3 and pF 3.7) calculated for the effective soil depth. Hindrance to root development downgrades the rating (see table 9). Although measurements at these pF values have not been carried out, profile EAK 16 can be placed in class 1, because the effective soil depth extends beyond a depth of two meters.

In short it is concluded that with respect to humic nitosols the land quality available moisture is determined by climate (precipitation and evapotranspiration). Soil moisture storage capacity is never a limiting factor because of the high porosity and deep profile development. Losses due to runoff do not easily take place because of the good infiltration capacity of the soil (see section 4.4). Profile EAK 16 has an ustic soil moisture regime, which limits available moisture. The humic nitosols with an udic soil moisture will not suffer from limited moisture.

4.3 OXYGEN AVAILABILITY

The assessment of the land quality oxygen availability is usually derived from the drainage conditions of the soil. Humic nitosols are almost always well drained due to the high porosity, good infiltration capacity (see section 4.4) and deep profile development without textural differences causing perched water tables. Therefore the oxygen availability for roots but also for the soil fauna is generally good in humic nitosols.

In the Kenyan land evaluation system (Braun et al., 1978) the oxygen availability is determined by the drainage condition of the soil and mottling of the soil (see table 10). Profile EAK 16 fits in class 1.

4.4 RESISTANCE TO EROSION

Factors controlling soil erosion are the erosivity of the eroding agent, the erodability of the soil, the slope of the land and the nature of the plant cover (Morgan, 1979). Only erosion caused by water is discussed here. The erosivity of the rainfall in tropical and subtropical areas is considerable. At Muguga 15% of the average yearly precipitation falls with intensities greater than 50 mm/hr (Periera et al., 1967). It is believed that erosion is almost entirely caused by rainfall with intensities greater than 25 mm/hr (Morgan, 1979, quoting Hudson, 1963).

The erodability of the soil is largely dependent on texture, aggregate stability and infiltration capacity. Soils with a high silt and fine sand content are most susceptible to erosion because the transport of particles larger than fine sand is hampered by the weight of the particles whereas clay particles are resistant to detachment because of their cohesion (Morgan, 1979). Humic nitosols generally have clayey textures although Ahn (1977) has demonstrated that the 'natural' texture, i.e. the texture determined without adding a dispersor, of a humic nitosol at Ruiru, Kenya falls in the silty loam textural class because of micro-aggradation of clay particles in the silt and fine sand size (see table 11). Greenland (1977) warns that soils with stable aggregates might be susceptible to erosion due to the low cohesion between the aggregates.

In general however, aggregate stability has a positive effect on resistance to erosion because, due to the stable aggregates, the permeability of the soil after wetting remains high. A high organic matter content in the topsoil is very important in this respect because the stable organically bonded aggregates in the topsoil inhibit surface structure slacking and consequent crust formation. Hence, aggregate stability and high organic matter content
as well as high porosity and deep profile development all create favourable conditions for a high infiltration capacity.

Henneman et al. (1974) reported final infiltration rates (= permeability) between 150 and 500 mm/hr on humic nitosols in the Kisii area in Kenya, recorded with infiltro-rings. Shitakha (1984) found values between 90 and 220 mm/hr on eutric nitosols with a high organic matter content in Embu, Kenya (also recorded with infiltro-rings). Wischmeier et al. (1971) assessed these values as rapid, the highest class of their rating of permeability.

Normally, humic nitosols occupy the more stable positions in the landscape like plateus, terraces, broad interfluves etc. which do not have steep slopes. Under natural conditions plant cover on humic nitosols with a (per)udic soil moisture regime in the warm temperature regions consists of tropical rainforest and on humic nitosols in a somewhat dryer environment of dry forest or moist woodland. When cultivated the soil surface is temporarily uncovered, particularly during the planting period at the start of the rainy season.

Recently, Gachena et al. (1984) proposed a revision of the criteria and rating used in assessing the land quality resistance to erosion in Kenya. Although these criteria are still subjected to further study, this new assessment of the resistance to erosion will be taken into account. To judge resistance to erosion a climate factor, a soil factor, a slope factor and a plant cover factor are considered. The authors linked the agroclimatic zone classification with the erosivity of the rainfall, by using a relationship between the mean annual rainfall and the kinetic energy of 15 min rain falling with an intensity of more than 25 mm/hr (see table 12).

Slope value and slope length together form the slope factor. The slope factor has a direct effect upon erosion by the component of the gravitational force that operates along the slope. Slope value is thought to have a major effect and is therefore heavily rated (see table 13).

The erodability of the soil, the soil factor, is believed to be a function of organic matter content, flocculation index, silt/clay ratio and bulkdensity of the topsoil (see table 14). Organic matter content and flocculation index are indicators for aggregate stability, bulkdensity for generalized infiltration properties and the silt/clay ratio for the susceptibility to sealing. The plant cover factor is rated according to the average plant cover of the soil during the rainy seasons (see table 15). The sum of the first three factors for soil profile EAK 16 is only six. Therefore, according to table 16, the final resistance to erosion of the soil is with a plant cover of 20% or more is high. Only with a bare soil surface (average plant cover less than 20%) the resistance to erosion will be moderate at the site EAK 16. Even when the humic nitosols in the central Province of Kenya are cultivated on steeper slopes than slope class A (0-2%) the resistance to erosion remains high to moderate according to the proposed assessment of Gachena et al. (1984), providing that the surface is sufficiently covered with plants.

4.5 ARABILITY AND TILTH

Arability or the workability for cultivation is dependent on the bearing capacity of the soil, the rock outcrop and the stoniness. Bearing capacity of humic nitosols is high as the soils are well drained and surface structure slacking is inhibited by the high organic matter of the topsoil. In general, humic nitosols are non stony and rock outcrops are seldom encountered in
areas with humic nitosols. The consistency of the topsoil is also important with respect to arability. Soil profile EAK 16 has a slightly sticky and slighty plastic consistency in the topsoil, which is favourable to arability. Mechanized kinds of landuse impose stronger requirements upon the land quality arability than hand cultivation.

