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SOIL MONOLITH PAPER 4

HUMIC NITOSOL
(OXIC PALEUSTALF)

KENYA

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CONTENTS

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 occurence 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 occurence 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. 1)(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 subhumic 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 tertiairy basic volcanic rock or precambrian rock (schist, gneiss, quarzite). 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 precambrian rock of the African shield (schist, gneiss, amphibolite, quarzite, charnockite), under humid or subhumid tropical climatic conditions.
Outside Africa the occurrence of humic nitosols is reported in Burma (vol. VII, North and Cental 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 semihot 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 intensivelly 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, sugercane 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 sugercane.
In Asia (The Phillipines, 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, sugercane, 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).
Climatic 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 1953 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 recieves 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 (Sombroek et al 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 6 (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 EAK 16 site, deduced from the ombro-thermic diagram (see fig. 2, the PE is in this case calculated from the Eo, that is determinated 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(transpi)ration and temperature. Temperature and potential evapo(transpi)ration 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 recieve more than the average rainfall during the long rains in Central Kenya is less than about 44 % and to recieve 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 accompagnying 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 bazaltic 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 sligthly convex interfluves, 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 Nairoby 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 Acasia 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 $1^{\circ}13'S/36^{\circ}38'E$ 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 cumulated 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 $^{\circ}C$, the soil temperature regime is considered as isothermic, with a mean annual soil temperature at a depth of 50 cm between 15 and 22 $^{\circ}C$ and a difference between mean summer and winter temperature less than 5 $^{\circ}C$.
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) 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 conspicious 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 significates that the clay fraction must be composed either of a fairly high amount of 2:1 clay minerals, particularly vermiculite or smectite (which is unprobable, see section 2.2.4), 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) measered 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 de deduced from the pF data (see appendix 1). The clear drop in the water content from pF 1.5 to pF 2.0 demonstrates that large macro-pores (> 50 µm) contribute in a considerable way to the porosity of the soil. The water content at pF 4.2 is still high (27-31 wt%) which points to the abundancy of micro-pores (< 0.2 µm), correlated with the high clay content. The available water content is therefore not very high.
Typic, strong bifringent, thin clayskins are present in the thin sections of the AB, Bt1 and Bt2 horizons (for the micro-morphological descriptions one is referred to apppendix 2). Their amount is rather low and increases slightly with depth. Part of the clayskins 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 mangane. 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 abundancy 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_2O) of the soil decreases with depth from 6.4 in the A horizon to 5.4 in the Bt2 horizon. In the A, AB and Bt1 horizon the difference between pH(H_2O) and pH(KCL), ΔpH , is one pH unit or more; in the Bt2 horizon ΔpH 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/ % clay] x 100 = x) and the CECc ([CEC/ % clay] x 100=y), it is evident that the organic matter content is largely responsable for the increased CEC values of the Bt1, AB and A

horizons. The CECc of all horizons, corrected for organic matter (method: Rochiman 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 (Bt1, Bt2) and below 50 % (AB).
The X-ray analyses indicate that the clay fraction consists of predominant kaolinitic clay minerals, of feltspar and of iron(hydr)oxides.
The 'free' iron(hydr)oxides (i.e. not bound to silicates) occur mostly in cristalline 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) (Andriesse, 1979) is relatively high in the topsoil (0.08) but drops to low values in the Bt2 (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 amourphous 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 valleybottoms, 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 altitudes (xx m) and into eutric nitosols with nito-chromic* cambisols and chromic acrisols , partly with a pisoferric* or petroferric fase at lower altitudes (xx m).

* according to the KSS classification (Sombroek, 1982)
nitochromic cambisol: FAO chromic cambisol
chromic 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 scarse 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 segragation of iron and aluminium, are inhibited in nitosols due to both the high supply of basis and the maintainance 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 (per)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 3.2.3) , 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 conspicious 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 ferrallitisation 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 cristal 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 recombinates with Si to form secondary kandic clayminerals (neoformation of clay).
Comparison of the SiO_2/Al_2O_3 ratio of the quarztrachyte of table 5 (5.2) with the SiO_2/Al_2O_3 ratio of the soil material of profile EAK 16 (between 3.1 and 2.3) reveals that desilication indeed has taken place. The SiO_2/Al_2O_3 ratio of the soil material <2 um shows values between 2.3 and 2.1; weathering thus has almost reached the stage of monosiallitisation (Pedro, 1977). Further indications of the strong degree of weathering of soil profile EAK 16 are the low silt/clay ratio (see apppendix 1), the rather high values of the Fe_d/Fe_t 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 year 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 SiO_2/R_2O_3 ratio of the soil material with depth is usually concieved 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 SiO_2/R_2O_3 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 ferralsols (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 aluminiumoxides 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 gradually looses basic cations 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 kaolinite is 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 responsable for the shiny appearance of the pedfaces, characteristic for the nitosols. Sombroek et al. (1977) have tentatively named this process 'metallization'.
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 ferralsol 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., 1977, Sombroek et al., 1982), suggests that inheretance 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. Particurlarly the activity of the abundantly occurring subterranean termites (Odontotermes sp.) is reported to have important consequences on soil formation (Wielemaker, 1984). 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 determinated 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 cristalline 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 heamatite in the topsoil is possibly related to the high concentration of organic components, that may prevent the formation of ferrihydrite, a necessary precursor of haematite (Schwertmann, 1977).
The high specific surface areas of soil profile EAK 16 (about 220 m^2/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 m^2/g respectively 100 m^2/g (Hillel, 1982; Scheffer et al., 1979). Bigham et al. (1978) indeed observed that the high specific surface area of well drained ulti- 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 cristalline ironoxides were responsable for the high specific surface areas. Values of specific surface area for oxisol ironoxides were lower than those obtained for ultisol ironoxides, which has also been reported by Sombroek et al. (1982). Bigham et al suggest that this blockage of ironoxide surfaces in oxisols is caused by aggradation of the ironoxides 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 ironoxides by an equivalent amount of cations or anions. The ZPC (zero point of charge)of synthetic goethite and heamatite 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 ironoxides 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 ironoxides showing the highest values of specific

