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COMPARATIVE CLASSIFICATION OF SOME DEEP, WELL-DRAINED RED CLAY SOILS OF MOZAMBIQUE

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CONTENTS

List of abbreviations:

- ST = Soil Taxonomy
- FAO = FAO-Unesco
- CEC = Cation Exchange Capacity
- ECEC = effective CEC
- BS = Base Saturation
- MOC1, etc. = Soil profile number
- AH = Argillic horizon

SUMMARY

Classification according to Soil Taxonomy and FAO-Unesco systems of deep, well drained red clay soils is problematic in many East African countries. This can be in first instance contributed to the uncompleteness of necessary morphological and analytical data. Therefore six soil profiles have been sent to ISRIC for monolith preparation and physical, chemical, mineralogical and micromorphological analysis, according to required methodology. With these data classification appeared to be still problematic. To test this, all available information of the six profiles have been sent to twenty expert soil scientists, which were requested to classify these soils.

The classification results and additional observation on these soils of eighteen experts are presented and studied in this paper. The variation in results indicates an acute first taxonomic level problem in both systems. Main causes of this variation are the still subjective assessment of diagnostic horizons and -criteria, and inconsistencies in the keying procedure.

1. INTRODUCTION

Deep, well drained red clayey soils occupy a considerable part of the northern half of Mozambique and constitute one of the country's most important land resources. Some of these soils have been described in different soil surveys, but no attempt has been made to study them systematically by correlating the existing information.

Classification of these soils in internationally known soil classification systems like the Soil Taxonomy (ST) and the FAO-Unesco Soil Map of the World Legend (FAO) is difficult because only limited analytical data are available, while the methodology employed is not always exactly the same as prescribed by these systems. Furthermore, special analyses like micromorphology, mineralogy, etc. cannot be realized.

The classification of the red soils in Mozambique, as well as in other countries, is further hampered by the fact that their characteristics do not correspond well with the central concepts of the diagnostic soil horizons as used in the ST and FAO systems. This applies especially to the definition of the argillic and oxic B horizon, resulting in uncertainty at the highest level of classification.

Six soil profiles, representative for large areas in northern Mozambique, were sent to ISRIC for monolith preparation, routine analyses and additional research. Even with the detailed information now available, classification appeared to be ambiguous. Twenty expert soil scientists have been consulted to bring in more expertise in the classification of these soils. All available information on the six soil profiles and their environment was sent to these experts, requesting them to classify these soils according to ST and FAO systems. The classification results and the analysis of their heterogenity is presented in this paper. This classification test forms part of a more comprehensive study of deep, well-drained, red clay soils of Mozambique (3).

Note: Numbers within parentheses refer to literature.

2. METHODOLOGY

Soils

The soil profiles used for this classification test were twice described, before and at the end of the rainy season, by two pedologists of which one is the author of this paper.

The soil samples were chemically and physically analyzed at ISRIC's laboratories according to the methods as described in Technical Paper no. 9 (4). The principles of which are summarized in Annex 5.

Micromorphological analysis was executed by the micromorphology section of the Netherlands Soil Survey Institute (STIBOKA). In this paper only the interpretation of the micromorphological descriptions is given, the terminology followed is according to Brewer.

Classification test

In September 1984 a comprehensive data set of six pedons, numbered MOC 1 to MOC 6, was sent to an international group consisting of twenty soil experts, alphabetically presented in Annex 1. Each participant was asked to classify the soils in the ST and FAO systems (1) (8).

The classification test was especially aimed at the morphologically rather uniform and similar pedons MOC 1 to MOC 4 with both textural and oxic B horizons. Pedons MOC 5 and MOC 6 were included as a reference since they offered less problems in classification.

In July 1985 classification results of eighteen participants were available. Most of the experts made additional comments on their classification.

In the annexes 2A and 2B results according to the ST and FAO systems are given. The ranking number is referring to the expert and is arbitrarily given by the chronology of incoming letters and is not corresponding with the alphabetical order of Annex 1 to safeguard anonimity.

Some of the eighteen participants classified only in one system, with the result that fourteen times the soils are classified in the ST system, ten times in the FAO system, and only seven times in both systems. Therefore, in the elaboration of the results most attention is given to the interpretation within each system while the comparison between both systems received less attention.

3. SOILS

3.1 Brief characterization

A short characterization of the six pedons is given here but detailed information will be found in Annexes 3A to 3D. Pedons MOC 1 to MOC 4 comprise very deep, well drained, dark or dusky red clay soils, having a weak to clear A horizon; there is a thin weakly, structured to thick, moderately structured textural B horizon. MOC 5 is a deep, well drained, dark reddish brown clay soil; it has a thick A horizon, a strongly structured (textural) B horizon and no oxic B horizon. Pedon MOC 6 is a deep, well drained, yellowish red, sandy clay soil, with a loamy sand topsoil; below 150 cm there is a strongly mottled, slowly permeable subsoil. The pedon has a thin A horizon, a clear textural B horizon and no oxic B horizon.

3.2 Argillic and Oxic Horizons

The argillic horizon

The identification of eluvial and illuvial horizons is problematic in many deep red clay soils. A substantial textural difference between topsoil and Bt is present in pedons MOC 1 to 4, which fulfils the textural requirement of an argillic horizon (AH). However, a clear eluvial horizon, with an abrupt or clear transition towards an illuvial does not exist.

Sheet wash (a very slow process of truncation) is probably the main cause of the textural differentiation. However, even considering lateral clay transport, the occurrence of vertical movement of some clay into the profile is likely as well.

The identification of cutans in the field is a very subjective action. The low correlation between macro- and micromorphological observations, as reported in the literature - is also found in the studied Mozambican pedons.

In the profile description the upper boundary of the illuvial horizon is set at the lower boundary of an A horizon, factually a colour criterion, which coincides with the textural gradient.

In the profile description the lower boundary of the illuvial horizon is set at an objectively observable gradual structure/consistency change towards an oxic B horizon, the latter having no or a very slight textural gradient.

In table 3 a summary of properties is given, identifying the argillic horizon. The brackets ( ) in this table indicate a disputable property classification; in the column of micromorphology it refers to the presence of argillans not enough to fulfill the requirements for an argillic horizon.

Table 3 - Summary of properties diagnostic for an argillic horizon (AH)

	Clay % diff. in top-subsoil	Struc./cons. difference in subsoil	Approx. thickness of the AH (cm)	Cutans macro	Cutans micro	loc.*	Presence of AH according to ST
MOC 1	22	+	40	(+)	(+)	top Bt	(+)
2	23	+	40	(+)	+	Bt	+
3	32	(+)	80	+	(+)	A+top Bt	(+)
4	34/40	+	95	(+)	+	A,Bt,Bws	+
5	36	-	50?	+	(+)	top B	(+)
6	32/46	-	110	-	+	Bt	+

* loc. = location in the profile

In the very deep highly weathered pedons MOC 1 to 4 the assumed argillic horizon differs from the central concept of an AH in that:

- there is no clear eluvial (E) horizon;
- the upper boundary of the illuvial (Bt) horizon is set at the gradual transition between A and B horizon - based on a colour criterion; however, the textural difference between the A horizon and illuvial horizon is large;
- the illuvial horizon is relatively thin and occurs in the upper part of the subsoil; macro visibility of clay cutans is disputable; micro identification of cutans is in all profiles positive, quantities are variable and only partly fulfilling the requirements of an argillic horizon;
- the lower boundary of the illuvial horizon is mostly set at a gradual or diffuse consistency/structure boundary separating the relatively thin illuvial horizon from a very thick oxic B horizon;
- textural difference between illuvial and the underlying horizon is mostly nil or the decrease in clay percentage is small.

The oxic horizon

The identification of the oxic horizon for profiles MOC 1 to 4 is relatively easy, due to the presence of all typical morphological and analytical properties, diagnostic for the oxic horizon, i.e.:

- very deep solum (4 or more meters)
- vague horizonation and gradual to diffuse boundaries
- (very) weak subangular blocky and/or massive porous structure
- CEC 7 <16 and ECEC <10 me/100g clay*
- frequently a low negative or positive delta pH value
- very low weatherable mineral content
- absence of argillans

* CEC 7 = at pH 7 buffered determination of CEC
ECEC = unbuffered determination of CEC

3.3 Summary of diagnostic horizons and properties

In table 4 a summary is given of the diagnostic horizons and properties necessary for classification.

Structure in the B horizon: Structure grade is diagnostic for the "tropeptic" category. In table 4 the following codes are used: w (weak); m (moderate); s (strong); mp stands for an apedal massive porous structure.

Mollic A horizon: According to definition and criteria in ST and FAO systems.

Argillic B horizon - See paragraph 3.2

Oxic B horizon - See paragraph 3.2

Base saturation: Strongly depends on the analytical method chosen for the determination of the CEC and/or the Exchangeable Acidity. Also the depth at which the BS had to be calculated is important. For a summary of analytical procedures to determine exchange properties one is referred to Annex 4.

Colour: Determination according to standard Munsell Soil Color Charts.

Table 4 - Diagnostic horizons and diagnostic properties in Pedons MOC 1 to 6

	Mol. A	Arg.B	Oxic B	structure in Arg. B	structure in Oxic B	BS[1] (%) top	BS[1] (%) sub[2]	BS[1] (%) sub[3]	colour subsoil
MOC 1	-	(+)	+	w/m	mp	38	18	28	2.5YR3-4/6
MOC 2	-	+	+	w	mp	17	16	14	1.5YR3/6
MOC 3	-	(+)	+	m	w	35	40	28	1.25YR3/5
MOC 4	+/-	+	+	w/m	mp	52	42	44	10R 3/5
MOC 5	+	(+)	-	s	.	72	75	53	2.5YR3/4-5
MOC 6	-	+	-	mp	.	50	37	46	5YR4/6

[1]BS (= base saturation) calculated on CEC (NH_4OAc, pH 7) in top- or subsoil

[2]BS according to FAO "in at least some part of the B horizon within 125 cm"

[3]BS according to ST calculated on CEC "sum of cations pH 8.2" at a depth of about 180 cm. The following approximation is used: BS based on "sum of cations" = 0.7 x BS "NH_4OAc", because CEC "sum of cations pH 8.2" has not been determined.

4. RESULTS

4.1 Classification according to Soil Taxonomy (1975)

In tables 1A and 2A the classification results listed in Annex 2A are presented according to the main taxonomic levels, i.e. order, suborder, great group and subgroup. The number in brackets refers to the number of experts with similar classification results; no number indication refers to a single result. A dotted line on the subgroup level means that no subgroup classification was given.

For each pedon an average of 14 responses from the experts was obtained. Classification results show a wide scattering, each pedon receiving 8 different subgroups names on the average.

Pedons MOC 1 to MOC 4

The variation in the classification of these pedons originates mainly from the first and fourth taxonomic steps, i.e. order and subgroup level.

The results of the first taxonomic step show the problematic decision whether to classify these pedons as Oxi-, Ulti-, or Alfisol. Table 2A shows the overall counts at order level. There is no clear preference visible in the results of pedons MOC 1, 2 and 3; only MOC 4 shows a clear dominance for Alfisols.

The second taxonomic step for all pedons has been executed in a very uniform way. Although only atmospheric climatic data were available, placing them in the Ustic moisture regime was not problematic. Also the great group level was uniformly classified, except for few deviations.

On the fourth taxonomic step, i.e. the subgroup level another scattering occurs.

Analysing the Oxisols population of MOC 1 to 4, the "restgroup" Haplustox was most frequently chosen. Only in two cases it ended as Eutrustox (probably caused by a wrong calculation of BS or by a confusion with the BS criteria of Euthrorthox). Most frequently typic was chosen, followed by tropeptic and rhodic, the latter not defined in ST but yet proposed by the experts.