Tilth, or the fitness of the soil as a seedbed is, apart from the above mentioned properties dependent on the size of the aggregates of the topsoil. In profile EAK 16 the structure of the topsoil is fine to very fine crumb, which is favourable for a seedbed.

In Kenya the land quality 'possibilities of agricultural implements' is applied to land evaluations. It depends on the steepness of slope, on the stoniness/rock outcrop/shallowness of the soil, on the workability of the soil, on the slope length and on the width of the field. The workability is composed of the dry and moist consistency of the soil. As part of these characteristics are related to mapping units rather than to soil profiles a rating of the possibility of agricultural implements could not be given for soil profile EAK 16.

4.6 INHERENT FERTILITY

To discuss the inherent fertility of soil profile EAK 16 and of the humic nitosols in general, literature data on the topsoils of 19 humic nitosols are compiled and listed in table 17. In section 3.2.2 a comparison of the same 19 profiles is made with respect to the classification according to the USDA Soil Taxonomy (Soil Survey Staff, 1975).

The pH(H₂O) of the topsoils of the 19 humic nitosols lies between pH 5 and 6, with an average of 5.4, leaving out soil profile M1 from Malaysia which has a markedly lower pH and two profiles from Kenya, CK 56 and WK 14, having pH values in the topsoil that are almost neutral (pH 6.6) probably due to fertilizer application. According to Sanchez (1976) acidity problems in soils are associated with the exchangeable aluminium content of the soil. Above pH 5 aluminium is not mobile, hence acidity problems in humic nitosols do not or only slightly occur.

The CEC (pH 7) of the topsoils ranges from 7.6 to 38 meq/100 g soil, with an average of 20.3 meq. These values are fairly high but, taking in account the pH of the topsoils, the effective CEC (at the pH of the soil) of the topsoils will be lower as both the organic matter and the sesquioxides in the soil have pH dependent charges.

The base saturation of the B horizon of humic nitosols is by definition low. The base saturation of the topsoils however can be very variable, as showed in table 17. The values vary between 90 and 14 % with a mean of 41%. It must be beared in mind that the base saturation determined at pH 7 exaggerates the acidity of the soil as does the base saturation determined by sum of cations at pH 8.2 (Sanchez, 1976). Unfortunately effective CEC values are not available.

The organic carbon content of the topsoils of the humic nitosols is by definition high. The values of the 19 profiles range from 1.1 to 6.6 %C. The two highest values (6.6 and 6.5) are obtained for soils with a forest cover. This does not imply that all profiles with a forest vegetation have a very high organic carbon content. The Profiles Passo Fundo, Brazil, and M1, Malaysia, also carry a forest vegetation but their % C is not markedly higher than that of the other, cultivated soil profiles. Moshl et al. (1974) investigated two humic nitosols at Muguga, one cultivated, and the other under forest. The cultivated profile, after 8 years of cultivation without
fertilizer application, contained about two third of the organic matter content of the forest profile (see table 18). The cultivated soil still easily fulfilled the requirements for the classification of the soil as humic nitosol. Van Wissen (1974) compared the contents of soil organic matter of 5 humic nitosols with different cultivation time-spans in the Kisii area, Kenya. The organic matter content of the soils decreased with increasing time of cultivation. After 30 years of cultivation the total amount of organic carbon was diminished with about 30% as compared to a non cultivated profile. Here the organic matter content of the soil with 30 years of cultivation also remained within the requirements of the humic nitosols.

From the above mentioned studies the conclusion can be drawn that at least in Kenya the organic matter content of humic nitosols remains fairly high during cultivation. Therefore, as in weathered tropical soils the organic matter accounts for most of the available bases, nitrogen and phosphorus (Sanchez, 1976), depletion of nutrients through cultivation is not expected to take place easily. This statement is confirmed by Lehrer (1966) for the Muguga area. He compared 156 cultivated with 154 uncultivated topsoils of humic nitosols in the Muguga area. Significant differences between the cultivated and non cultivated profiles were only obtained for the calcium and magnesium content of the topsoils, but deficiencies were not observed. With a high organic matter content the N content of the humic nitosols is expected to be high as well. The figures for % N of the 19 topsoils vary between 0.37 and 0.13%. According to Sanchez (1976) total soil nitrogen usually is poorly correlated with nitrogen response in the field. With few exceptions nitrogen soil tests are also not reliable enough to predict nitrogen response. Field experiments must be used to evaluate the nitrogen supply of soils. Therefore no general assessment of the N availability in humic nitosols can be made on the basis of the data in table 17.

Semb et al (1967a) found that in field trials with maize on the humic nitosols at Muguga no response to nitrogen fertilizers occurred. They concluded, also with the aid of previous investigations (Semb, 1967b), that the humic nitosols at Muguga were sufficiently supplied with nitrogen. The figures of available phosphor content of the 19 humic nitosols cannot be compared directly as they are obtained through different analytic methods. According to ratings that are in use for the various methods (Mehlich's analysis according to standards of the National Agricultural Laboratories of Kenya; for ratings of the Olsen and Truog methods one is referred to SMP 5, Schotten et al, 1982) the underlined values are assessed as low. This means that the majority of the topsoils of the examined humic nitosols are deficient in P. The fixation of P by iron(sesquioxide) and in minor extent also by kaolinite probably causes the low availability of P in humic nitosols (see also section 3.1.6). The investigations of Moshi et al. (1974) were undertaken to study the effects of organic matter on the phosphate adsorption characteristics of the humic nitosols at Muguga. They observed that after cultivation the organic matter content of the humic nitosols at Muguga decreased and P sorption increased. According to these authors the P sorption is correlated with the height of the positive charges in the soil mostly determined by free sesquioxides. Organic matter reduces the positive charges in the soil and hence the P sorption.