surface area absorbed most phosphate. A link with the composition of the ironoxides could however not be ruled out, as according to the observations of these authors, soil goethite had a higher specific surface area than soil heamatite. As the available P (Olsen) in soil profile EAK 16 is very low, it must be reckened 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. (1977) 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 polimerization 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 retaines 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 CEC(NH_4CL) 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_4OAC) 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 easely 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 fulfil 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 partical 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 um) 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 180 cumulative days or it is continuously moist in some part for at least 90 consecutive days. Van Wambeke (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 $^{\circ}$C at a depth of 50 cm with a yearly variation of less than 5 $^{\circ}$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 alfisol, 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 determinated 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, isthermic, 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, 197?)
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 alfisol. 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 palehumult, 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 BCtg 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, looses 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 ofcourse also apliccable 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 sesquioxides de fer' and the 'sols ferrallitiques'. According to this system soil profile EAK 16 belongs to the classe sols ferrallitic, sous classe faiblement desaturés 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 thirth class is introduced by upgrading the two subclasses of the 'sols a sesquioxides de fer' to two substantive classes. The three classes formed in this way, fersiallitic, ferruginous and ferrallitic soils, represent three 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 pervection, 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 fersiallitic soils. The exchange complex lies between 25 and 16 meq/100 g clay.

Phase 3: ferallitisation. 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 controll 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 <u>class</u>: **Fermonosialsol.** The mineral horizon below the humus horizon (mineralon) 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 30 % or less; an amount of weatherable minerals of 10 % or less in the 20-200 um fraction.

<u>subclass</u>: **kaoli-** and **goethi-**. Kaoli- means that more than half of the clay minerals of the mineralon consist of kaolinite. Goethi- means that more than half of the free iron oxides of the mineralon consist of goethite.

level II <u>great group</u>: **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).

<u>group</u>: **argillanic.** The mineralon contains more than 5 % argillans (when this is not the case the soil belongs to the orthic group).

<u>subgroup</u>: **red, prismatic, shiny**

<u>family</u>: **alterite of quartz trachyte**

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

<u>type</u>: **clay, medium available water volume in the topsoil, low available water volume in the subsoil.**

<u>variety</u>: **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* (Klamt 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_2O_3 content, high magnetic susceptability and effervescence with H_2O_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 decribed 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 nitisols. 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 m^2/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 recources 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 recources 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 determinated 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 standarized because thew 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 or 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 imput 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 densily 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 farmsize ?? 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 availibility 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 susceptability 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 determinated 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 determinated 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 assesment 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 watertables. 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 availbility is determinated 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 susceptable 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 determinated 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 susceptable 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) beween 150 and 500 mm/hr on humic nitosols in the Kisii area in Kenya, recorded with infiltro-rings. Shitakha (1984) found values bwteen 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 plateaus, 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 temporarely 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 assesment 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 susceptability 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 arablility 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 depents 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(H_2O) 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 slighty 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 determinated at pH 7 exaggerates the acidity of the soil as does the base saturation determinated 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. Moshi 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 easely 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 diminuished 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 easely. 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 correllated with nitrogen responce in the field. With few exceptions nitrogen soil tests are also not reliable enough to predict nitrogen responce. Field experiments must be used to evaluate the nitrogen supply of soils. Therefore no general assesment 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 responce to nitrogen fertilizers occured. 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, Scholten et al, 1982) the underlined values are assesed as low. This means that the majority of the topsoils of the examinated humic nitosols are deficient in P. The fixation of P by iron(hydr)oxides 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 correllated 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 montmorrolinitic clayminerals can not 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 at 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 assesment 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 sensative 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. As most profiles data needed for the first criterion were not available, in all cases the second criterion is used. This significates 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 toxity 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. Occasionaly the soil is stronger acid.