Tropeptic, referring to a pedal macrostructure, more strongly developed than weak, has been given especially to profile MOC 3. Although MOC 3 does not show so clearly the apedal microgranular structure, the structure grade is still weak in the oxic B horizon and as such not really tropeptic.

The Ultisol population, with one exception, shows unanimously Paleustult. No subgroups are defined in ST for the Paleustults. However, half of the participants gave a subgroup classification, mostly oxic, followed by typic, rhodic and orthoxic. Because of the high organic matter content pedon MOC 4 was once classified as Palehumult.

The Alfisol population shows most frequently Paleustalf. Only twice Rhodustalf was chosen, probably caused by an erroneous rejection of the 'Pale' depth and textural criteria. Subgroup classification for the Paleustalfs shows equally rhodic, oxic or oxic/rhodic, the latter being the most complete characterization (i.e. no lime, BS 75%, CEC 24 me and a colour redder than 5YR).

Pedon MOC 5

The classification of this pedon shows a scattering at all taxonomic levels. At order level there is a preference for the Mollisols, recognizing the mollic epipedon as main diagnostic horizon. For this order the second and third taxonomy steps were uniformly executed and resulted in Argiustoll.

At subgroup level a clear preference was given to udic as no free calcium carbonate horizon is present in the profile; when this criterion was not recognized, the pedon was placed as typic, aquic or pachic vertic.

Four times the soil was classified as Alfisol, probably because of the lack of a horizon containing free calcium carbonate. The pedon was only in one case classified as Xeralf, the three other cases as Ustalf. For the latter classification on great group level resulted in three different answers. This variation is probably caused by the profile description, being not clear whether the CB horizon should be considered as a paralithic contact.

Pedon MOC 6

Because of absence of confusing combinations of diagnostic horizons, this pedon was most easy classified at order level. Twelve times as Alfisol and only one time the pedon was allocated to the Mollisols, presumably because it was not recognized that the depth and the base saturation of the epipedon did not meet the criteria of the Mollic.

In the Alfisol population scattering originates at the third and fourth taxonomic levels. At great group level the pedon was most frequently allocated to the Paleustalf category followed by Haplustalf, and one time to Rhodustalf. At subgroup level the most frequent classifications are oxic and arenic oxic, referring to the thick sandy loam epipedon and the low CEC. Probably erroneously, twice the allocation resulted in the ultic and typic subgroups.

4.2 Classification according to FAO-Unesco system

In tables 1B and 2B classification results listed in Annex 2B have been presented according to the first and second 'taxonomic' levels, although the FAO system is strictly speaking a mono categorical system with 106 units which for logical presentation are organized in 26 groups (3).

For every pedon on the average 10 responses were obtained. Classification results show a wide scattering, each pedon got on the average 5 different names. This scattering originates mainly at the first 'taxonomic' level and only partly at the second.

Pedons MOC 1 to MOC 4

Table 2B shows the overall counts at the first taxonomic level. The variation of the results on the first taxonomic level is showing the problematic decision whether to classify these pedons as Ferralsols or non-Ferralsols (i.e. Acri-, Nito-, Luvi-, Phaeo-, or Cambisol). There is no clear preference visible in the results of pedons MOC 1 to 4, however most frequently they were allocated to Ferralsols, Acrisols and Nitosols. The overall allocation percentages for Ferralsol, Acrisol, Nitosol, and other categories are 35, 33, 20 and 13% respectively.

Analyzing the Ferralsol population of MOC 1 to 4, the rhodic category was most frequently chosen followed by Acri-rhodic, while orthic was only once allocated, probably by an erroneous rejection of the 'rhodic' colour criterion of the rhodic category.

The Acrisol population shows quite unanimously the ferric category, only twice humic was allocated due to the darker coloured A horizon in MOC 4.

In the Nitosol population the eutric and dystric categories are most frequently allocated, while humic is only once found. Difference in base saturation calculation, which is discussed in Chapter 3 causes this variation.

Pedon MOC 4 was three times allocated to the Luvic Phaeozem category. Ferric Luvisol and Ferralic Cambisol were only once allocated to pedon MOC 2.

Pedon MOC 5

Mollic A epipedon was rejected, it came out as Ferric Luvisol. Only once the pedon was allocated as Chernozem because of the assumption that free calcium carbonate would be present, which was inferred from the high pH value.

Pedon MOC 6

This pedon was most frequently allocated as ferric Luvisol and due to differences in base saturation calculations, it came also out as ferric Acrisol.

Due to the rather sandy texture of the first half metre and the absence of macromorphologically visible cutans, the pedon was placed once as Cambic Arenosol.

Table 1A - Classification of 6 Mozambican pedons according to Soil Taxonomy (1975), executed by an international panel

Pedon nr.	Order	Suborder	Great Group	Subgroup
A2/MOC 1	Oxisol	Ustox	Haplustox	Typic (4)
				Rhodic
				Tropeptic
	Ultisol	Ustult	Paleustult	Oxic (3)
				...... (2)
	Alfisol	Ustalf	Paleustalf	Rhodic (2)
				Oxic
L1/MOC 2	Oxisol	Ustox	Haplustox	Typic (2)
				Acric Rhodic
	Ultisol	Ustult	Paleustult	Typic
				Rhodic Orthoxic
				Oxic (2)
				...... (2)
	Alfisol	Ustalf	Paleustalf	Rhodic
				Oxic (2)
				Rhodic Oxic
	Inceptisol	Tropept	Dystropept	Ustoxic
L2/MOC 3	Oxisol	Ustox	Eutrustox	Typic
			Haplustox	Typic
				Tropeptic (3)
	Ultisol	Ustult	Paleustult	Oxic (3)
				Rhodic Oxic (2)
				...... (2)
	Alfisol	Ustalf	Paleustalf	Oxic (2)
			Rhodustalf	......
C1/MOC 4	Oxisol	Ustox	Eutrustox	Typic
	Ultisol	Ustult	Paleustult	Typic
				......
		Humult	Palehumult	Ustic
	Alfisol	Ustalf	Paleustalf	Rhodic
				Oxic Rhodic (2)
				Oxic (2)
				Ultic
				...... (2)
			Rhodustalf	Oxic
	Mollisol	Ustoll	Paleustoll	Udic
N2/MOC 5	Mollisol	Ustoll	Argiustoll	Typic (2)
				Udic (6)
				Pachic Vertic
				Aquic
	Alfisol	Ustalf	Paleustalf	Rhodic
			Rhodustalf	Typic
			Haplustalf	Udic
		Xeralf	Haploxeralf	....
N3/MOC 6	Alfisol	Ustalf	Paleustalf	Oxic (4)
				Arenic Oxic (3)
				......
			Rhodustalf	Typic
			Haplustalf	Oxic
				Arenic Oxic
				Ultic
	Mollisol	Ustoll	Paleustoll	Typic

Table 1B - Classification of 6 Mozambican profiles according to the FAO system (1974), executed by an international panel

Profile	Soil unit	Subdivision
MOC 1	Ferralsol	rhodic (3) orthic acrirhodic
	Nitosol	eutric (2)
	Acrisol	ferric (3)
MOC 2	Ferralsol	acrirhodic (2) rhodic
	Nitosol	dystric eutric
	Acrisol	ferric (3)
	Luvisol	ferric
	Cambisol	ferralic
MOC 3	Ferralsol	rhodic (4)
	Nitosol	dystric (2) eutric
	Acrisol	ferric (3)
MOC 4	Ferralsol	.... rhodic
	Phaeozem	luvic (4)
	Nitosol	humic
	Acrisol	ferric (2) humic ferric humic
MOC 5	Chernozem	luvic
	Phaeozem	luvic (5)
	Luvisol	chromic (2) vertic
MOC 6	Arenosol	cambic
	Acrisol	ferric (3)
	Luvisol	ferric (5)

Table 2A - Summary of first order classification according to the ST system (derived from Table 1A)

Pedon	Oxisol	Ultisol	Alfisol	Mollisol	Inceptisol
MOC 1	6	5	3		
MOC 2	3	6	4		1
MOC 3	5	7	3		
MOC 4	1	3	9	1	
MOC 5			4	10	
MOC 6			12	1	
sub-total MOC 1-4:					
	15	21	19	1	1
idem in %:	26	37	33	4	

Table 2B - Summary of "first taxonomic level" classification according to the FAO system

Pedon	Ferral-*	Acri-	Nito-	Phaeo.	Luvi-	Areno-	Cherno.	Cambisol
MOC 1	5	3	2					
MOC 2	3	3	2		1			1
MOC 3	4	3	3					
MOC 4	2	4	1	4				
MOC 5				5	3		1	
MOC 6		3			5	1		
subtotal MOC 1-4:								
	14	13	8	4	1			1
idem in %:	35	33	20	8			5	

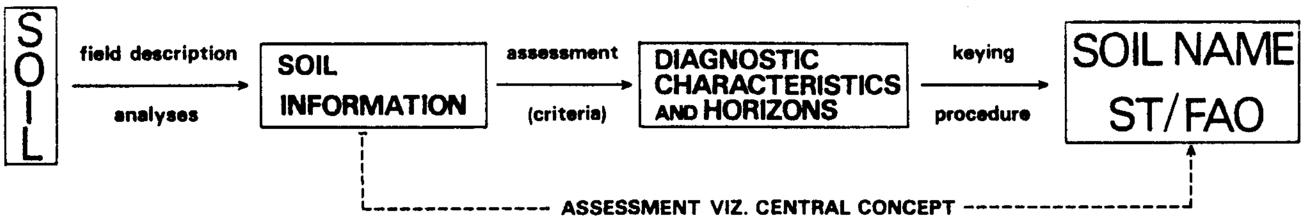
5. DISCUSSION

5.1 Trouble points or causes of the variation

The large variation in classification results shown in Tables 1A, B, and 2A, B is surprising. Such large differences for same profiles cannot be allowed in any taxonomic system

In this paragraph the 'trouble points' which are causing the variation in the classification will be given. The assumptions, interpretations, observations, doubts and notes which were given by several of the experts are of great help for this listing.

Below all necessary activities for classification are presented schematically:



With regards to their source, the causes of variation are originating from the field description and laboratory analysis, or from the assessment of diagnostic horizons and diagnostic properties, or from the keying procedures itself.

Field description and laboratory analysis

Although not a major source of variation, incompleteness and vagueness in the profile information was in a few cases the cause of variation. In the environmental information the soil moisture and temperature is lacking. Unfortunately, this is a normal situation in many countries. This lack of information was frequently mentioned by the experts, but it appeared not to be a problem because the classification at suborder level came out remarkably uniform.

In the profile morphology data the dry (crushed) soil colours and the consistency when dry (pedon MOC 4) are lacking which are criteria used in the mollic definition.

In the analytical data the following comments were given:

- missing of $CaCO_3$ data in pedon MOC 5, while pH is slightly above 7; in one case presence of $CaCO_3$ was assumed which classifies then as Chernozem;
- confusion about textural information of topsoil of MOC 6; lab data indicate sandy loam, while field description gives loamy sand, the latter positively for the arenic subgroup (ST).
- twice given clay percentage in the topsoil was disputed with the arguments: incomplete dispersion and presence of 'pseudo silt'.
  Laboratory procedures for the data given is as follows: pipette textural analysis is done on H_2O_2 pretreated samples, which have been shaked overnight with dispersion agent. Repetition of the textural analyses for all topsoils samples after deferration gives for pedons MOC 1 to 3 an increase of between 5-10% clay (absolute). Although clay percentage may increase after deferration, textural differences between top and subsoil without deferration still fulfill the requirements.
  The presence of pseudo silt and fine sand has been checked microscopically on sand fractions resulting from the textural analyses with a magnification of about 50X. Deviating parts in the clay vs. depth diagram indeed originates from pseudo silt forms (e.g. the 'negative' bulge in MOC 2).
- one remark was made on the sand fraction on which mineral counting had been realized. Required is the 20-200 u fraction, however for practical reason the 50-500 fraction has been used.
- incomplete horizon sampling (especially of MOC 1) was disputed because it may hamper the construction of clay vs. depth diagrams. Certainly this incomplete slicing is incorrect, but as this is mainly restricted to the very deep homogenous subsoil, it does not effect the diagrams.
- generally the information on analytical procedures was found to be insufficient, but this was not reported as a serious trouble point by the experts.