The exchangeable potassium of the topsoils of the humic nitosols varies between 2.5 and 0.1%. When K-rich weatherable minerals are present, as in soil EAK 16, K deficiencies are not likely to occur. The parent materials of humic nitosols, basic rock, usually but not necessarily contain K bearing minerals. The low amount of weatherable minerals in humic nitosols may
account for low values of exchangeable potassium. K-fixation by montmorillonitic clay minerals cannot explain low K figures in humic nitosols.

According to van Wambeke (1974) potassium deficiencies are observed in ferralsols in which the amount of exchangeable K is lower than 0.1 meq/100 g soil. In the fertility capability classification of Buol et al. (1975; Sanchez, 1982) the critical value of 0.2 is used. Most humic nitosols from table 17 are thus sufficiently supplied with K.

In Kenya the assessment of chemical fertility is derived from the CEC of the topsoil, from the combination of results of the Mehlich's analyses for K and P, P sorption and acidity of the topsoil, and from the total amount of nutrients in the topsoil. As most of these analyses are either not available or not carried out to the standards of the Kenya Soil Survey department a comparison of the data of profile EAK 16 with the ratings for chemical soil fertility is not possible.

**Fertility capability classification**

A quantitative classification system for grouping soils according to fertility limitations has been introduced by Buol et al. (1975). An abstract of this system, revised by Sanchez et al. (1982), concerning the fertility classification of the 19 examined humic nitosols is presented in table 19. Almost all listed humic nitosols have clayey topsoils and marked textural differences with the subsoil do not occur. Acidity and P fixation are the most common modifiers of the 19 profiles.

The acidity modifier refers to a moderate level of acidity in the topsoil that would retard the growth of some Al sensitive crops. The Fe-P fixation is used to designate soils in which phosphorus fixation by iron compounds is of major importance. The application of this modifier gives some problems as the first criterion does not agree with the second criterion, except for profile WK 16. Almost all profiles data needed for the first criterion were not available, in all cases the second criterion is used. This signifies that almost all profiles show Fe-P fixation, which is in accordance with the general low available P figures of the soils.

An ustic soil moisture regime, related to restrictions with respect to available water, is observed in almost all humic nitosols from Central Kenya. Four profiles exhibit a potassium deficiency. The modifier that indicates toxicity of aluminium and Al-P fixation, occurs only in two profiles. The modifiers of low CEC and bad drainage conditions do not occur in the 19 humic nitosols. The classification according to the fertility capability classification of the 19 profiles is presented in table 20.

Overall picture of the humic nitosols, according to this classification system is a clayey, slightly acid soil with high Fe-P fixation that may show K deficiency and may occur in a somewhat dry environment. Occasionally the soil is stronger acid.
REFERENCES


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ORSTROM, Office de la Recherche Scientifique et Technique Outre-Mer


Sleneman et al, (1977?) ??????


**Figure 3**  
Baker, 1989a

*Diagrammatic sections showing development of the Central Rift in Kenya*

**Late Miocene - early Pliocene**

1. Phonolites erupted on crest of uplift.
2. Faulting on west side of rift, monoclinal flexuring on east side.

**Late Pliocene**

3. Faulting of floor of rift; renewal of movement on main fractures; new fractures on rift shoulders.
4. Trachytic-basaltic volcanicity in rift floor.

**Quaternary**

5. Further uplift of rift shoulders; renewal of movement on faults in rift floor; new closely spaced fractures develop in median zone.
6. Small plugs and larger calderas built in rift floor; some central volcanoes on the rift shoulders.
Legend:

1. Humic nitosol
2. Humic nitosol
3. Humic Acrisol
4. Ferric Acrisol
5. Humic nitosol
6. Pellic Vertisol / Humic Gleysol

Local:
- Kikuyudark red
- Kikuyu chocolate
- Muguga orange brown
- Muguga brown with murnun
- Kikuyu creep
- Black Ulley

Legend:

- 0 100 200 m

Figure 5: Soil map of Miana estate
Table 1: Climatic data of Muguga station, EAMD, 1975.

<table>
<thead>
<tr>
<th>Month</th>
<th>Tmax</th>
<th>Tmin</th>
<th>Tmean</th>
<th>P</th>
<th>Eo</th>
<th>PE</th>
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<tbody>
<tr>
<td>Jan.</td>
<td>22.4</td>
<td>11.1</td>
<td>16.8</td>
<td>66</td>
<td>188</td>
<td>141</td>
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<tr>
<td>Feb.</td>
<td>23.3</td>
<td>11.4</td>
<td>17.3</td>
<td>45</td>
<td>174</td>
<td>130</td>
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<tr>
<td>March</td>
<td>23.1</td>
<td>12.3</td>
<td>17.7</td>
<td>73</td>
<td>179</td>
<td>134</td>
</tr>
<tr>
<td>April</td>
<td>21.4</td>
<td>12.5</td>
<td>17.3</td>
<td>240</td>
<td>125</td>
<td>94</td>
</tr>
<tr>
<td>May</td>
<td>19.8</td>
<td>11.6</td>
<td>15.7</td>
<td>190</td>
<td>101</td>
<td>76</td>
</tr>
<tr>
<td>June</td>
<td>19.0</td>
<td>9.7</td>
<td>14.4</td>
<td>40</td>
<td>90</td>
<td>68</td>
</tr>
<tr>
<td>July</td>
<td>18.2</td>
<td>8.7</td>
<td>13.5</td>
<td>21</td>
<td>84</td>
<td>63</td>
</tr>
<tr>
<td>Aug.</td>
<td>18.8</td>
<td>9.0</td>
<td>13.9</td>
<td>25</td>
<td>95</td>
<td>71</td>
</tr>
<tr>
<td>Sept.</td>
<td>21.0</td>
<td>9.5</td>
<td>15.3</td>
<td>21</td>
<td>142</td>
<td>106</td>
</tr>
<tr>
<td>Oct.</td>
<td>22.0</td>
<td>11.1</td>
<td>16.6</td>
<td>53</td>
<td>171</td>
<td>128</td>
</tr>
<tr>
<td>Nov.</td>
<td>20.6</td>
<td>11.8</td>
<td>16.2</td>
<td>133</td>
<td>135</td>
<td>101</td>
</tr>
<tr>
<td>Dec.</td>
<td>21.2</td>
<td>11.3</td>
<td>16.3</td>
<td>88</td>
<td>163</td>
<td>122</td>
</tr>
<tr>
<td>Year</td>
<td>20.9°C</td>
<td>10.8°C</td>
<td>15.9°C</td>
<td>995 mm</td>
<td>1647 mm</td>
<td>1234 mm</td>
</tr>
</tbody>
</table>

Table 4: Rainfall probability table for the east-Central area of Kenya, Braun, 1977.