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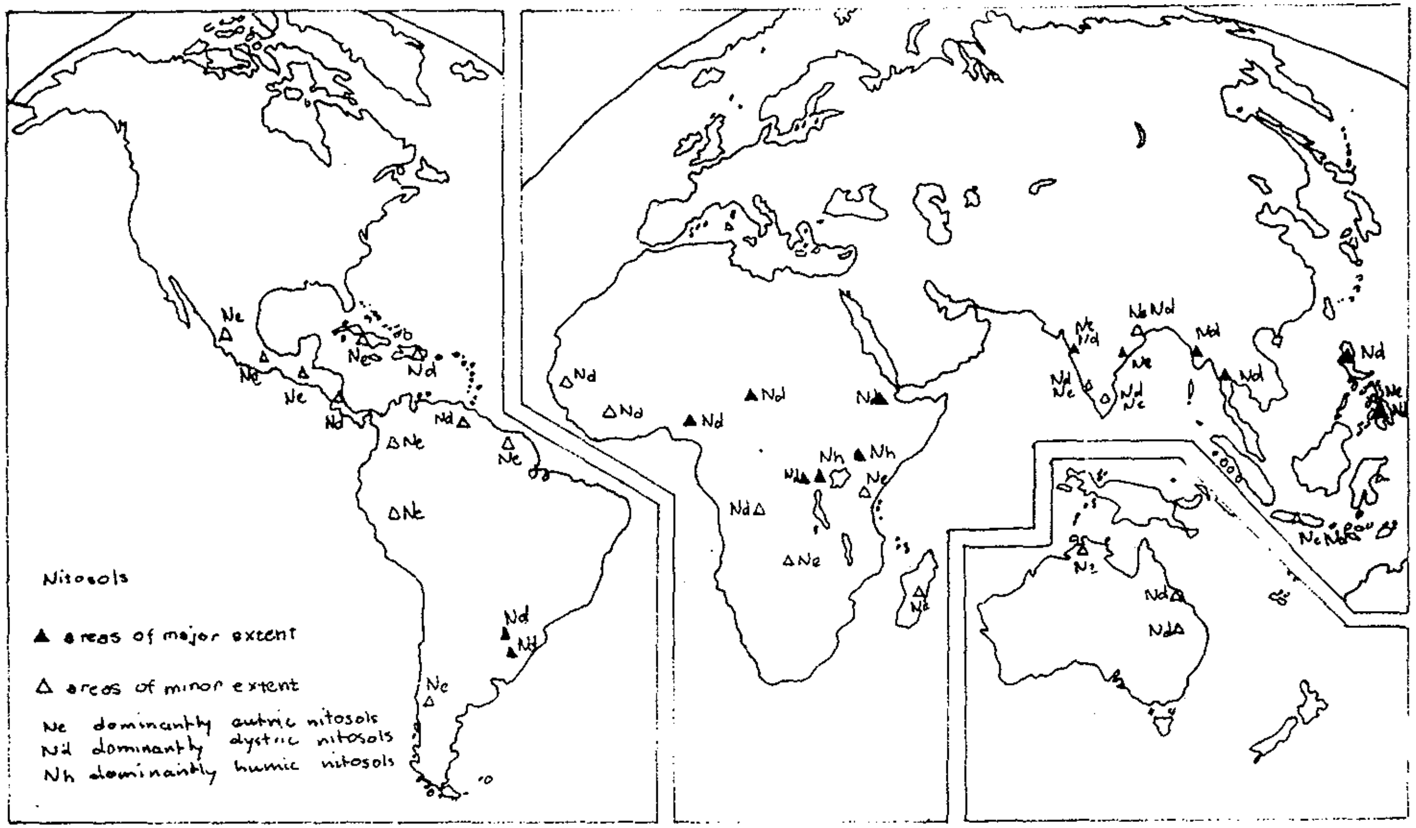

Nitosols
areas of major extent
areas of minor extent
Ne dominantly eutric nitosols
Nd dominantly dystric nitosols
Nh dominantly humic nitosols

figure 1

figure 3 BAKER 1965a

DIAGRAMMATIC SECTIONS SHOWING DEVELOPMENT OF

THE CENTRAL RIFT IN KENYA

Late Miocene - early Pliocene

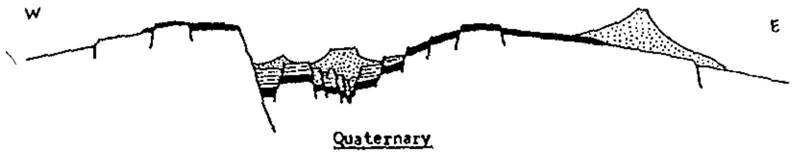
1. Phonolites erupted on crest of uplift.