As regards the micromorphology data set remarks were made on the information related to clay illuviation features, being not always sufficiently quantitatively expressed. It appears that one uses phrases such as 'some isolated clay illuviation features', pro or contra the presence of an argillic horizon.

Assessment of diagnostic horizons and diagnostic properties

The ST and FAO systems both considered to be objective and quantitative has still subjective aspects in the assessment of diagnostic horizons and -properties. This is an important cause of variation in the classification results. The variation caused by the assessment of base saturation, argillic and oxic horizons, and mollic horizon will be discussed below.

Base saturation

Base saturation (BS) is a criterion required in many definitions like the mollic horizon, Ulti-Alfisols and many other categories.
The BS value depends on the CEC method chosen and on the depth at which this value is calculated, see Annex 4 for a summary of procedures and Table 4 for BS values.

Only a few participants stated explicitely the procedure they used for BS calculation:

- the use of a BS limit of 50% based on CEC (pH 7, NH_4OAc) to distinguish Alfi- and Ultisols; while the ST system requires "base saturation by sum of cations of 35%", i.e. based on a calculated CEC (pH 8.2);
- the use of BS derived from unbuffered CEC (=ECEC), because of variable charge character of most pedons;
- the use of the assumed correlation:
  BS of 35% (pH 8.2, 'sum of cations') = **BS of 50%** (pH 7, NH_4OAc)

Unfortunately often the procedure for the BS calculation was not mentioned by the experts, as well as information on the depth at which BS was calculated. However, it appears from the results of the classification, that an important part of the variation is caused by differences in the derivation of the BS.

Note as well the conflicting classification results for profiles MOC 4 and MOC 6. According to FAO they should be classified as Acrisols (BS $<50\%$), according ST they should be allocated to the Alfisols (BS $>35\%$).

The CEC procedure (sum of bases and exchangeable acidity buffered at pH 7) actually in use in the National Soils Laboratory of Mozambique, results in much higher BS values than derived from the standard NH_4OAc procedure of ST. Consequently soils are often classified as Alfi- or Luvisols while they should come out as Ulti- or Acrisol, according to ST or FAO procedures. This will be further discussed in the study of red clayey soils of Mozambique (1).

Argillic and Oxic horizons

The combination of characteristics diagnostic both for the argillic and the oxic horizon is another main trouble point. Due to the conventional 'mutual exclusivity' of those horizons one is forced to make a choice, although both horizons are present. The identification of a very thick oxic horizon in pedons MOC 1 to 4 is relatively easy due to the presence of all diagnostic properties.

The identification of an argillic horizon overlying the oxic horizon is problematic. As discussed in paragraph 4.1, pedons MOC 1 to 4 are showing a gamma of argillic horizons. From thin (about 40 cm) and weakly developed towards thick (about 100 cm) and more clearly developed. This difficulty was frequently expressed. Below some statements of the experts:

- "difficult because of intergrading characteristics";
- "some of the characteristics do not match well with the definitions agreed upon both in FAO Legend and ST";
- "in the field unworkable classification";
- "field morphology is pointing to an argillic horizon while micromorphology is indicating to an oxic";
- "as soon as macro cutans are described it is an argillic horizon, irrespective of micro analyses".
  Insufficiently quantified micro clay illuviation features were used pro or contra the argillic or oxic horizon; even a quantified statement from the micromorphology report - clay illuviation features not enough for the requirements of a AH - was waived by some experts, because of other evidences pointing to an argillic (i.e. "the large textural differentiation, the high water dispersable clay content, the large faunal activity destroying the cutans", etc.).
- the process of "selective erosion" or a "superficial colluvial process" resulting in a coarser textured topsoil was mentioned, especially in the case of pedon MOC 6. As indicated before, sheetwash is probably the main cause of textural differentiation in all pedons;
- "in many aspect an oxic but intergrading towards an argillic horizon";
- "in all aspects oxic except for the weatherable mineral content and "I assume you have a mineral count error" (MOC 2);
- corrobative properties used by some of the experts for the oxic horizon are: low or negative delta pH values, weak structure and low silt/clay ratio;
- "rejuvenated oxisol due to airborne new material" (MOC 1);
- "the lack of water dispersable clay below 15 cm, the relative high amount of muscovite (more than 6%) and the fairly uniform textural profile, make me classify this soil (MOC 2) into the Inceptisols".

Mollic horizon

Difficulties related to missing information and the base saturation have been mentioned above.

The organic matter content of 1% as lower limit has been recognized as too low, resulting in the identification of a mollic horizon where it is considered not to be corresponding with the underlying central concept. Twice pedon MOC 4 was mentioned as having a mollic horizon, but according to ST it is not a Mollisol due to BS subsoil less than 50%, while in FAO it comes out as Phaeozem (Luvic) because there low subsoil BS values are implicitly allowed (by oversight).

Keying procedure

The classification activity, here referred as the keying procedure or classification "pathway", can be a cause of variation due to a combination of diagnostic horizons or properties which are not foreseen in the systems. Another cause may be the use of classification keys in a rigid (automatic) or more interpretative way, this aspect is often disputed among pedologists. Even correction through a check afterwards of the outcome, viz. original central concept may result in variation.

Unfortunately, little remarks on the keying procedure were received and mostly given in a general way by the experts.

Although the procedural aspects were not explicitly stated, an attempt to reveal the trouble points will be given with the FAO system as an example. The possible combinations of diagnostic horizons and properties are listed in table 5, the sequence is taken in accordance with the key of the FAO system.

Table 5 - Possible classification pathways, according to FAO system

	Presence of diagnostic horizons			
Pathway	oxic	mollic	argillic*	Classification results
1	-	-	-	Cambisol
2	-	-	+	Nito/Acri/Luvisol (pedon MOC 6)
3	-	+	-	Phaeozem
4	-	+	+	Phaeozem (MOC 5)
5	+	-	-	Ferralsol
6	+	-	+	Nito/Acri/Luvisol or Ferralsol (MOC 1, 2, 3)
7	+	+	-	Ferralsol
8	+	+	+	Ferralsol, Nito/Acri/Luvisol or Phaeozem? (MOC 4)

* the argillic horizon overlies the oxic

Table 5 - (cont.)

<u>Nito-, Acri- and Luvisol pathways</u> (continuation of patways 2, 6 and 8)

pathway	decrease of clay%	plinthite		ferric			BS%*	
a	<20	-		-	**Nitosol**			
b	<20	+	and/or	+	)			
c	>20	-		-	) no Nitosol	e	<50	**Acrisol**
d	>20	+	and/or	+	)	f	>50	**Luvisol**

* BS = Base saturation

Some remarks on classification pathways causing variation:

ad 6) For pedons MOC 1 to 4 the combination of an argillic and an oxic horizon is a main trouble point. Roughly one third of the classification results are Ferralsols while two-third comes out as non-Ferralsol.

The conventional choice between the two diagnostic horizon is a difficult one as both are important. Some possible reasons for a particular choice are given:

Either prevalence for the argillic B as diagnostic horizon, because of:

- classification rule (FAO, 1974, p. 32): "when two or more B horizon occur within 135 cm of the surface, it is the upper B horizon which is determining for the classification";
- rejection of the presence of an oxic B (FAO, 1974, p. 27): "the oxic B horizon is a horizon that is not argillic";

Or prevalence for the oxic B as diagnostic horizon, because:

- in the FAO key the use of an oxic horizon 'keys' out earlier than the argillic horizon.
- the argillic B is rejected being relatively too thin in comparison to the oxic B, or too weakly developed, or disputable, viz. central concepts of the argillic horizon.

ad 7) Mollic Ferralsol is not defined

ad 8) - For the choice between oxic or argillic horizon, see ad 6)
- Phaeozem is disputable by definition because Phaeozems should lack an oxic B
- Presence of a mollic in Nito/Acri/Luvisol is excluded by definition

ad a) The lack of a strong (sub)angular blocky structure and clear shiny ped faces in pedons MOC 1 to 4 - when classified as Nitosols - was mentioned twice. This refers to the original central concept underlying the Nitosols, however these characteristics are not included in the definition.
The rigid application of the few criteria given in the definition of the Nitosols and the lack of significant diagnostic criteria for the Nitosols has been discussed by Sombroek and Siderius (6).
In the ST system the structure grade and form is used as checking element for "younger" soils (tropeptic).

General comments

The experts had to rely on the information given without the field contact. This appeared to be not a serious problem as this was only once mentioned. In fact, the pedons were recognized by many experts as "very similar to widespread soils in other countries with similar classification problems, particularly in regard to argillic horizon identification". Countries mentioned are Australia, Brazil, India and Kenya.

However, one cannot deny that the conventional profile morphology description has still subjective aspects, but this test was not designed for testing this. It is assumed that this subjectivity will not substantially influence this classification test, as this assumption is in fact also the base for the existing classification systems. Although profiles have been described twice, with carefully attention by two pedologists, an unknown portion of the variation may be attributed to this phenomenon.

5.2 Proposed changes in ST and FAO

Both Soil Taxonomy and FAO systems have been used in a number of countries. Improvements were proposed by many soil scientists. For ST a number of international committees are working on the improvement of the system. FAO has created a working group for this purpose.

ST - the kandic horizon

The trouble points for classification with regard to the argillic horizon and to the combination of both argillic and oxic horizon, which have been discussed before are subject of investigation of the international ST committees ICOMLAC and ICOMOX.

The International Committee on Classification of Alfisols and Ultisols with low activity clays (ICOMLAC) was organized in 1975 by the Soil Conservation Service, USDA.

Without being complete a great part of the discussions and the outcoming results of this committee can be found in Isbell (1980) and Moormann and Buol (7). Below the essentials are given.

The problem of the controversial 'mutual exclusivity' of oxic and argillic horizon has been solved with the introduction of the kandic horizon. The kandic horizon can be considered as a low activity clay containing textural horizon, combining as such oxic- and argillic B horizon properties, however it differs from the oxic and argillic B in the following way:

- the kandic horizon has an ECEC of less than 12 me per 100 g clay and or a CEC(7) of less than 16 me per 100 g clay.
- the increase of clay percentage (more or less similar to the argillic horizons) must be reached within a vertical distance of 15 cm or less.

Central in the proposed amendments for ST is the introduction of the kandic horizon at the great group level of Alfisols and Ultisols.

Irrespective of having a kandic horizon low activity clay Alfisols and Ultisols are distinguished from Oxisols by a textural limit, i.e. when a topsoil of 18 cm contains more than 40% clay it is allocated to the Oxisols. This is a rather arbitrarely criterion which may cause that e.g. many Nitosols of the FAO Legend will be classified in the Oxisol order.

FAO

A summary of the proposed main changes of interest for the Mozambican profiles in the FAO system is given. This is taken from the revision of the Legend, third draft of October 1985 (2).