Table 5. Elemental and normative mineral composition of a quartz trachyte. 1954

<table>
<thead>
<tr>
<th>elemental composition</th>
<th>normative composition</th>
</tr>
</thead>
<tbody>
<tr>
<td>element % weight</td>
<td>mineral</td>
</tr>
<tr>
<td>SiO₂</td>
<td>quartz</td>
</tr>
<tr>
<td>Al₂O₃</td>
<td>orthoclase</td>
</tr>
<tr>
<td>Fe₂O₃</td>
<td>albite</td>
</tr>
<tr>
<td>FeO</td>
<td>anorthite</td>
</tr>
<tr>
<td>MgO</td>
<td>diopside</td>
</tr>
<tr>
<td>CaO</td>
<td>illmenite</td>
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<tr>
<td>Na₂O</td>
<td>apatite</td>
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</tbody>
</table>

99.98
<table>
<thead>
<tr>
<th>Zone</th>
<th>r/Eo (%)</th>
<th>Classification</th>
<th>Average Annual Rainfall (mm)</th>
<th>Potential Eo Evaporation (mm)</th>
<th>Vegetation</th>
<th>Plant Growth</th>
<th>Altitude (%)</th>
<th>Soil Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>&gt; 80</td>
<td>Humid</td>
<td>1100 - 2700</td>
<td>1200 - 2000</td>
<td>Moist forest</td>
<td>Very high</td>
<td>Extremely low (0 - 1%)</td>
<td></td>
</tr>
<tr>
<td>II</td>
<td>65 - 80</td>
<td>Sub-humid</td>
<td>1000 - 1600</td>
<td>1300 - 2100</td>
<td>Moist and dry forest</td>
<td>Very low</td>
<td>Extremely low (1 - 5%)</td>
<td></td>
</tr>
<tr>
<td>III</td>
<td>50 - 65</td>
<td>Semi-humid</td>
<td>800 - 1400</td>
<td>1450 - 2200</td>
<td>Dry forest and moist woodland</td>
<td>Fairly low</td>
<td>Very low (5 - 10%)</td>
<td></td>
</tr>
<tr>
<td>IV</td>
<td>40 - 50</td>
<td>Semi-humid to semi-arid</td>
<td>600 - 1100</td>
<td>1550 - 2200</td>
<td>Dry woodland and bushland</td>
<td>Medium</td>
<td>Low (10 - 25%)</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>25 - 40</td>
<td>Semi-arid</td>
<td>450 - 900</td>
<td>1650 - 2300</td>
<td>Bushland</td>
<td>Marginal</td>
<td>High (25 - 75%)</td>
<td></td>
</tr>
<tr>
<td>VI</td>
<td>15 - 25</td>
<td>Arid</td>
<td>300 - 550</td>
<td>1900 - 2400</td>
<td>Bushland and scrubland</td>
<td>Low</td>
<td>Very high (75 - 95%)</td>
<td></td>
</tr>
<tr>
<td>VII</td>
<td>&lt; 15</td>
<td>Very Arid</td>
<td>150 - 350</td>
<td>2100 - 2500</td>
<td>Desert scrub</td>
<td>Very low</td>
<td>Extremely high (95 - 100%)</td>
<td></td>
</tr>
</tbody>
</table>

Table 3: TEMPERATURE ZONES with an indication of mean maximum, mean minimum and absolute minimum temperatures, night frost, altitude range and range of various crops.

- **These are averages for the whole country; for areas in and west of the Rift Valley the temperature range is one degree warmer and for areas east of the Rift Valley one degree colder than indicated.**
- **r is - 20 to 23 resp.**
<table>
<thead>
<tr>
<th>Land quality</th>
<th>Land characteristic(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate</td>
<td>ecological zones</td>
</tr>
<tr>
<td></td>
<td>(climatic characteristics)</td>
</tr>
<tr>
<td>Soil moisture storage</td>
<td>soil depth</td>
</tr>
<tr>
<td></td>
<td>total productive available moisture (TPAM)</td>
</tr>
<tr>
<td></td>
<td>profile hindrance to root development (rootable depth)</td>
</tr>
<tr>
<td>Chemical soil fertility</td>
<td>CEC soil or sum of cations</td>
</tr>
<tr>
<td></td>
<td>available nutrients</td>
</tr>
<tr>
<td></td>
<td>mineral reserve (total mineral content of soil)</td>
</tr>
<tr>
<td>Possibilities for the use of agricultural</td>
<td>steepness of slope</td>
</tr>
<tr>
<td>implements (possibilities for</td>
<td>stoniness and rockiness of the soil or shallowness of the</td>
</tr>
<tr>
<td>mechanisation)</td>
<td>bed rock</td>
</tr>
<tr>
<td></td>
<td>slope length</td>
</tr>
<tr>
<td></td>
<td>&quot;workability&quot; of the soil</td>
</tr>
<tr>
<td>Resistance to erosion</td>
<td>slope class</td>
</tr>
<tr>
<td></td>
<td>climate</td>
</tr>
<tr>
<td></td>
<td>slope length</td>
</tr>
<tr>
<td></td>
<td>&quot;erodability&quot; (susceptibility to sealing)</td>
</tr>
<tr>
<td>Presence of hazard of water logging (Availability of oxygen for root growth)</td>
<td>drainage</td>
</tr>
<tr>
<td>Hindrance by vegetation</td>
<td>thickness of vegetation in terms of physiognomic types</td>
</tr>
<tr>
<td>Presence of overgrazing</td>
<td>visual observations of the present status of overgrazing</td>
</tr>
<tr>
<td>Availability of foothold for roots</td>
<td>depth to hindering layer</td>
</tr>
</tbody>
</table>
7: waterbalance of a soil with a storage capacity (STo) of 200 mm at Muga, according to Thorntwaite 1955.