2. Faulting on W.side of rift, monoclinal flexuring on E.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.

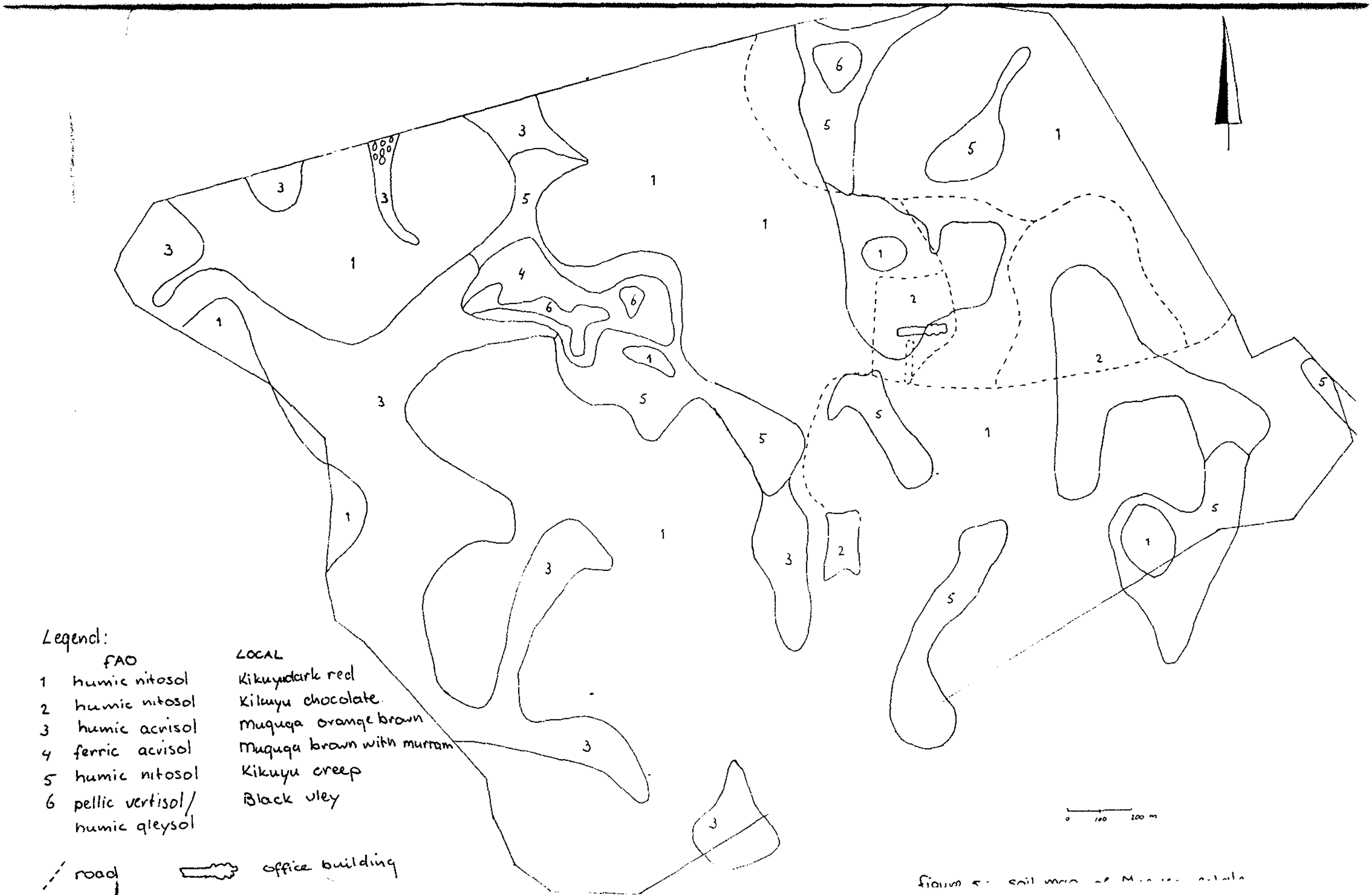


figure 5: soil map of [illegible]

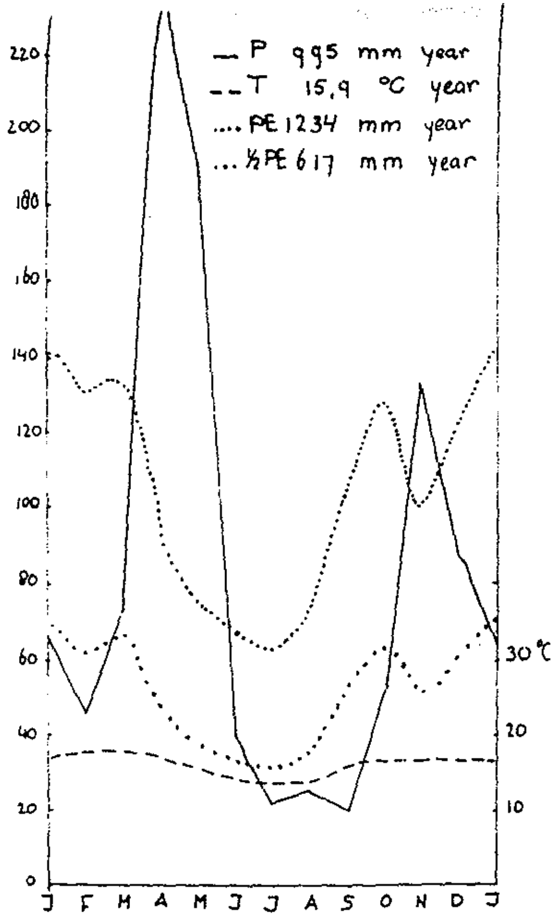


figure 2

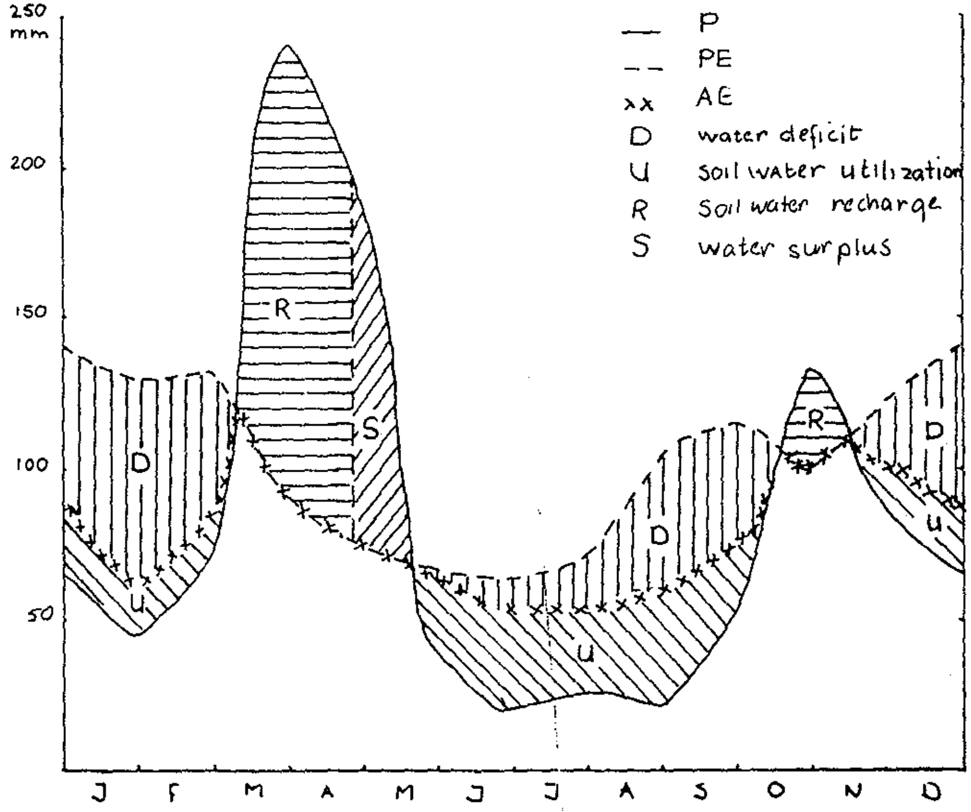


figure 7

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

Table 1: climatic data of Muguga station, EAMD, 1975.