Ferralsols - no changes

Nitosols - improved definition

Luvisols - restricted now to soils with an argillic horizon with high BS and high clay activity (i.e. CEC7 >16)

Lixisols - a new major soil group for soils with an argillic horizon with high BS and low clay activity (i.e. CEC7 < 16)

Alisols - a new major soil group for soils with an argillic horizon with low BS and high clay activity

Acrisols - restricted now to soils with an argillic horizon with low BS and a low clay activity

Plinthosols - the plinthic Gleysols will be deleted and form a new major soil group.

6. CONCLUSIONS

The results of a classification test of six deep, well drained red clayey 'upland' soils of Mozambique carried out by a group of experienced soil scientists show a large variation. It appears that classification according to ST and FAO systems for the given profiles is still an ambiguous activity.

The variation in the results show an acute first order taxonomic problem. Main causes of this variation are the subjective assessment of the presence of diagnostic horizons and -properties, as well as the unforeseable combinations of these in the classification key. In this test this is shown at first by the conventional mutual exclusivity of the argillic and oxic horizons and secondly by the very confusing situation in the application of cations exchange properties.

The Mozambican soils show that the argillic and oxic horizons are not mutual exclusive in low activity clay soils. Argillic horizons may develop on top of or in an oxic horizon. The newly developed kandic horizon concept seems to be a promising pragmatic solution, which will overcome a part of the problem in respect of the conflicting presence of both argillic and oxic horizons. However, once approved it has to be tested whether it solves the taxonomic problem at order level. The latter conclusion is as well applicable to the proposed changes in FAO's system.

The variation in results caused by the confusing application of exchange properties can be solved by the introduction of an unambiguous standardized procedure of CEC determination and derived parameters like base saturation.

ACKNOWLEDGEMENT

This classification experiment entirely depended on the participation of soil scientists with experience in tropical soils. I am greatly indebted to the group of experts who contributed in a very cooperative way.

I should like to express my appreciation for the assistance received from the International Soil Reference and Information Centre (ISRIC), which contributed to this test by preparing the monoliths and completing the sample analyses. The stimulating role of director Dr. W.G. Sombroek should be especially mentioned.

I should like to thank the National Agricultural Research Institute (INIA) of Mozambique for the assistance I received during the fieldwork, and to the Directorate General of International Cooperation of the Netherlands (DGIS) who made it possible to elaborate the results at ISRIC.

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ANNEX 1 - List of participants in the classification test

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Mr. R. Sant'Anna and colleague, Ghana
Dr.Ir. W.G. Sombroek, Netherlands
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Drs. L. Touber, Mozambique
Dr.Ir. W.J. Veldkamp, Zambia
Drs. R. Voortman, Mozambique
Drs. J. van Wambeke, Mozambique

ANNEX 2A - Classification of 6 Mozambican profiles according to the Soil Taxonomy (1975) system, executed by an international panel

Expert Rank	MOC1	MOC2	MOC3	MOC4	MOC5	MOC6
1	Paleustult	Paleustult	Paleustult	Paleustalf	Udic Argiustoll	Oxic Paleustalf
2	Oxic Paleustult	Ustoxic Dystropept	Oxic Paleustult	Oxic Rhodic Paleustalf	Udic Argiustoll	Oxic Paleustalf
3	Rhodic Haplustox	Acric/Rhodic Haplustox	Tropeptic Haplustox	--	Rhodic Paleustalf	--
4	Oxic Paleustult	Oxic Paleustult	Oxic Rhodustalf	Oxic Rhodustalf	Udic Argiustoll	Arenic/Oxic Haplustalf
5	Typic Haplustox	Rhodic Paleustalf	Typic Haplustox	Rhodic Paleustalf	Udic Rhodustalf	Oxic Paleustalf
6	--	Typic Paleustult	Paleustult	Paleustalf	Udic Argiustoll	Ultic Haplustalf
7	(Typic) Haplustox	(Rhodic) (Orthoxic) Paleustult	Rhodic Oxic Paleustult	Rhodic Oxic Paleustalf	Typic Argiustoll	Arenic oxic Paleustalf
8	Tropeptic Haplustox	Typic Haplustox	Tropeptic Haplustox	Typic Paleustult	Typic Argiustoll	Typic Paleustoll
9	Paleustult	Paleustult	Paleustalf	Paleustult	Haploxeralf	Paleustalf
10	Rhodic Paleustalf	Oxic Paleustalf	Typic Eutrustox	Typic Eutrustox	Typic Rhodustalf	Typic Rhodustalf
12	Typic Haplustox	--	Tropeptic Haplustox	Ultic Paleustalf	--	--
14	Oxic Paleustalf	Oxic Paleustalf	Oxic Paleustalf	Oxic Paleustalf	Udic Haplustalf	Arenic Oxic Paleustalf
15	Rhodic Oxic Paleustalf	Rhodic Oxic Paleustalf	Rhodic Oxic Paleustalf	Udic Paleustoll	Pachic Vertic Argiustoll	Arenic Oxic Paleustalf
16	Typic Haplustox	Typic Haplustox	Oxic Paleustult	Oxic Paleustalf	Udic Argiustoll	Oxic Paleustalf
18	Oxic Paleustult	Oxic Paleustult	Oxic Paleustult	Ustic Palehumult	Aquic Argiustoll	Oxic Haplustalf

Annex 2B - Classification of 6 Mozambican profiles according to the FAO-Unesco Soil Map of the World legend (1974), executed by an international panel

Expert Rank	MOC1	MOC2	MOC3	MOC4	MOC5	MOC6
2	Rhodic Ferralsol	Rhodic Ferralsol	Rhodic Ferralsol	Ferralsol or Humic Acrisol	Chromic Luvisol	Cambic Arenosol
3	Ferric Acrisol	Ferralic Cambisol	Ferric Acrisol	Humic Acrisol	Luvic Phaeozem	Ferric Luvisol
4	Ferric Acrisol	Ferric Acrisol	Ferric Acrisol (Nitosol)	Ferric Acrisol	Luvic Phaeozem	Ferric Acrisol
7	--	--	--	Luvic Phaeozem	--	--
9	Ferric Acrisol	Dystric Nitosol	Ferric Acrisol	Ferric Acrisol	Vertic Luvisol	Ferric Acrisol
10	Eutric Nitosol	Ferric Luvisol	Rhodic Ferralsol	Rhodic Ferralsol	Chromic Luvisol	Chromic Luvisol
11	Acri Rhodic Ferralsol	Acri-Rhodic Ferralsol	Dystric Nitosol	Luvic Phaeozem (ferric Luvisol)	Luvic Phaeozem	Ferric Luvisol
12	Rhodic Ferralsol	Ferric Acrisol	Rhodic Ferralsol	Humic ferric Acrisol	--	--
13	Orthic Ferralsol	Ferric Acrisol	Rhodic Ferralsol	Luvic Phaeozem	Luvic Phaeozem	Ferric Luvisol
15	Eutric Nitosol	Eutric Nitosol	Eutric Nitosol	Luvic Phaeozem	Luvic Chernozem	Ferric Luvisol
17	Rhodic Ferralsol	Rhodic Ferralsol	Dystric Nitosol (Rhodic Ferralsol)	Humic Nitosol (Luvic Phaeozem)	Luvic Phaeozem	Ferric Acrisol

ANNEX 3 - Soil information of pedons MOC 1 to MOC 6

CONTENT

- Key to the soil profile descriptions (3 pag.)
- The following information is available for each pedon:
  - soil profile description
  - soil physical and chemical analyses
  - property versus depth graphs
  - X-ray clay mineralogy
  - interpretation of the micromorphological data (Dr. M.J. Kooistra, Stiboka, the Netherlands)
- Mineralogical composition of the fine sand fraction (50-500 μ) of selected samples
- Mineralogical composition of parent rock samples

KEY FOR INTERPRETING SOIL PROFILE DESCRIPTIONS

PROFILE : number or code

Date of examination : (season)

Authors :

Higher category classification

- (FAO-UNESCO 1974)
- (Soil Taxonomy 1975)

Environmental information

Location : country, province, district, village/town nearby

Coordinates : S, N

Elevation : m

Landform : general physiography, overall sloperange; land elements

Slope of site : type, shape, length, position of pit

Vegetation : descriptive (for species classification see anex)

Land use : permanency, size+tecnology, main crop(s)

Climate : unimodal, P annual, Ep annual, lenght of dry season, leaching rainfall= $\Sigma(P-Ep)$ (see anex for more details)

General information on the soil

Parent material : general information or rock type (see anex for mineralogy)

Drainage conditions : drainage class SSM

Moisture conditions : dry/moist/wet + depth

Ground water level : depth cm (also indicates perched ground water table, temporarely saturation

Termitaria : form, size, density

Surface characteristics: sheet wash planes, rill/gully erosion

Miscellaneous

Local soil name : (language name)

Brief description of the profile

always mention depth (of solum =A+B or effective soil depth)
drainage class (SSM)
colour (subsoil)
texture (subsoil)
additionally structure grade(shallow subsoil and the deeper subsoil)
porosity
thickness of a dark topsoil
....
....

KEY FOR INTERPRETING SOIL PROFILE DESCRIPTIONS

HORIZON CODE according guidelines FAO with additionally:

- Bt = increase of clay percentage with depth (argillic horizon)
- Bt' = weakly structured Bt horizon
- Bt" = moderately structured
- Bt"' = strongly structured
- Btg = Bt with gleying
- Bws = porous massive horizon (oxic horizon)
- BC = transition horizon

BOUNDARY		TOPOGRAPHY	
a	abrupt	s	smooth
c	clear	w	wavy
g	gradual	i	irregular
d	diffuse	b	broken

COLOUR without indication is moist soil

- D dry soil
- W wet soil

TEXTURE

S	sand	LS	loamy sand	sgr = slightly gravelly
L	loam	SL	sandy loam	
Si	silt	SCL	sandy clay loam	
C	clay	SC	sandy clay	

PEDAL STRUCTURE

GRADE		SIZE		TYPE	
w	weak	vf	very fine	gr	granular
m	moderate	f	fine	cr	crumb
s	strong	m	medium	ab	angular blocky
		c	coarse	sb	subangular blocky
				pl	platy

APEDAL STRUCTURE

TYPE		COHERENT	
sg	single grain	nc	non coherent
mp	massive porous	wc	weakly coherent
		mc	moderately coherent
		sc	strongly coherent

CONSISTENCY

DRY		MOIST		WET			
dl	loose	ml	loose	ns	non sticky	np	non plastic
s	soft	vfr	very friable	ss	slightly sticky	sp	slightly plastic
sh	slightly hard	fr	friable	s	sticky	p	plastic
h	hard	fi	firm	vs	very sticky	vp	very plastic
vh	very hard	vfi	very firm				
eh	extremely hard	efi	extremely firm				

CUTANS

QUANTITY		VISIBILITY		TYPE	
p	patchy	f	faint	C	clay
b	broken	d	distinct	ir	iron
c	continuous	p	prominent		

POROSITY

QUANTITY		SIZE	
f	few	vf	very fine
c	common	f	fine
m	many	m	medium
vm	very many	c	coarse
a	abundant	vc	very coarse

ROOTS

QUANTITY		SIZE	
f	few	vf	very fine
c	common	f	fine
m	many	m	medium
		c	coarse

MOTTLING

ABUNDANCE		SIZE		CONTRAST		COLOUR
f	few	f	fine	f	faint	in general Munsell notation
c	common	m	medium	d	distinct	
m	many	c	coarse	p	prominent	

NODULES

QUANTITY		SIZE		HARDNESS		SHAPE		TYPE	
vf	very few	s	small	s	soft	s	spherical	ir	iron
f	few	m	medium	h	hard	a	angular	C	clay
fr	frequent	l	large			i	irregular	Mn	manganese
vfr	very frequent								
do	dominant								