<table>
<thead>
<tr>
<th></th>
<th>J</th>
<th>F</th>
<th>M</th>
<th>A</th>
<th>M</th>
<th>J</th>
<th>J</th>
<th>A</th>
<th>S</th>
<th>O</th>
<th>N</th>
<th>D</th>
<th>YEAR</th>
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<td>16.3</td>
<td>15.9</td>
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<td>T</td>
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<td>73</td>
<td>240</td>
<td>190</td>
<td>90</td>
<td>21</td>
<td>25</td>
<td>24</td>
<td>53</td>
<td>133</td>
<td>88</td>
<td>128</td>
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<tr>
<td>T</td>
<td>48</td>
<td>31</td>
<td>23</td>
<td>169</td>
<td>200</td>
<td>174</td>
<td>141</td>
<td>112</td>
<td>73</td>
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<td>82</td>
<td>69</td>
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<td>E</td>
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<td>62</td>
<td>81</td>
<td>94</td>
<td>76</td>
<td>66</td>
<td>54</td>
<td>54</td>
<td>60</td>
<td>76</td>
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<td>101</td>
<td>912</td>
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<td>E</td>
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<td>53</td>
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<td>9</td>
<td>17</td>
<td>46</td>
<td>52</td>
<td>0</td>
<td>21</td>
<td>322</td>
</tr>
<tr>
<td>S</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>83</td>
<td>0</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>83</td>
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8: This table is dropped.


<table>
<thead>
<tr>
<th>Rating</th>
<th>TRAM (Total Readily Available Moisture pf 2.3-pf 3.7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very high</td>
<td>160-200</td>
</tr>
<tr>
<td>High</td>
<td>120-160</td>
</tr>
<tr>
<td>Moderate</td>
<td>80-120</td>
</tr>
<tr>
<td>Low</td>
<td>40-80</td>
</tr>
<tr>
<td>Very low</td>
<td>Less than 40</td>
</tr>
</tbody>
</table>
Availability of oxygen for root growth

<table>
<thead>
<tr>
<th>Drainage Class</th>
<th>Colour and Mottling</th>
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</thead>
<tbody>
<tr>
<td>No well to excessively drained</td>
<td>No distinct mottling within 90 cm, and/or reduced colours within 150 cm</td>
</tr>
<tr>
<td>Slight moderately well drained</td>
<td>No distinct mottling within 50 cm and/or reduced colours within 120 cm</td>
</tr>
<tr>
<td>Imperfectly drained</td>
<td>No reduced colours or distinct mottles within 50 cm</td>
</tr>
<tr>
<td>Poorly drained</td>
<td>Partly reduced colours and distinct mottles within 50 cm</td>
</tr>
<tr>
<td>Very poorly drained</td>
<td>Predominantly reduced colours</td>
</tr>
</tbody>
</table>

Brown et al, 1977

---

Particle size distribution of the upper horizons of a humic nutosol from Ruiny Coffee Research station with addition of a dispersing agent (above) and without addition of a dispersing agent (below) from Ahn, 1977

<table>
<thead>
<tr>
<th>Horizon</th>
<th>2000-600 µm</th>
<th>600-200 µm</th>
<th>200-60 µm</th>
<th>60-20 µm</th>
<th>20-6 µm</th>
<th>6-2 µm</th>
<th>&lt;2 µm</th>
<th>Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-8</td>
<td>1.0</td>
<td>1.9</td>
<td>1.2</td>
<td>14.7</td>
<td>15.1</td>
<td>7.8</td>
<td>58.4</td>
<td>clay</td>
</tr>
<tr>
<td>-15</td>
<td>1.0</td>
<td>2.0</td>
<td>1.6</td>
<td>21.3</td>
<td>13.3</td>
<td>9.4</td>
<td>51.5</td>
<td>clay</td>
</tr>
<tr>
<td>-30</td>
<td>1.5</td>
<td>1.5</td>
<td>1.4</td>
<td>8.2</td>
<td>9.9</td>
<td>8.3</td>
<td>69.8</td>
<td>clay</td>
</tr>
<tr>
<td>0-50</td>
<td>1.5</td>
<td>1.5</td>
<td>2.2</td>
<td>4.4</td>
<td>8.3</td>
<td>6.1</td>
<td>77.0</td>
<td>clay</td>
</tr>
<tr>
<td>5-30</td>
<td>.3</td>
<td>5.1</td>
<td>14.2</td>
<td>17.8</td>
<td>28.1</td>
<td>14.0</td>
<td>20.5</td>
<td>silt loam</td>
</tr>
<tr>
<td>0-50</td>
<td>1.2</td>
<td>2.4</td>
<td>30.6</td>
<td>21.2</td>
<td>16.3</td>
<td>8.4</td>
<td>18.9</td>
<td>loam</td>
</tr>
<tr>
<td>0-30</td>
<td>1.0</td>
<td>2.4</td>
<td>36.4</td>
<td>25.6</td>
<td>15.2</td>
<td>15.2</td>
<td>4.2</td>
<td>silt loam</td>
</tr>
<tr>
<td>0-50</td>
<td>.5</td>
<td>1.6</td>
<td>34.8</td>
<td>23.9</td>
<td>30.5</td>
<td>3.1</td>
<td>1.6</td>
<td>silt loam</td>
</tr>
</tbody>
</table>
### Table 12: Rating of theClimate Factor, Gachema et al., 1984