	100	150	200	250	300	350	400	450	500 mm precipitation
long rains	100	100	98	92	87	80	68	56	44 % probability
short rains	95	86	68	50	32	22	15	8	3 % probability

long rains: march-may 503 mm precipitation, 228 mm potential evapotranspiration
short rains: oct.-dec. 274 mm precipitation, 393 mm potential evapotranspiration

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 Baker 1954

elemental composition		normative composition		
element	% weight	mineral	%	formula
SiO_2	59.17	quartz	2.06	SiO_2
Al_2O_3	17.19	orthoclase	21.90	$KAlSi_3O_8$
Fe_2O_3	5.51	albite	55.90	$NaAlSi_3O_8$
FeO	1.02	anorthite	6.30	$CaAl_2Si_2O_8$
MgO	0.87	diopsite	1.84	$Ca(Mg,Fe)Si_2O_6$
CaO	2.39	illimenite	2,41	$(Fe,Ti)_2O_3$
Na_2O	6.60	apatite	1.10	$Ca_5F(PO_4)_3$
K_2O	3.70			
H_2O ±	1.48			
TiO_2	1.47			
P_2O_5	0.46			
F	0.12			
	99.98			

zone	r/Eo (%)	classification	average annual rainfall (mm) r	average annual potential Eo evaporation (mm)	vegetation	potential for plant growth	risk of failure of an adapted maize crop
			excluding areas above 10,000 ft altitude			assuming that soil conditions are not limiting	
I	> 80	humid	1100 - 2700	1200 - 2000	moist forest	very high	extremely low (0 - 1%)
II	65 - 80	sub-humid	1000 - 1600	1300 - 2100	moist and dry forest	high	very low (1 - 5%)
III	50 - 65	semi-humid	800 - 1400	1450 - 2200	dry forest and moist woodland	high to medium	fairly low (5 - 10%)
IV	40 - 50	semi-humid to semi-arid	600 - 1100	1550 - 2200	dry woodland and bushland	medium	low (10 - 25%)
V	25 - 40	semi-arid	450 - 900	1650 - 2300	bushland	marginal	high (25 - 75%)
VI	15 - 25	arid	300 - 550	1900 - 2400	bushland and scrubland	low	very high (75 - 95%)
VII	< 15	very arid	150 - 350	2100 - 2500	desert scrub	very low	extremely high (95 - 100%)

Sombroek et al, 1982

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

zone	mean annual temperature (°C)	classification	mean maximum temperature (°C)	mean minimum temperature (°C)	absolute minimum temperature (°C)	night frost	altitude (feet)	altitude (meters)	general description
9	less than 0	cold to very cold	less than 16	less than 4	less than - 4	very common	more than 10,000	more than 3050	Afro-Alpine Highlands
8	10 - 12	very cool	16 - 18	4 - 6	- 4 to - 2	common	9000 - 10,000	2750 - 3050	Upper Highlands
7	12 - 14	cool	18 - 20	6 - 8	- 2 to 0	occasional	8000 - 9000	2450 - 2750	
6	14 - 16	fairly cool	20 - 22	8 - 10	0 - 2	rare	7000 - 8000	2150 - 2450	Lower Highlands
5	16 - 18	cool temperate	22 - 24	10 - 12	2 - 4	very rare	6000 - 7000	1850 - 2150	
4	18 - 20	warm temperate	24 - 26	12 - 14	4 - 6	none	5000 - 6000	1500 - 1850	Midlands
3	20 - 22 **	fairly warm	26 - 28	14 - 16	6 - 8	none	4000 - 5000	1200 - 1500	
2	22 - 24 **	warm	28 - 30	16 - 18	8 - 10	none	3000 - 4000	900 - 1200	
1	24 - 30 **	fairly hot to very hot	30 - 36 *	18 - 24 *	10 - 16	none	0 - 3000	0 - 900	Lowlands

** 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

* at the Coast 28 - 31 and 20 - 23 resp.

Sombroek et al, 1982

Table 6 <u>Land qualities and their land characteristics</u> from nyandat et al 1980

Land quality	Land characteristic (s)
Climate	ecological zones (climatic characteristics)
Soil moisture storage	soil depth total productive available moisture (TPAM) profile hindrance to root development (rootable depth)
Chemical soil fertility	CEC soil or sum of cations available nutrients mineral reserve (total mineral content of soil)
Possibilities for the use of agricultural implements (possibilities for mechanisation)	steepness of slope stoniness and rockiness of the soil or shallowness of the bed rock slope length "workability" of the soil
Resistance to erosion	slope class climate slope length "erodability" (susceptibility to sealing)
Presence of hazard of water logging (Availability of oxygen for root growth)	drainage
Hindrance by vegetation	thickness of vegetation in terms of physiognomic types
Presence of overgrazing	visual observations of the present status of overgrasing
Availability of foothold for roots	depth to hindering layer

7: waterbalance of a soil with a storage capacity (ST_0) of 200 mm at Muguga, according to Thorntwaite 1955.