/ = to; + = and; . = not described; - = not present

1	=	profile number	
2	=	sample number	
BEG	=	begin sampling depth	cm
END	=	end sampling depth	cm
AVE	=	average sampling depth	cm
CS1	=	coarse sand (1000-2000μ)	%
CS2	=	coarse sand (500-1000μ)	%
CS3	=	coarse sand (250-500μ)	%
FS1	=	fine sand (100-250μ)	%
FS2	=	fine sand (50-100μ)	%
SI1	=	coarse silt (20-50μ)	%
SI2	=	fine silt (2-20μ)	%
AG	=	clay (<2μ)	%
DISP	=	water dispersable clay	%
H20	=	pH-H20	
KCl	=	pH-KCl	
H+Al	=	exchangeable acidity, unbuffered	me/100g
Al	=	exchangeable aluminium, unbuffered	me/100g
C	=	organic carbon	%
N	=	nitrogen	%
C/N	=	organic carbon/nitrogen quotient	
Ca	=	exchangeable calcium	me/100g
Mg	=	exchangeable magnesium	me/100g
K	=	exchangeable potassium	me/100g
Na	=	exchangeable sodium	me/100g
EC	=	electrical conductivity	mS/cm
Si/AG	=	silt%/Clay%	
DIFPH	=	pH(H2O) - pH(KCl)	
ECEC	=	sum of cations + exchangeable acidity (H+Al) unbuffered	me/100g
CEC	=	cation exchange capacity, pH7 buffered	me/100g

PROFILE: MOC-1

Date of examination: 16 October 1982 (end of dry season)
Author : J.H. Kauffman

Higher category classification

- (FAO-UNESCO, 1974)
- (Soil Taxonomy, 1975)

Environmental information

Location : Mozambique, Tete, Angonia, south of Calomué
Coordinates : 14°27' S, 34°22' E
Elevation : 1480 m
Landform : plateau, weakly undulating; smooth interfluves and "dambo's", few bare rock inselbergs
Slope of site: uniform, weakly convex; gradient 2-3%, length > 400 m, upper slope position (see annex)
Vegetation : "Miombo" woodland, recently strongly cut for fuelwood
Land use : shifting cultivation, small farmer, maize
Climate : Unimodal, P = 930, Ep = 1435, 6 months dry season, L.R. = 290 mm ± 300 mm (see annex)

General information on the soil

Parent material : Basement complex; probably felsic to intermediate gneiss
Drainage conditions : well drained
Moisture conditions : 0-200 cm dry, > 200 cm moist
Ground water level : no evidence within 400 cm
Termitaria : dome-shaped mounds, medium, 1 ≤ ha
Surface characteristics: smooth planes indicate superficial lateral flow of water

Miscellaneous

Local soil name : Katonde (Chinhandje/Chichewa)

Brief description of the profile

Very deep, well drained dark red clay soil; weakly to moderately structured up to 62 cm than massive porous.

HORIZON CODE	DEPTH	BOUND	COLOUR	TEXTURE	STRUCTURE	CONSISTENCY D	M	W	CUTANS	POROSITY	ROOTS	OTHER CHARACTERISTICS
Ah	0-15	g-s	5YR3/3	SC	m vf/f sb+cr	sh	vfr	ss+sp	-	a vf/f	m vf	
AB	15-25	g-s	2.5YR3/4	C	m vf/f sb	h	fr	ss+sp	-	vm vf/f	c vf/f	
Bt'	25-62	g-s	2.5YR3/6	C	w vf/f sb	h	fr	ss+sp	b d C	vm vf/f	c vf/f	
Bws	62-170+		2.5YR3-4/6	C	mp-wc[1]	sh	vfr	ss+sp	b d C	vm vf/f	f vf/f	very few, medium, sof to hard spherical cla nodules
	augering 170-400	d-.	2.5YR4/6	C	.	.			.	.	.	very few medium to la hard clay nodules
	400-600		2.5YR4/6	C	.	.			.	.	.	few medium, hard, spherical Iron + Mn concretions

Notes

[1] Structure is difficult to describe, no clear ped visible, in fact every "ped" size can be made with a slight force; massive porous weakly coherent can also be described as very weak, very fine to fine subangular blocky.
- The nodules have the same colour as the soil matrix. They differ from the soil by their coherency and the absence of pores.
- Spherical termite holes with flat bottom and Ø of about 8 cm are visible in the whole soil profile with a density of 1 to 2 per m^2; mainly empty but sometimes filled with fungus combs.

1	2	SAMPLING DEPTH BEG	END	AVE	COARSE SAND CS1	CS2	CS3	FINE SAND FS1	FS2	SILT SI1	SI2	CLAY AG	DISP	pH H2O	KCl	H+Al	Al	C	N	C/N	Ca	Mg	K	Na	EC
2	1	0	4	2.0	3.4	10.0	16.2	16.0	4.9	5.9	12.6	31.0	8.5	5.7	5.0	0.10	0.00	1.70	0.11	15.5	2.6	1.5	0.5	0.0	0.08
2	2	5	15	10.0	2.4	8.0	14.1	15.5	4.8	6.0	3.4	45.9	9.9	5.5	4.8	0.11	0.00	1.26	0.07	18.0	1.8	0.9	0.4	0.0	0.08
2	3	30	45	37.5	3.5	7.2	9.1	10.7	4.1	5.4	7.1	53.1	0.5	5.1	4.6	0.18	0.00	0.30	0.03	10.0	0.8	0.4	0.3	0.0	0.03
2	4	70	85	77.5	2.9	6.9	8.5	11.9	4.7	6.4	8.4	50.7	0.0	5.6	5.6	0.00	0.00	0.17	0.01	17.0	0.8	0.5	0.2	0.0	0.01
2	5	130	145	137.5	3.0	6.5	6.6	9.3	4.7	7.9	11.2	50.8	0.0	5.5	5.6	0.00	0.00	0.16	0.01	16.0	1.8	1.0	0.2	0.0	0.01
2	6	260	290	275.0	3.3	5.2	5.5	7.7	5.1	11.1	13.6	48.5	0.0	5.4	5.7	0.02	0.00	0.08	0.01	8.0	1.6	0.8	0.1	0.0	0.01

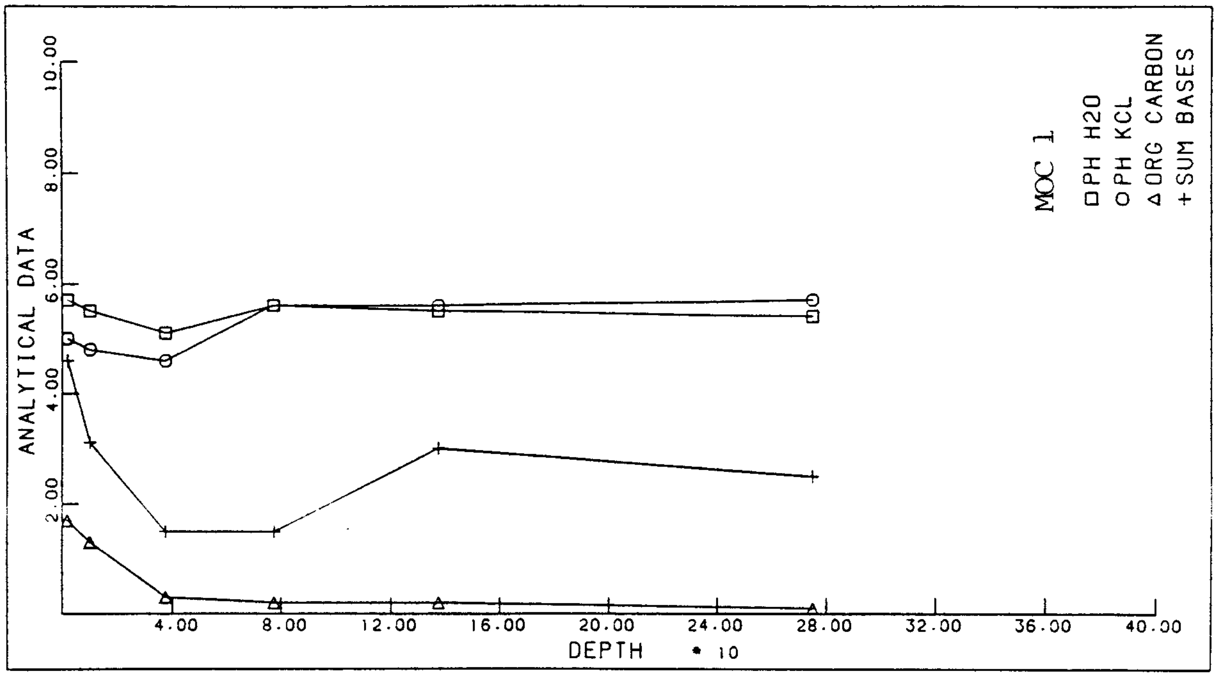
MOC 1 - Analytical results

Depth (cm)	Si/AG	DIFPH	ECEC	CEC
0-4	.60	.7	4.7	11.4
5-15	.20	.7	3.2	8.4
30-45	.24	.5	1.7	8.3
70-85	.29	.0	1.5	6.7
130-145	.38	-.1	3.0	7.4
260-290	.51	-.3	2.5	7.5

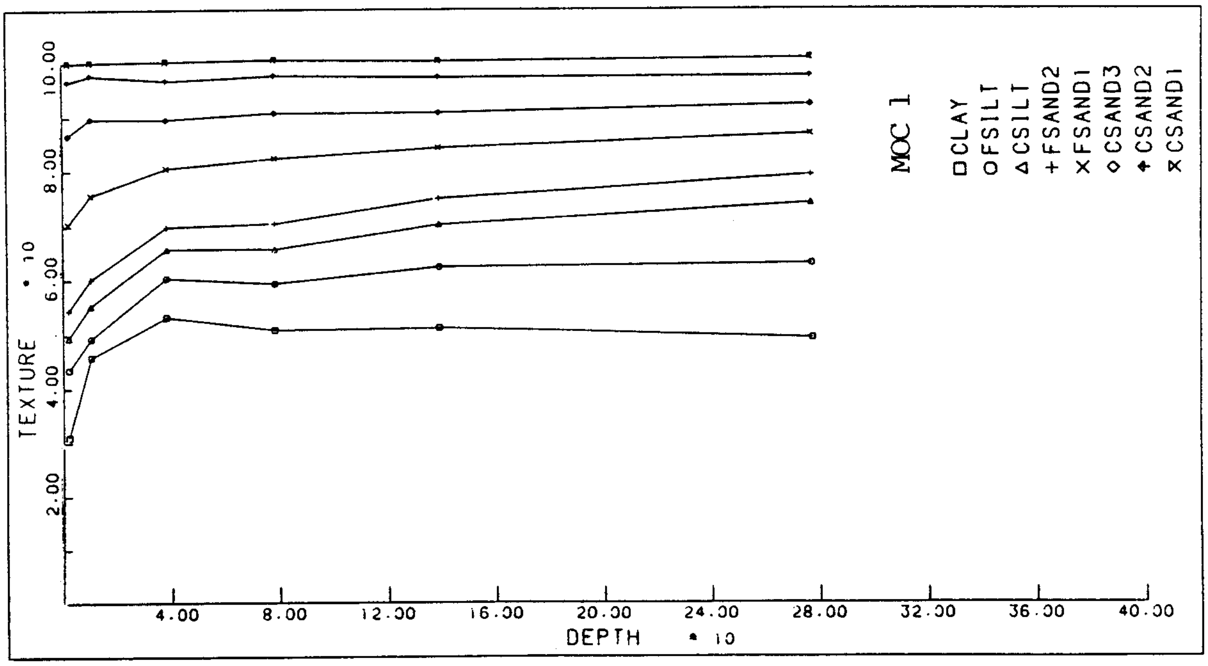
Sample Depth (cm)	elemental composition of the total soil (weight %)										
	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	TiO2	MnO	P2O5	BaO	Ign. loss	
0-4	63.37	15.06	9.32	0.10	0.10	0.29	3.61	0.13	0.32	0.01	8.45	100.77
5-15	60.15	17.19	9.65	0.07	0.06	0.30	3.54	0.12	0.28	0.02	8.80	100.17
30-45	57.48	22.04	9.81	0.03	0.07	0.24	2.77	0.08	0.33	0.01	8.85	101.70
70-85	55.91	21.70	10.21	0.03	0.06	0.23	2.99	0.06	0.17	0.01	8.92	100.29
130-145	53.19	23.37	10.38	0.03	0.07	0.23	2.78	0.06	0.17	0.01	9.55	99.84
260-290	51.96	25.37	10.59	0.04	0.07	0.16	2.38	0.06	0.14	0.01	9.86	100.64