<table>
<thead>
<tr>
<th>Rating</th>
<th>KE</th>
<th>Agro-climatic Zone</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&lt;5,000</td>
<td>VI, VII</td>
</tr>
<tr>
<td>2</td>
<td>5,000-10,000</td>
<td>III, IV, V</td>
</tr>
<tr>
<td>3</td>
<td>&gt;10,000</td>
<td>I, II</td>
</tr>
</tbody>
</table>

### Table 13: Rating of the Slope Factor, Gachema et al., 1984

<table>
<thead>
<tr>
<th>Slope Class</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;50</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>50-100</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>100-200</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>9</td>
</tr>
<tr>
<td>&gt;200</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>7</td>
<td>7</td>
<td>9</td>
<td>11</td>
</tr>
</tbody>
</table>

### Table 15: Plant Cover Factor

The rated criteria for the plant cover factor is the average plant cover during the rainy season, expressed as percentage. The ratings are as follows:

<table>
<thead>
<tr>
<th>Rating</th>
<th>Plant Cover</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>&gt;70</td>
</tr>
<tr>
<td>2</td>
<td>50-70</td>
</tr>
<tr>
<td>4</td>
<td>20-49</td>
</tr>
<tr>
<td>7</td>
<td>&lt;20</td>
</tr>
</tbody>
</table>

### Table 16: Final Rating “Resistance to Erosion”, Gachema et al., 1982

The final rating is obtained by the summation of the subratings shown by the individual factors climate, slope, soil, and plant cover. These final ratings can be classified as follows:

<table>
<thead>
<tr>
<th>Rating</th>
<th>Sum Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>≤10</td>
</tr>
<tr>
<td>2</td>
<td>11-15</td>
</tr>
<tr>
<td>3</td>
<td>16-20</td>
</tr>
<tr>
<td>4</td>
<td>≥21</td>
</tr>
</tbody>
</table>
The subratings for the mentioned characteristics are the following:

**$r_1$: Organic matter**

<table>
<thead>
<tr>
<th>% OM</th>
<th>%C</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;5</td>
<td>&gt;3.0</td>
</tr>
<tr>
<td>2-5</td>
<td>1.2-3.0</td>
</tr>
<tr>
<td>&lt;2</td>
<td>&lt;1.2</td>
</tr>
</tbody>
</table>

**$r_2$: Bulk density (g/cm$^3$)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;1.20</td>
<td></td>
</tr>
<tr>
<td>1.20-1.50</td>
<td></td>
</tr>
<tr>
<td>&gt;1.50</td>
<td></td>
</tr>
</tbody>
</table>

**$r_3$: Silt/clay ratio (hydrometer method)**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.20</td>
<td></td>
</tr>
<tr>
<td>0.20-0.59</td>
<td></td>
</tr>
<tr>
<td>0.60-1.00</td>
<td></td>
</tr>
<tr>
<td>&gt;1.00</td>
<td></td>
</tr>
</tbody>
</table>

**$r_4$: Flocculation index**

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;70%</td>
<td></td>
</tr>
<tr>
<td>40-70</td>
<td></td>
</tr>
<tr>
<td>10-39</td>
<td></td>
</tr>
<tr>
<td>&lt;10</td>
<td></td>
</tr>
</tbody>
</table>

The total soil factor rating is obtained by adding the subratings of the individual soil characteristics. The overall classification is as follows:

<table>
<thead>
<tr>
<th>Soil factor rating</th>
<th>sum subratings ($r_1 + r_2 + r_3 + r_4$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>high</td>
<td>≤9</td>
</tr>
<tr>
<td>medium</td>
<td>10-14</td>
</tr>
<tr>
<td>low</td>
<td>&gt;15</td>
</tr>
</tbody>
</table>

*Flocculation index = 100(1 - % natural clay), in which total clay is obtained by using a dispersing agent, for natural clay no dispersing agent is used in the determination.*
<table>
<thead>
<tr>
<th>Profile</th>
<th>pH</th>
<th>CEC</th>
<th>BS %</th>
<th>%C</th>
<th>av.P</th>
<th>exch.K</th>
<th>%N</th>
<th>free</th>
<th>% clay</th>
<th>Hue</th>
<th>YR</th>
</tr>
</thead>
<tbody>
<tr>
<td>EAK 16</td>
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<td>55</td>
<td>6.4</td>
<td>22.1</td>
<td>2.5</td>
<td>.37</td>
<td>7.8</td>
<td>78</td>
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</tr>
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<td>-</td>
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<td>-</td>
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<td>5</td>
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<td>-</td>
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<td>5</td>
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<td>12*</td>
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<td>1.6</td>
<td>1.5*</td>
<td>74</td>
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<td>2.1</td>
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<td>.26</td>
<td>-</td>
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<td>16*</td>
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<td>-</td>
<td>68</td>
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<td>.21</td>
<td>-</td>
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<td>75</td>
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<td>4*</td>
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<td>-</td>
<td>-</td>
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<td>67*</td>
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<td>-</td>
<td>-</td>
<td>43</td>
<td>5</td>
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<td>19.7</td>
<td>14</td>
<td>2.9</td>
<td>-</td>
<td>1.1</td>
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<td>3.1</td>
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<td>7.5-5</td>
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<td>.28</td>
<td>-</td>
<td>51</td>
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</tr>
<tr>
<td>BR 8</td>
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<td>11.1*</td>
<td>51*</td>
<td>1.7</td>
<td>-</td>
<td>2</td>
<td>.19</td>
<td>-</td>
<td>59</td>
<td>5-2.5</td>
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<td>9.2*</td>
<td>33*</td>
<td>1.4</td>
<td>1.3*</td>
<td>.1</td>
<td>.15</td>
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<td>71</td>
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<td>-</td>
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<td>.2</td>
<td>.17</td>
<td>7.1*</td>
<td>43</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>

Table 17: Acidity, cation exchange capacity (NH₄Cl), base saturation, organic carbon, available phosphor, exchangeable potassium, nitrogen, free iron and clay content, and colour of topsoils of 19 humic nitosols (weighted average of top 30 cm of the soil).