	16.8	17.3	17.7	17.0	15.7	14.4	13.5	13.9	15.3	16.6	16.2	16.3	15.9 °C
	141	130	134	94	76	68	63	71	106	128	101	122	1234 mm
	66	45	73	240	190	40	21	25	21	53	133	88	995 mm
PE	-75	-85	-61	146	114	-28	-42	-46	-85	-75	32	-34	
WL	-285	-370	-431	-33	0	-28	-70	-116	-201	-276	-176	-210	
T	48	31	23	169	200	174	141	112	73	50	82	69	
ST	-21	-17	-8	146	31	-26	-33	-29	-39	-23	32	-13	
E	87	62	81	94	76	66	54	54	60	76	101	101	912 mm
	54	68	53	0	0	2	9	17	46	52	0	21	322 mm
	0	0	0	0	83	0	0	0	0	0	0	0	83 mm
	J	F	M	A	M	J	J	A	S	O	N	D	YEAR

temperature

E potential evapotranspiration

precipitation

PWL accumulated deficit of precipitation

ST storage in soil profile

ΔST change of storage in soil profile

AE actual evapotranspiration

D deficit in soil profile

S surplus

8: This table is dropped

9: rating of soil moisture storage capacity. Braun et al, 1977

rating	TRAM (Total Readily Available Moisture pf 2.3 - pf 3.7)
1 very high	160 - 200
2 high	120 - 160
3 moderate	80 - 120
4 low	40 - 80
5 very low	less than 40

table 10 Availability of oxygen for root growth   Braun et al, 1977

ratings:	drainage class	....colour and mottling
1. No....	well to excessively drained soils	... no distinct mottling within 90cm, and/or reduced colours within 150 cm
2. Slight ...	moderately well drained soils	... no distinct mottling within 50cm and/or reduced colours within 120 cm
3. Moderate..	imperfectly drained soils	... no reduced colours or distinct mottles within 50 cm
4. High....	poorly drained soils	... partly reduced colours and distinct mottles within 50 cm
5. Very high..	very poorly drained soils	... predominantly reduced colours

11: particle size distribution of the upper horizons of a humic nitosol from Ruiru Coffee Research station with addition of a dispersing agent (above) and without addition of a dispersing agent (below) from Ahn, 1977

izon pth cm	2000-600 µm	600-200 µm	200-60 µm	60-20 µm	20-6 µm	6-2 µm	<2 µm	texture
-8	1.0	1.9	1.2	14.7	15.1	7.8	58.4	clay
-15	1.0	2.0	1.6	21.3	13.3	9.4	51.5	clay
-30	.8	1.5	1.4	8.2	9.9	8.3	69.8	clay
0-50	.5	1.5	2.2	4.4	8.3	6.1	77.0	clay
-8	.3	5.1	14.2	17.8	28.1	14.0	20.5	silt loam
-15	1.2	3.4	30.6	21.2	16.3	8.4	18.9	loam
5-30	1.0	2.4	36.4	25.6	15.2	15.2	4.2	silt loam
0-50	.5	1.6	34.8	23.9	34.5	3.1	1.6	silt loam

table 12 rating of the climate factor, Gachena et al, 1984

rating	$KE_{15}>25$	agro-climatic zone*
1	<5,000	VI, VII
2	5,000-10,000	III, IV, V
3	>10,000	I, II

table 13: rating of the slope-factor, Gachena et al, 1984

slope length(m) \ slope class %	A 0-2	B 2-5	C 5-8	D 8-16	E 16-30	F 30-45	G >45
<50	1	1	3	3	5	5	7
50-100	1	3	3	5	5	7	7
100-200	1	3	5	5	7	7	9
>200	3	5	5	7	7	9	11

table 15 Gachena et al, 1984

Plant cover factor

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

rating	plant cover %
1	>70
2	50-70
4	20-49
7	<20

table 16: Final rating "resistance to erosion" Gachena 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:-

rating	sum factors
1	≤10
2	11-15
3	16-20
4	≥21

table 14 rating of the soil factor, Gachene et al 1984

The subratings for the mentioned characteristics are the following:-

r_1: Organic matter

	% OM	or	%C
1	>5		>3.0
2	2-5		1.2-3.0
3	<2		<1.2

r_2: Bulk density (g/cm^3)

1	<1.20
2	1.20-1.50
3	>1.50

r_3: Silt/clay ratio (hydrometer method)

1	<0.20
2	0.20-0.59
3	0.60-1.00
4	>1.00

r_4: Flocculation index*

1	>70%
2	40-70
4	10-39
6	<10

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

Soil factor rating		sum subratings ($r_1 + r_2 + r_3 + r_4$)
1	high	⩽9
3	medium	10-14
5	low	⩾15

---

* flocculation index = $100(1 - \frac{\%\ \text{natural clay}}{\%\ \text{total clay}})$, in which total clay is obtained by using a dispersing agent, for natural clay no dispersing agent is used in the determination

profile	pH H_2O	CEC me% *a	BS %	%C	av.P ppm	exch.K me% *b	% N	free Fe_2O_3	% clay	Hue YR
EAK 16	5.9	22.8	55	6.4	2.1	2.5	.37	7.8	78	2.5
CK 19	4.7*c	26.6	44	6.6	-	.3	-	-	51	5
CK 28	5.2	25.5	23	2.7	3.3*d	.5	-	-	45	2.5
CK 51	6.2	38.0	40	2.5	56*e	2.0	.36	-	65	5
CK 54	5.0	21.8	24	2.6	12*e	.5	.16	1.5*f	74	5-2.5
CK 56	6.6	19.0	66	2.1	33*e	2.3	.26	-	69	2.5
exc.5	5.6	24.0	29	1.5	16*e	.3	.24	-	68	5
WK 13	5.1	22.4	53	2.1	16*g	.6	.21	-	56	5
WK 14	6.6	25.0	93	3.1	30*g,h	.4	.37	4.6	65	7.5-5
WK 16	5.2	20.3	59	2.4	5*g	.4	-	10.2	62	5
WK 18	4.5*p	22.8	52	-	-	1.7	-	-	75	7.5-5
WK 20	5.0	12.3	31	2.2	4*g,i	.3	-	-	55	5-2.5
Kib 92	5.0	13.4	46	1.1	67*e	.3	-	-	43	5
SA 21	5.6	19.7	14	2.9	-	.1	.13	3.1	31	7.5-5
PasFun	5.4	16.2	50	2.2	2*j	1.1	.28	-	51	2.5
BR 8	5.5	11.1*k	51*l	1.7	-	.2	.19	-	59	5-2.5
BR 25	4.9	9.2*k	33*l	1.4	1.3*m	.1	.15	-	71	5-2.5
KB 3	5.4	8.7	15	2.3	-	-	-	-	scl	10
M 1	3.6	7.2	7	1.6	-	.2	.17	7.1*n	43	10