Depth (cm)	Mineralogical composition of the clay fraction				
	Kaol	Quar	Gibb	Goeth	Hem
0-4	+++	0-tr	tr	x	tr-x
5-15	+++	0-tr	tr	x	tr-x
30-45	+++	0-tr	tr	x	tr-x
70-85	+++	0-tr	tr-x	x	tr-x
130-145	+++	0-tr	tr	x	tr-x
260-290	+++	0-tr	tr	x	tr-x

SELECTED ANAYTICAL DATA versus DEPTH



TEXTURE versus DEPTH diagram



Interpretation of the micromorphological data Profile MOC 1

- In the studied pedon clay illuviation has occurred, but the scope cannot be traced. Only in the top of the B horizon (30-45 cm) isolated clay illuviation features are observed: Deeper in the B horizon they are not observed and most probably never occurred as here only sepic plasmic fabrics are present in the undisturbed groundmass zones.
- The soil fauna plays the dominant role in this pedon. The structure and porosity is determined by the animal activity, viz. the large extent of interconnected infillings, consisting of shaped mineral excrements also responsible for the enaulic coarse/fine related distribution. Several species are responsible. One, most probably a species of the Vermes, produces shapeless excreta in which the organic material is inseparable mixed with mineral material, including a few recognizable larger organic fragments, giving the groundmass a darker colour. The mull humus form in the A horizon consists of this material and it occurs in a few massive infillings, which locally tend to striotubules, in the upper part of the B horizon*. The coatings along faunal voids and infillings are produced by the soil fauna by plastering with excrements or by compaction of infilling material adjoining the void. These coatings and compactions give the soil material a higher coherence than expected from the extent of infillings with mineral aggregates. These coatings and compactions are the reason that the soil material under slight pressure breaks into any "ped size".

* Described as mottles in the profile description.

PROFILE: MOC-2

Date of examination: 25 October 1982 (end of dry season); rep.: 5 April 1983
(end of rainy season)

Authors : J.H. Kauffman/M. Vilanculos

Higher category classification

- (FAO-UNESCO, 1974)
- (Soil Taxonomy, 1975)

Environmental information

Location : Mozambique, Niassa, Lichinga, Lichinga
Coordinates : 13°18' S, 35°16' E
Elevation : 1325 m
Landform : Plateau, (weakly) undulating; smooth interfluves and dambo's
Slope of site: uniform, convex, gradient 1-2%, length ± 500 m; position: top of interfluves
Vegetation : fallow grass/herb
Land use : shifting cultivation, small farmer, maize
Climate : Unimodal, P = 1060, Ep = 1260, 6 months dry season, L.R. = 480 mm 500 mm (see annex)

General information on the soil

Parent material : Basement complex; diorite (see annex)
Drainage conditions : well drained
Moisture conditions : 0-130 cm dry, > 130 cm moist
Ground water level : no evidence within 500 cm
Termitaria : dome-shaped mounds, very large, 1-2/ha
Surface characteristics: surface smooth by superficial lateral flow of water

Miscellaneous

Local soil name : Chicunja (Jaua language)

Brief description of the profile

A very deep, well drained dark red clay soil, weakly structured up to 58 cm than porous massive, topsoil is weakly developed.

HORIZON CODE	HORIZON DEPTH	BOUND	COLOUR	TEXTURE	STRUCTURE	CONSISTENCY D M W	CUTANS	POROSITY	ROOTS	OTHER CHARACTERISTICS
Ap	0-15	a-s	2.5YR3/4	SC	m vf/f sb+cr	sh vfr ss+sp		a vf/f	m f	
Bt'	15-58	d-s	1.25YR3/6	C	m/w vf/f sb	h fr ss+sp	b d C	vm vf/f	m f	
Bws	58-180		1.25YR3/6	C	pm-wc	sh vfr ss+sp	p f C	vm vf/f	c f	very few, medium, soft, spherical and irregular clay modules
	augering									
Bws	180-400		1.25YR3/6	C	.	.	.	.	.	
BC	400-650		idem but with increasing percentage of minerals (rotten rock)							

Notes

- Structure is difficult to describe; every "ped" size can be formed with little force! Clear natural ped surfaces are not present in the subsoil > 58 cm. Horizon differentiation is a combined effect of structure and consistency. The subsoil > 58 cm can be described in term of "floury", "coffee granules".
- The massive soft, probably iron cemented clay nodules with same colour as soil matrix are present from about 100 cm.
- A few fine vertical cracks are visible in the profile.
- Magnetite is present in the whole profile; weatherable minerals are visible from 200 cm and deeper.
- Presence of cutans in deeper subsoil is disputable.

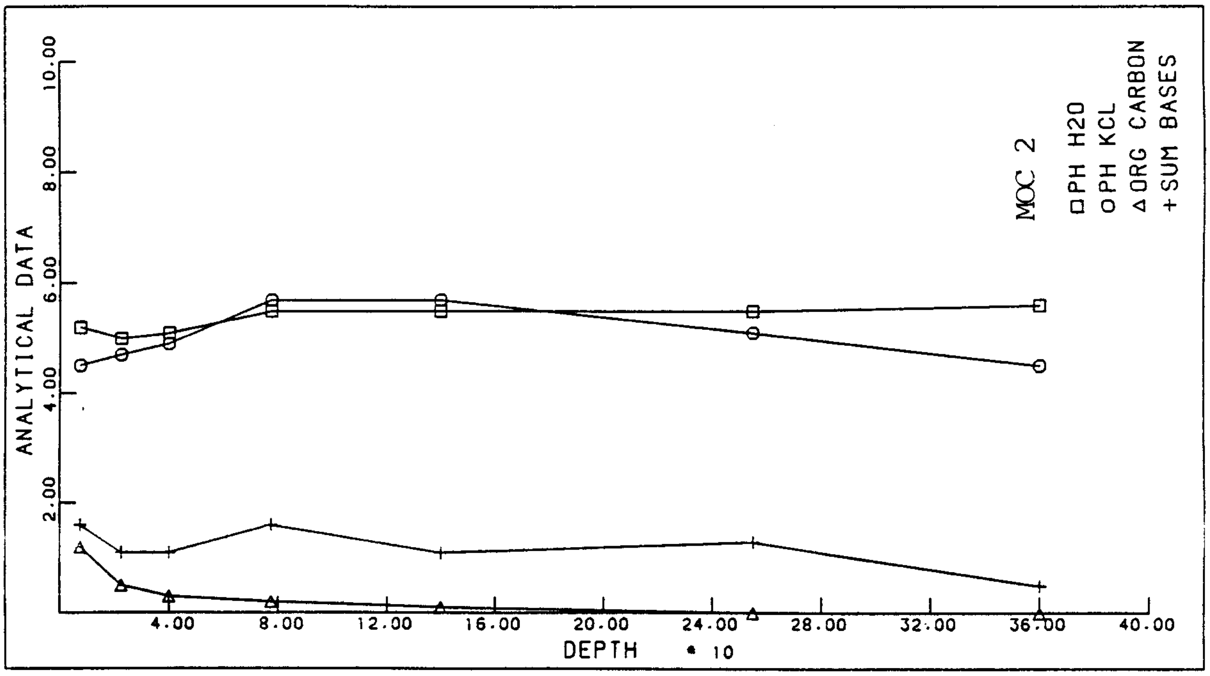
		SAMPLING DEPTH			COARSE SAND			FINE SAND		SILT		CLAY		pH											
1	2	BEG	END	AVE	CS1	CS2	CS3	FS1	FS2	SI1	SI2	AG	DISP	H20	KCl	H+Al	Al	C	N	C/N	Ca	Mg	K	Na	EC
4	1	0	15	7.5	0.1	1.7	9.8	20.1	9.7	8.2	13.6	36.9	11.6	5.2	4.5	0.28	0.00	1.19	0.08	14.9	0.6	0.8	0.2	0.0	0.03
4	2	15	30	22.5	0.1	1.7	5.8	12.4	6.9	4.6	5.6	63.0	0.0	5.0	4.7	0.16	0.00	0.46	0.04	11.5	0.2	0.8	0.1	0.0	0.01
4	3	30	50	40.0	0.2	1.3	5.2	11.5	6.5	4.8	6.9	63.5	0.0	5.1	4.9	0.06	0.00	0.32	0.04	8.0	0.2	0.8	0.1	0.0	0.02
4	4	65	90	77.5	0.1	1.3	6.2	14.1	7.3	4.2	12.6	54.3	0.0	5.5	5.7	0.02	0.00	0.15	0.03	5.0	0.6	0.9	0.1	0.0	0.01
4	5	130	150	140.0	0.2	1.1	3.6	9.6	8.2	6.8	8.5	62.1	0.0	5.5	5.7	0.03	0.00	0.14	0.03	4.7	0.2	0.1	0.7	0.1	0.00
4	6	240	270	255.0	0.4	2.3	4.4	8.7	6.7	7.0	14.2	56.2	0.0	5.5	5.1	0.15	0.00	0.05	0.02	2.5	0.6	0.4	0.2	0.1	0.01
4	7	350	370	360.0	0.2	1.9	4.7	7.8	6.1	5.1	15.6	58.6	0.0	5.6	4.5	0.62	0.00	0.05	0.00	-.1	0.0	0.1	0.2	0.2	0.01
4	8	550	600	575.0	0.1	2.7	9.4	16.0	9.1	6.8	33.5	22.3	0.0	5.5	4.2	2.08	1.80	0.04	0.02	2.0	0.2	0.0	0.1	0.1	0.01