*a meq/100 g clay  
*b meq/100 g soil  
*c pH CaCl₂  
*d extraction with 0.5 M NaHCO₃ (method Olsen)  
*e extraction with 0.1 N HCl/0.025 N H₂SO₄ (method Mehlich)  
*f first 18 cm  
*g determined at NAL (Mehlich?)  
*h first 20 cm  
*i first 16 cm  
*j extraction with 0.002 N H₂SO₄ (method Truong)  
*k CEC by sum of cations + extrac H + Al (pH 7)  
*l BS by sum of cations/CEC according to *k  
*m extraction with 0.05 N HCl/0.025 H₂SO₄ (Method Mehlich modified or North Carolina)  
*n free iron as Fe?  
*p pH KCl  

Underlined: low P-availability
### Table 18

Chemical properties and mechanical analysis of the two soil profiles (percent oven-dry soil)

<table>
<thead>
<tr>
<th>Profile</th>
<th>Depth (cm)</th>
<th>pH</th>
<th>Carbon (%)</th>
<th>Mechan. analysis (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>sand</td>
<td>silt</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0-15</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15-30</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>30-45</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>45-60</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>60-90</td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>90-120</td>
<td>15</td>
</tr>
</tbody>
</table>

**Profile Description:**
- **Cultivated Profile:**
  - 0-15 cm: pH 5.4, Carbon 3.8, Sand 17, Silt 28, Clay 54
  - 15-30 cm: pH 5.5, Carbon 3.9, Sand 17, Silt 29, Clay 54
  - 30-45 cm: pH 5.7, Carbon 1.8, Sand 18, Silt 26, Clay 56
  - 45-60 cm: pH 5.6, Carbon 1.4, Sand 18, Silt 25, Clay 57
  - 60-90 cm: pH 5.5, Carbon 0.9, Sand 17, Silt 23, Clay 60
  - 90-120 cm: pH 5.7, Carbon 0.6, Sand 15, Silt 31, Clay 55

- **Leafy Profile:**
  - 0-15 cm: pH 7.0, Carbon 6.8, Sand 18, Silt 34, Clay 47
  - 15-30 cm: pH 7.0, Carbon 4.6, Sand 15, Silt 32, Clay 53
  - 30-45 cm: pH 6.6, Carbon 2.8, Sand 16, Silt 28, Clay 56
  - 45-60 cm: pH 6.1, Carbon 1.8, Sand 16, Silt 25, Clay 57
  - 60-90 cm: pH 5.8, Carbon 1.1, Sand 14, Silt 26, Clay 60
  - 90-120 cm: pH 6.1, Carbon 0.8, Sand 13, Silt 24, Clay 63

**Soil Test Parameters:**
- **Type:**
  - Sandy loam
  - Clay loam
- **pH:**
  - 5.0-6.5
- **Carbon Content:**
  - 1-5%
- **Mechanical Analysis:**
  - Sand: 0-15%, Silt: 15-30%, Clay: 30-60%

**Legend:**
- **Cultivated:**
  - Sandy loam
  - Clay loam
- **Leafy:**
  - Sandy loam
  - Clay loam

**Additional Information:**
- **Fertility-capability grouping of 19 humic nitosols.
  - Type and substrate type (clay, loam, etc.)
  - Condition modifier (h, d, a, k, etc.)
  - Soil test parameters (pH, CEC, etc.)
  - Soil texture (sandy, clayey, etc.)

**Notes:**
- Soil tests conducted at various depths and conditions to determine fertility and capability.
**EAK 16 Soil profile description**

Physiography: rolling volcanic upland
Geology: Tertiary volcanics, trachytes
Altitude: 2170 m (7000 ft)
Slope: 0-2 % (flat to almost flat)
Slope length: 200 m
Vegetation: forest (trees 40%, shrubs 20% and herbs 40%)

**Soil drainage:**

**Soil moisture:**

**Soil profile description**

<table>
<thead>
<tr>
<th>horizon</th>
<th>depth in cm</th>
<th>description</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0 - 10</td>
<td>dark reddish brown (2.5YR2.5/4) clay loam; very fine and fine crumb; slightly hard dry, very friable moist, slightly sticky and slightly plastic wet; many fine, medium and coarse roots; clear smooth boundary to</td>
</tr>
<tr>
<td>AB</td>
<td>10 - 35</td>
<td>dark reddish brown (2.5YR3/4) clay; moderate fine, medium and coarse subangular blocky; slightly hard dry, very friable moist, sticky and plastic wet; few thin argillans; many fine and common medium pores; many fine, medium and coarse roots; some charcoal fragments; gradual wavy boundary to</td>
</tr>
<tr>
<td>Bt1</td>
<td>35 - 100</td>
<td>dusky red (10R3/3) clay; moderate fine, medium and coarse angular blocky; very friable moist, sticky and plastic wet; common thin argillans; pores as in AB; many fine and common medium roots; gradual smooth boundary to</td>
</tr>
<tr>
<td>Bt2</td>
<td>100 - 150+</td>
<td>dusky red (10R3/6) clay; strong medium and coarse angular blocky; friable moist, sticky and plastic wet; common thin argillans; very few soft sesquioxidic accumulations; many fine and common medium pores; common fine and medium roots.</td>
</tr>
</tbody>
</table>
### Elemental composition of the total soil (weight %)