Table 17: Acidity, cation exchange capacity (NH_4CL), 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 $CaCl_2$
*d extraction with 0.5 M $NaHCO_3$ (method Olsen)
*e extraction with 0.1 N HCl/0.025 N H_2SO_4 (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 H_2SO_4 (method Truog)
*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 H_2SO_4 (Method Mehlich modified or North Carolina)
*n free iron as Fe?
*p pH KCl
underlined: low P-availability

MOSHI et al, 1974

TABLE 18

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

Profile	Depth (cm)	pH	Carbon (%)	Mech. analysis (%)		
				sand	silt	clay
cultivated	0--15	5.4	3.8	17	28	54
	15--30	5.5	3.9	17	29	54
	30--45	5.7	1.8	18	26	56
	45--60	5.6	1.4	18	25	57
	60--90	5.5	0.9	17	23	60
	90--120	5.7	0.6	15	31	55
forest	0--15	7.0	6.8	18	34	47
	15--30	7.0	4.6	15	32	53
	30--45	6.6	2.5	16	28	56
	45--60	6.1	1.8	16	28	57
	60--90	5.8	1.1	14	26	60
	90--120	6.1	0.8	13	24	63

Table 19 Fertility-capability classification. buol et al, 1975

TYPE

Texture is average of plowed layer or 20 cm depth, (8") whatever is shallower

S = Sandy topsoils: loamy sands and sands (USDA).

L = Loamy topsoils: < 35% clay but not loamy sand or sand

C = Clayey topsoils: > 35% clay.

O = Organic soils: > 30% O.M. to a depth of 50 cm or more

SUBSTRATA TYPE

Used if textural change or hard root restricting layer is encountered within 50 cm (20").

S = Sandy subsoil: texture as in type.

L = Loamy subsoil: texture as in type.

C = Clayey subsoil: texture as in type.

R = Rock or other hard root restricting layer.

CONDITION MODIFIERS:

In plowed layer or 20 cm (8"), whichever is shallower unless otherwise specified (*)

*g = (Gley)

Mottles ≤ 2 chroma within 60 cm of surface and below all A horizons or saturated with H_2O for > 60 days in most years.

*d = (Dry):

Ustic or xeric environment; dry > 60 consecutive days per year within 20-60 cm depth.

e = (Low CEC):

< 4 meq/100 soil by Σ bases + unbuffered Al.

< 7 meq/100 soil by Σ cations at pH 7.

< 10 meq/100 soil by Σ cations + Al + H at pH 8.2.

*a = (Al toxic):

> 60% Al saturation of CEC by (Σ bases and unbuffered Al) within 50 cm.

> 67% Al saturation of CEC by (Σ sations at pH 7) within 50 cm.

> 86% Al saturation of CEC by (Σ cations at pH 8.2) within 50 cm. or pH < 5.0 in 1:1 H_2O except in organic soils.

*h = (Acid):

10-60% Al saturation of CEC by (Σ bases and unbuffered Al) within 50 cm. or pH in 1:1 H_2O between 5.0 and 6.0.

i = (Fe-P fixation):

% free Fe_2O_3/% clay > 0.15 or hues redder than 7.5YR and granular structure. (only in texture type clay)

k = (K deficient):

< 10% weatherable minerals in silt and sand fraction within 50 cm or exch. K < 0.20 meq/100 g or K < 2% of Σ of bases, if Σ of bases < 10 meq/100 g.

condition modifier combination	type and substrata type clay	loam	total
l	1	-	1
h	-	1	1
hl	6	-	6
dl	2	-	2
al	1	-	1
hk	-	1	1
dhi	4	-	4
hlc	2	-	2
aik	1	-	1
			19

Table 20: Fertility-capability grouping of 19 humic nitosols.

Appendix 1

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 climate: soil moisture regime (SMR): ustic

soil temperature regime (STR): isothermic

Agro-ecological zone:

Length growing season:

Soil classification: USDA Soil Taxonomy:

FAO :

Soil drainage :

Soil moisture :

Soil profile description

horizon	depth in cm	description
A	0 - 10	dark reddish brown (2.5YR2.5/4) (moist) 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
AB	10 - 35	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
Bt1	35 - 100	dusky red (10R3/3) clay; moderate fine, medium and coarse angular blocky; very friable moist, sticky and plastic wet; common ~~thick argillans~~ shiny pedfaces, possibly argillans; pores as in AB; many fine and common medium roots; gradual smooth boundary to
Bt2	100 - 150+	dusky red (10R3/6) clay; strong medium and coarse angular blocky; friable moist, sticky and plastic wet; common ~~thick argillans~~ shiny pedfaces, possibly argillans; very few soft sesquioxidic accumulations; many fine and common medium pores; common fine and medium roots.