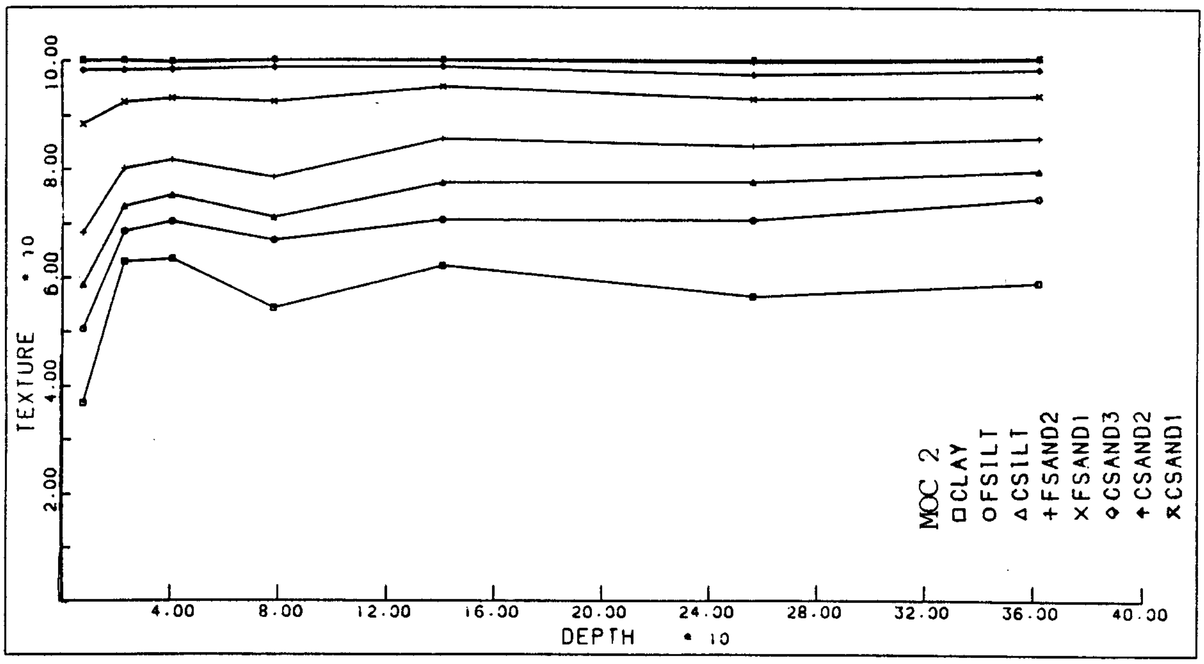
MOC 2 - Analytical results

Depth (cm)	Si/AG	DIFPH	ECEC	CEC
0-15	.59	.7	1.9	9.1
15-30	.16	.3	1.3	8.1
30-50	.18	.2	1.2	6.7
65-90	.3	-.2	1.6	5.2
130-150	.2	-.2	1.1	5.4
240-270	.18	.4	1.3	5.8
350-370	.3	1.1	1.1	6.3
550-600	.81	1.3	2.5	4.6

Sample Depth (cm)	elemental composition of the total soil (weight %)										
	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	TiO2	MnO	P2O5	BaO	Ign. loss
0-15	58.23	18.70	10.85	0.03	0.05	0.10	2.98	0.12	0.18	9.61	100.86
15-30	47.52	25.78	11.87	0.01	0.04	0.08	2.44	0.09	0.18	11.39	99.39
30-50	45.96	27.03	12.11	0.02	0.06	0.07	2.40	0.08	0.16	11.76	99.67
65-90	47.89	25.26	12.14	0.00	0.06	0.08	2.66	0.07	0.08	11.36	99.60
130-150	43.83	27.70	12.93	0.00	0.07	0.08	2.67	0.07	0.07	11.70	99.11
	46.80	27.49	12.45	0.00	0.02	0.07	2.35	0.09	0.06	10.96	100.28
240-280	47.70	27.70	12.44	0.00	0.03	0.07	2.32	0.09	0.06	10.83	101.23
350-370	46.98	27.26	12.18	0.00	0.02	0.06	2.06	0.06	0.05	10.73	99.38
550-600	50.14	26.19	11.47	0.00	0.08	0.05	1.51	0.05	0.03	10.32	99.81

Depth (cm)	Mineralogical composition of the clay fraction				
	Kaol	Quar	Gibb	Goeth	Hem
0-15	+++	0-tr	x	x	tr-x
15-30	+++	0-tr	x	x	tr-x
30-50	+++	0-tr	x	x	tr-x
65-90	+++	0-tr	x	x	tr-x
130-150	+++	0-tr	x	x	tr-x
	+++	0-tr	tr-x	x	tr-x
240-280	+++	0-tr	tr	x	tr-x
350-370	+++	0-tr	-	x	tr-x
550-600	+++	0-tr	tr	x	tr-x


ANALYTICAL DATA
DEPTH * 10
MOC 2
□PH H20
○PH KCL
△ORG CARBON
+SUM BASES


TEXTURE * 10
DEPTH * 10
MOC 2
□CLAY
○FSILT
△CSILT
+FSAND2
×FSAND1
◇CSAND3
✦CSAND2
✕CSAND1

Interpretation of the micromorphological data Profile MOC 2

- Clay illuviation has occurred in the studied pedon. In the small areas (30% of the goundmass) undisturbed by faunal activity in the first two thin sections (20-35 cm, 60-75 cm) the abundance fulfills the requirements of an argillic horizon. The animal activity is of such a type that after disturbance and production of excrements only a few fragments of the clay illuviation features can be detected.
- The influence of the soil fauna is large. The structure and porosity is determined by the animal activity, viz the large extent of interconnected infillings dominantly consisting of shaped mineral excrements. Along faunal voids, as results of faunal activity, compacted zones occur increasing the coherence of the soil material. Several species are responsible of which one producing small excrements and soil aggregates with diameters varying between 40-100 µm, most probably a kind of termite and a larger species producing ellipsoidal to bacillocylindrical excrements, have most impact. the latter species is also responsible for the infilled voids with compact clay-rich groundmass-material occurring over the whole studied depth.
- The incorporated charchal fragments are indicative for burning practises of men. The incorporation till 70 cm depth is most probably a consequence of the high biological activity.

PROFILE: MOC-3

Date of examination: 26 October 1982 (end of dry season); re.: 7 April 1983
(end of rainy season)

Authors : J.H. Kauffman, M. Vilanculos

Higher category classification

- (FAO-UNESCO, 1974)
- (Soil Taxonomy, 1975)

Environmental information

Location : Mozambique, Niassa, Sanga, Unango
Coordinates : 12°57' S, 35°23' E
Elevation : 1075 m
Landform : Plateau, weakly undulating; smooth interfluves and dambo's, few rocks, outcrops/inselbergs
Slope of site: uniform, weakly convex, gradient 1-2%, > 500 m; position: upper slope
Vegetation : Brachystegia Woodland (see annex)
Land use : recently cleared for permanent mechanized farming, maize
Climate : Unimodal, P = , Ep = , 6 months dry, L.R. = (see annex)

General information on the soil

Parent material : Basement complex, diorite (see annex)
Drainage conditions : well drained
Moisture conditions : 0-17 moist, 17-200 dry, > 200 cm moist
Ground water level : no evidence within 600 cm
Termitaria : dome-shaped mounds, very large, < 1/ha
Surface characteristics: ± 2 cm dry litter present

Miscellaneous

Local soil name : Chicunja (Jaua language)

Brief description of the profile

A very deep, well drained, dark red clay soil, moderately structured.

HORIZON CODE	DEPTH	BOUND	COLOUR	TEXTURE	STRUCTURE	CONSISTENCY D	M	W	CUTANS	POROSITY	ROOTS	OTHER CHARACTERISTICS
Ah	0-15	c-s	2.5YR3/3	C	m vf/f sb+cr	.	fr		-	vm vf/f	m f+m	
AB	15-25	g-s	2.5YR3/4	C	m vf/m sb	h	fr		b f C	vm vf/f	m f+m	
Bt''	25-70	d-s	1.25YR3/4	C	m vf/m sb	h	fr		c p C	m vf/f	m f	few faint black mottli
Bt'	70-105	d-s	1.25YR3/5	C	m/w vf/f sb	(s)h	vfr		b d C	m vf/f	m f	very few medium soft
Bws	105-185+		1.25YR3/5	C	w vf/f sb	sh	vfr		p d C	m vf/f	c f	clay nodules
Bws	augering 185-400		idem with few weatherable minerals visible									
BC	400-600		idem with increasing percentage of weatherable minerals									
C	600-670+		rotten rock									

Notes

- Magnetite is present in whole profile.
- Soft nodules has same colour as soil matrix, inner side of nodules is massive.
- Horizon boundaries in subsoil are very diffuse.

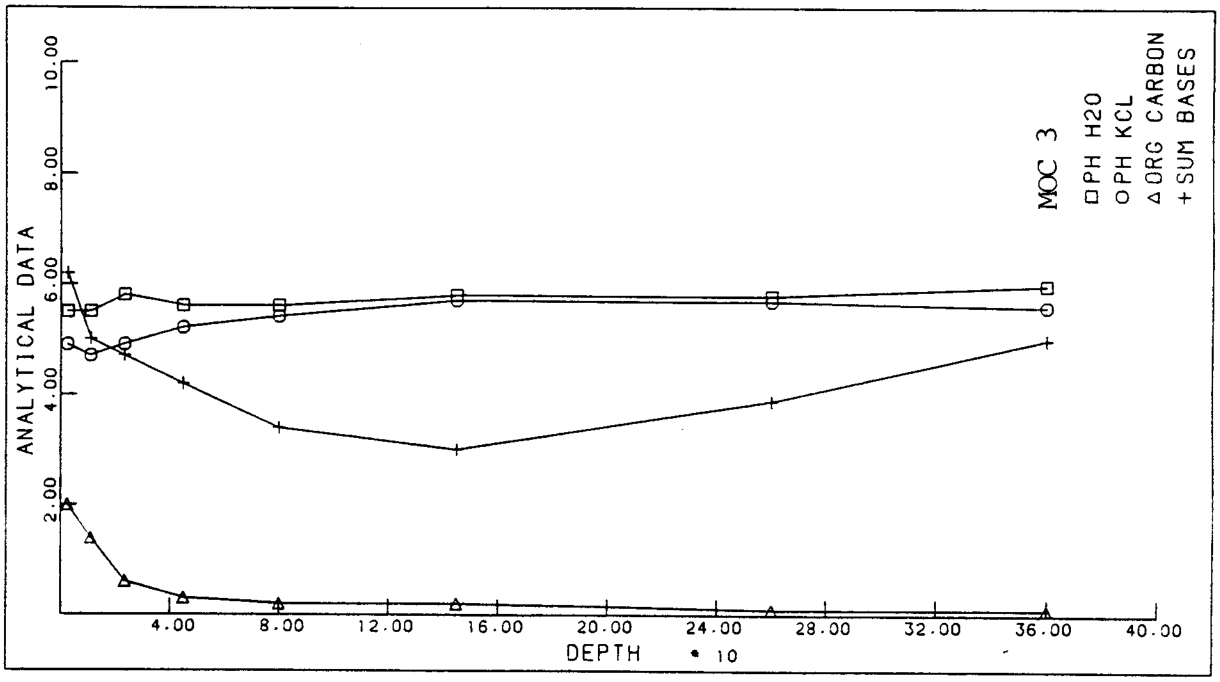
		SAMPLING DEPTH			COARSE SAND			FINE SAND		SILT		CLAY		pH											
1	2	BEG	END	AVE	CS1	CS2	CS3	FS1	FS2	SI1	SI2	AG	DISP	H2O	KCl	H+Al	Al	C	N	C/N	Ca	Mg	K	Na	EC
5	1	0	5	2.5	0.4	2.9	8.3	14.6	7.8	7.2	19.1	39.8	28.5	5.5	4.9	0.13	0.00	1.98	0.14	14.1	2.9	2.5	0.7	0.1	0.09
5	2	5	17	11.0	0.4	2.7	7.3	12.6	6.7	4.3	12.2	53.7	17.4	5.5	4.7	0.12	0.00	1.36	0.11	12.4	2.5	1.8	0.6	0.1	0.05
5	3	17	30	23.5	0.4	2.3	5.4	8.8	5.2	4.5	6.2	67.2	21.8	5.8	4.9	0.04	0.00	0.64	0.06	10.7	2.5	1.6	0.5	0.1	0.03
5	4	30	60	45.0	0.3	1.8	4.0	6.7	3.8	4.5	6.3	72.6	1.5	5.6	5.2	0.00	0.00	0.29	0.05	5.8	2.1	1.4	0.6	0.1	0.02
5	5	65	95	80.0	0.4	1.9	4.4	7.5	4.3	5.4	14.3	61.8	0.0	5.6	5.4	0.00	0.00	0.19	0.03	6.3	1.6	1.1	0.5	0.2	0.01
5	6	130	160	145.0	0.4	1.6	3.0	6.0	4.5	7.1	15.3	62.1	0.0	5.8	5.7	0.00	0.00	0.15	0.02	7.5	1.4	1.2	0.3	0.1	0.01
5	7	230	290	260.0	1.9	4.0	4.3	5.6	4.2	8.6	15.4	56.0	0.0	5.8	5.7	0.02	0.00	0.07	0.04	2.0	1.9	1.3	0.5	0.2	0.01
5	8	330	390	360.0	0.5	2.2	3.5	5.7	4.9	9.8	23.8	49.5	0.0	6.0	5.6	0.02	0.00	0.06	0.03	2.0	2.3	2.1	0.4	0.2	0.01