<table>
<thead>
<tr>
<th>Soil</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>TiO₂</th>
<th>MnO</th>
<th>P₂O₅</th>
<th>BaO</th>
<th>Ign. loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.10</td>
<td>22.21</td>
<td>13.13</td>
<td>6.54</td>
<td>3.86</td>
<td>1.20</td>
<td>1.66</td>
<td>0.18</td>
<td>0.2</td>
<td>0.02</td>
<td>0.14</td>
<td>0.43</td>
<td>0.01</td>
</tr>
<tr>
<td>1.05</td>
<td>22.43</td>
<td>14.16</td>
<td>6.73</td>
<td>3.57</td>
<td>1.20</td>
<td>1.61</td>
<td>0.17</td>
<td>0.2</td>
<td>0.02</td>
<td>0.14</td>
<td>0.43</td>
<td>0.01</td>
</tr>
<tr>
<td>1.10</td>
<td>24.15</td>
<td>19.18</td>
<td>6.27</td>
<td>3.13</td>
<td>0.38</td>
<td>1.50</td>
<td>0.19</td>
<td>0.1</td>
<td>0.14</td>
<td>0.23</td>
<td>0.24</td>
<td>0.01</td>
</tr>
<tr>
<td>0.07</td>
<td>30.01</td>
<td>20.82</td>
<td>5.67</td>
<td>2.57</td>
<td>0.15</td>
<td>1.49</td>
<td>0.19</td>
<td>0.1</td>
<td>0.14</td>
<td>0.23</td>
<td>0.24</td>
<td>0.01</td>
</tr>
</tbody>
</table>

### Elemental composition of the clay fraction (weight %)

<table>
<thead>
<tr>
<th>Soil</th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>K₂O</th>
<th>Na₂O</th>
<th>TiO₂</th>
<th>MnO</th>
<th>P₂O₅</th>
<th>BaO</th>
<th>Ign. loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>9.14</td>
<td>22.43</td>
<td>13.13</td>
<td>6.54</td>
<td>3.86</td>
<td>1.20</td>
<td>1.66</td>
<td>0.18</td>
<td>0.2</td>
<td>0.02</td>
<td>0.14</td>
<td>0.43</td>
<td>0.01</td>
</tr>
<tr>
<td>8.92</td>
<td>22.43</td>
<td>14.16</td>
<td>6.73</td>
<td>3.57</td>
<td>1.20</td>
<td>1.61</td>
<td>0.17</td>
<td>0.2</td>
<td>0.02</td>
<td>0.14</td>
<td>0.43</td>
<td>0.01</td>
</tr>
<tr>
<td>8.51</td>
<td>24.15</td>
<td>19.18</td>
<td>6.27</td>
<td>3.13</td>
<td>0.38</td>
<td>1.50</td>
<td>0.19</td>
<td>0.1</td>
<td>0.14</td>
<td>0.23</td>
<td>0.24</td>
<td>0.01</td>
</tr>
<tr>
<td>8.50</td>
<td>30.01</td>
<td>20.82</td>
<td>5.67</td>
<td>2.57</td>
<td>0.15</td>
<td>1.49</td>
<td>0.19</td>
<td>0.1</td>
<td>0.14</td>
<td>0.23</td>
<td>0.24</td>
<td>0.01</td>
</tr>
</tbody>
</table>

### Clay mineralogy

- **K₁/K₂**: 1+<br>- **Verm**: 2+<br>- **Chlor**: 1+<br>- **Smec**: 0+<br>- **Mix**: 0+<br>- **Quar**: 0+<br>- **Feld**: 0+<br>- **Gibb**: 0+<br>- **Goeth**: 0+<br>- **Ham**: 0+

### Sand mineralogy

- **Quar**: 0+<br>- **Feld**: 0+<br>- **Gibb**: 0+<br>- **Goeth**: 0+<br>- **Ham**: 0+

### Water soluble salts

<table>
<thead>
<tr>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>Na</th>
<th>Sum</th>
<th>Exch.</th>
<th>Soil</th>
<th>Clay</th>
<th>BS</th>
<th>BS</th>
<th>EC (mS/cm)</th>
<th>Ca</th>
<th>Mg</th>
<th>K</th>
<th>Na</th>
<th>CO₃</th>
<th>HCO₃</th>
<th>CI</th>
<th>SO₄</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>2.3</td>
<td>0.1</td>
<td>1.1</td>
<td>3.5</td>
<td>3.9</td>
<td>18.1</td>
<td>11.1</td>
<td>2.5</td>
<td>1.7</td>
<td>4.7</td>
<td>25</td>
<td>1.2</td>
<td>1.6</td>
<td>1.2</td>
<td>2.5</td>
<td>10</td>
<td>2</td>
<td>1.1</td>
</tr>
</tbody>
</table>

### Exchangeable cations

- **Ca**: 0.1<br>- **Mg**: 0.2<br>- **K**: 0.3<br>- **Na**: 0.4

### pH

- **pH**: 7.2

### EC

- **EC (mS/cm)**: 1.7
<table>
<thead>
<tr>
<th>Sample</th>
<th>Moisture retention (wt %)</th>
<th>Bulk density g/cm³</th>
<th>Available moisture wt % vol % m³/cm³</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>45.4 40.7 36.2 33.6 31.3 27.6 24.9 1.07</td>
<td>9.4 10.1 1.0</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>43.1 40.4 35.0 31.9 28.8 28.7 24.4 1.14</td>
<td>7.6 8.4 0.9</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>44.6 42.7 37.4 34.5 32.5 33.3 31.2 1.15</td>
<td>5.4 6.1 0.6</td>
<td></td>
</tr>
</tbody>
</table>

| Sample | Spec. surf. m²/g  
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>soil</td>
<td>clay</td>
</tr>
<tr>
<td>A</td>
<td>158</td>
</tr>
<tr>
<td>AB</td>
<td>192</td>
</tr>
<tr>
<td>Bt1</td>
<td>186</td>
</tr>
<tr>
<td>Bt2</td>
<td>192</td>
</tr>
</tbody>
</table>

| Sample | Na⁺ (g/m³) Al% Fe%  
|--------|---------------------|
|        | NH₄ Ox (g/m³) Al% Fe%  
| Na⁺ (g/m³) | Fe/Al (soil) Fe/Al (clay)  |
| A      | 0.5 7.48 0.23 0.60 0.71 0.13 0.10 0.57 |
| AB     | 0.5 7.40 0.26 0.64 0.19 0.26 0.10 0.56 |
| Bt1    | 0.8 7.68 0.22 0.54 0.29 0.09 0.09 0.54 |
| Bt2    | 0.8 8.05 0.09 0.17 0.14 0.03 0.09 0.54 |