EPA 16

Particle size distribution (µm in weight %)

Depth cm	Horizon	>2 mm	Sand 2000–1000	Sand 1000–500	Sand 500–250	Sand 250–100	Sand 100–50	Silt 50–20	Silt 20–2	Clay <2	pH H_2O	pH KCl	Silt/Clay %	Org. matter C %	Org. matter N % / C/N	'Free' Fe_2O_3 %	P avail. mg/1000gr
-10	A	-	0.2	0.7	1.3	2.3	1.3	2.9	6.4	74.8	6.36	5.37	0,22	6.54	0,55 0,51 12,00		4.0
-35	AB	-	0.2	0.6	1.0	1.8	1.2	1.2	14.3	79.6	5.66	4.03	0,18	2.91	0,28 0,21 0,55		1.2
-100	Bt1	-	0.1	0.3	0.8	1.3	0.9	0.3	12.7	83.6	5.75	4.26	0,15	0,96	0,14 0,16 7,0		2.4
-150	Bt2	-	0.1	0.2	0.3	0.5	0.3	0.6	7.6	90.3	5.43	3.99	0,08	0,34	0,06 0,06 6,0		2.1

Exchangeable cations pH 7,0

Ca	Mg	K	Na	Sum	Exch. acid. TEA	CEC Soil	CEC Clay	BS %	BS Sum of Cations	EC 1:2½ (mS/cm)
8	8.1	2.9	0.0	22.8		30.9	41.3	74	72	0.28
2	2.8	2.3	0.1	8.4		18.8	23.6	45	38	0.16
1.0	[illegible]	1.0	0.1	8.4		14.7	17.6	57	47	0.08
[illegible]	3.1	0.8	0.0	6.3		12.2	13.5	52	41	0.07
8	7.9	3.0	0.0	22.7	8.9	30.9				
8	2.7	2.4	0.0	7.9	13.6	19.7				
7	3.0	0.8	0.0	7.5	9.4	15.7				
0	[illegible]	0.9	0.0	6.0	9.1	12.6				

Water soluble salts

Ca	Mg	K	Na	CO_3	HCO_3	Cl	SO_4
meq/100 g							

Elemental composition of the total soil (weight %)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	Ign. loss	Molar ratios SiO_2/Al_2O_3	SiO_2/Fe_2O_3	SiO_2/R_2O_3	Fe_2O_3/Al_2O_3	Σ
1.10	22.21	13.13	0.64	0.36	1.20		1.44	0.57	0.18	0.14	19.82	3.14	8.32	2.78	2.65	100.79
1.05	24.49	14.16	0.17	0.23	1.09		1.57	0.52	0.11	0.14	14.73	2.85	7.70	2.08	2.71	98.20
1.68	26.50	14.28	0.15	0.21	0.88		1.50	0.33	0.07	0.14	12.25	2.67	7.75	1.99	2.90	97.77
10.07	30.01	14.82	0.06	0.13	0.43		1.56	0.15	0.06	0.13	12.45	2.27	7.18	1.72	3.43	99.93

Elemental composition of the clay fraction (weight %)

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	TiO_2	MnO	P_2O_5	BaO	Ign. loss	Molar ratios SiO_2/Al_2O_3	SiO_2/Fe_2O_3	SiO_2/R_2O_3	Fe_2O_3/Al_2O_3	Σ
9.14	28.93	6.48	0.15	0.22	0.54		1.62	0.18	0.28	1.74	12.69	2.30	6.31	1.68	2.75	100.24
0.22	30.37	6.30	0.02	0.19	0.51		1.56	0.23	0.19	1.60	12.31	2.25	6.56	1.67	2.92	101.77
8.51	29.91	15.27	0.03	0.19	0.43		1.42	0.21	0.12	1.57	12.26	2.19	6.70	1.65	3.07	98.38
9.50	31.59	14.60	0.01	0.18	0.29		1.37	0.13	0.11	1.49	12.40	2.12	7.19	1.64	3.39	100.14

Clay mineralogy

Kaol	Mi/Ill	Verm	Chlor	Smec	Mix	Quar	Feld	Gibb	Goeth	Hem
++	tr-+					x			x	
++	tr-+					x			x	
++	tr					tr-x			x	
+++	tr					–			x	

Sand mineralogy	Bulk density (kg/dm³)	Soil moisture pF 2.0 (weight %)	pF 2.5	pF 4.2
50–500				

3.7 particle density (specific gravity)

ample izon depth	moisture retention (wt %)							bulk density	available moisture pF 2,0 - pf 4,2		
	pf 1	pf1,5	pf 2,0	pf2,5	pf 3,0	pf 3,4	pf4,2	g/cm³	wt %	vol %	mm/cm³
3 21cm	45,4	40.7	36,2	33.6	31.3	27.8	26,8	1.07	9,4	10.1	1,0
1 65cm	43,1	40,4	35,0	31.9	29.8	28.7	27.4	1.14	7.6	8.7	0,9
1 78cm	44.6	42.7	37.4	34.5	32,5	33.3	31.2	1.15	5,4	6,1	0,6
2 115cm	43.3	40.0	35.7	33.3	31,5			1.14			

sample	spec. surf. m²/g soil	clay
A	158	212
AB	172	216
Bt1	186	223
Bt2	192	213

sample	NaD (soil) Al%	Fe %	NH4 Ox (soil) Al%	Fe %	NaP (soil) Al%	Fe %	fed (soil) /clay%	fed/fet (soil)
A	.47	7.48	.23	.60	.07	.13	0,10	0,57
AB	.57	7.90	.26	.64	.19	.26	0,10	0,56
Bt1	.55	7.68	.22	.54	.29	.09	0,09	0,54
Bt2	.28	8,05	.09	.17	.14	.03	0,09	0,54