MOC 3 - Analytical results

Depth (cm)	Si/AG	DIFPH	ECEC	CEC
0-5	.66	.6	6.3	16.2
5-16	.31	.8	5.1	14.0
17-30	.16	.9	4.7	12.3
30-60	.15	.4	4.2	9.8
65-95	.32	.2	3.4	7.9
130-160	.36	.1	3.0	7.5
230-290	.43	.1	3.9	9.0
330-390	.68	.4	5.0	10.1

Sample Depth (cm)	elemental composition of the total soil (weight %)										
	Si02	A1203	Fe203	CaO	MgO	K20	Ti02	MnO	P205	BaO	Ign. loss	
0-5	44.35	20.44	18.25	0.16	0.19	0.34	5.34	0.22	0.29	0.03	10.83	100.43
5-16	43.30	22.38	17.57	0.13	0.17	0.32	4.75	0.20	0.24	0.02	10.73	99.80
17-30	42.43	25.82	16.22	0.10	0.13	0.25	3.78	0.17	0.23	0.01	11.02	100.15
30-60	40.81	28.52	14.96	0.07	0.11	0.21	3.07	0.14	0.16	0.00	11.76	99.81
65-95	41.83	28.43	15.67	0.06	0.09	0.21	3.40	0.11	0.08	0.00	11.19	101.07
130-160	40.24	29.44	15.92	0.05	0.11	0.16	3.33	0.09	0.08	0.00	11.57	101.00
230-290	42.38	29.06	15.74	0.06	0.13	0.04	2.63	0.29	0.09	0.06	10.97	101.50
330-390	42.13	29.36	14.33	0.07	0.11	0.07	2.31	0.09	0.07	0.00	11.37	99.90

Depth (cm)	Mineralogical composition of the clay fraction				
	Kaol	Quar	Gibb	Goeth	Hem
0-5	+++	0-tr	x	x	tr-x
5-16	+++	0-tr	tr-x	x	tr-x
17-30	+++	0-tr	x	x	tr-x
30-60	+++	0-tr	x	x	tr-x
65-95	+++	0-tr	x	x	tr-x
130-160	+++	0-tr	x	x	tr-x
230-290	+++	0-tr	tr	x	tr-x
330-390	+++	0-tr	-	x	tr-x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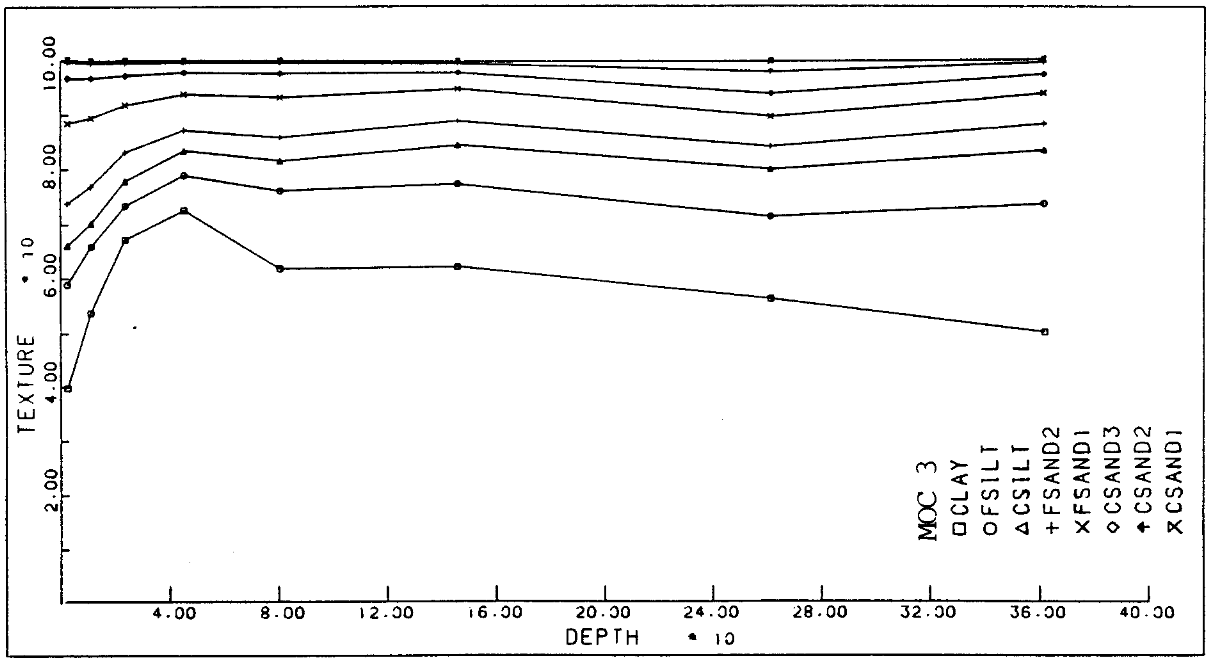
DEPTH * 10
4.00 8.00 12.00 16.00 20.00 24.00 28.00 32.00 36.00 40.00
MOC 3
□ PH H20
○ PH KCL
Δ ORG CARBON
+ SUM BASES


TEXTURE * 10
2.00 4.00 6.00 8.00 10.00
DEPTH * 10
4.00 8.00 12.00 16.00 20.00 24.00 28.00 32.00 36.00 40.00
MOC 3
□ CLAY
○ FSILT
Δ CSILT
+ FSAND2
X FSAND1
◇ CSAND3
CSAND2
CSAND1

Interpretation of the micromorphological data Profile MOC 3

- Clay illuviation has occurred in the present A horizon and top of the B horizon. In undisturbed zones in the groundmass the abundance of ferri argillans and infilled voids, especially in the top of the B horizon (32-47 cm) is enough for an argillic horizon. These zones, however, cover too small an area to fulfill the requirements. Indicative for the disturbance are the papules, which are common in the zone where most undisturbed remnants of clay illuiation are present.
- The occurrence of clay illuviation features in the A horizon indicates that the topsoil is eroded. In the A horizon the quantity of coarse autochtoneous mineral grains is higher than in the B horizon supporting disappearance of fine-grained material. As not any indication is observed of illuviation of fine-grained material in the B horizon, lateral erosion has to be taken place.
- In the A horizon, strongly decreasing in quantity with depth in the B horizon, charcoal is present, as large fragments up to 3 mm ∅, as part of the coarse material and as small black particles in the fine grained material. The charcoal is formed by burning of vegetation at the surface and incorporated in the soil material, whereby the fauna has played an important role. The incorporation of charcoal particles resulted in a darker colour of the A horizon, and is not related to a mollic epipedon.
- The colour of the fine material in the A horizon is not homogeneous. Material of the B horizon is incorporated, indicating an impact of cultivation practices.
- The influence of the fauna is dominant in the studied zones and mainly results in homogenization. Soil animals produce voids systems, many of which are partly or completely infilled with loosely packed, shaped mineral excrements. These void systems are often interconnected. Locally zones of the groundmass only consists of these loosely packed mineral excrements. In the horizon and top of the B horizon common distinct void systems have a compact coating of mainly fine-grained material. These are also a product of faunal activity, generally formed by compaction of excrements along the walls. Deeper in the pedon they hardly occur.
- Roots occur over the whole studied depth and produced a part of the voids.
- In de deepest section (125-140 cm) a few less weathered minerals and rock fragments occur and also some larger grains up to 3 mm ∅ are found, marking the zone where weathering has been less.

Note: The micromorphology of this pedon very much resembles the one of the Indian Benchmark Soil Thekadi. Pedon no. 57. Micromorphological analyses and characterization of 70 Benchmark Soils of India by M.J. Kooistra, 1982, Netherlands Soil Survey Institute, p. 622-630.

PROFILE: MOC-4

Date of examination: 12 November 1982 (start of rainy season);
repeat: 30 March 1983 (end of rainy season)

Authors : J.H. Kauffman, M. Vilanculos

Higher category classification

- (FAO-UNESCO, 1974)
- (Soil Taxonomy, 1975)

Environmental information

Location : Mozambique, Cabo Delgado, Montepuez, Chipembe
Coordinates : 13°09' S, 38°37' E
Elevation : 500 m
Landform : Planation surface, weakly undulating; very broad smooth interfluves
Slope of site: uniform, straight, gradient about 1%, length about 2 km, position: on upper slope or top of interfluve
Vegetation : closed Bambu forest with scattered high trees (see annex)
Land use : nearby permanent mechanized farming, maize and cotton
Climate : Unimodal, P = 930, Ep = 1445, 6 months dry, L.R. = 300 mm (see annex)

General information on the soil

Parent material : Basement; probably gabro norite (see annex)
Drainage conditions : well drained
Moisture conditions : 0-25 cm moist, 25-30 cm dry
Ground water level : no evidence within 300 cm
Termitaria : dome-shaped mounds, medium/large, about 1/5 ha
Surface characteristics: about 1 cm litter (in the agricultural field few signs of sheet erosion)

Miscellaneous

Local soil name : Ithaya yoquilla (Macau language)

Brief description of the profile

A very deep, well drained, dusky red clay soil, weakly to moderately structured up to 125 cm than porous massive, with a dark coloured topsoil.

CODE	HORIZON DEPTH	BOUND	COLOUR	TEXTURE	STRUCTURE	CONSISTENCY D	M	W	CUTANS	POROSITY	ROOTS	OTHER CHARACTERISTICS
Ah	0-18	c-s	5YR2.5/2	SCL	w vf/f cr	.	vfr	ns+sp	-	vm vf/m	m f/m	
AB	18-30	g-s	2.5YR3/2	SC	w vf/f sb	.	vfr	ss+sp	-	vm vf/f	m f/m	
Bt''	30-60	d-s	1.25YR3/4	C	w/m vf/f sb	h	vfr	ss+sp	b d C	m vf/f	m f	
Bt'	60-125	d-s	10 R3/5	C	w vf/f sb	sh	vfr	ss+sp	p f C	m vf/f	c f	
Bws	125-175+		10 R3/5	C	pm-wc	sh	vfr	ss+sp	p f C	m vf	c f	very few medium soft clay nodules
	augering											
Bws	175-320		10 R3/5	C	.	.			.	.	.	
	320-400		10 R3/5		.	.			.	.	.	few medium soft/hard spherical Iron + Mn concretions
	400-430				.	.			.	.	.	
R	430+		abrupt to hard rock or stone									

Note
- The upper horizon has few holes filled with reddish subsoil; the subsoil has few holes filled with dark coloured topsoil
- Traces of magnetite are present from 30 cm and deeper.
- Spherical termite holes with flat bottom and with a diameter of 4 to 8 cm are visible in the whole soil profile, density is about 4/m^2

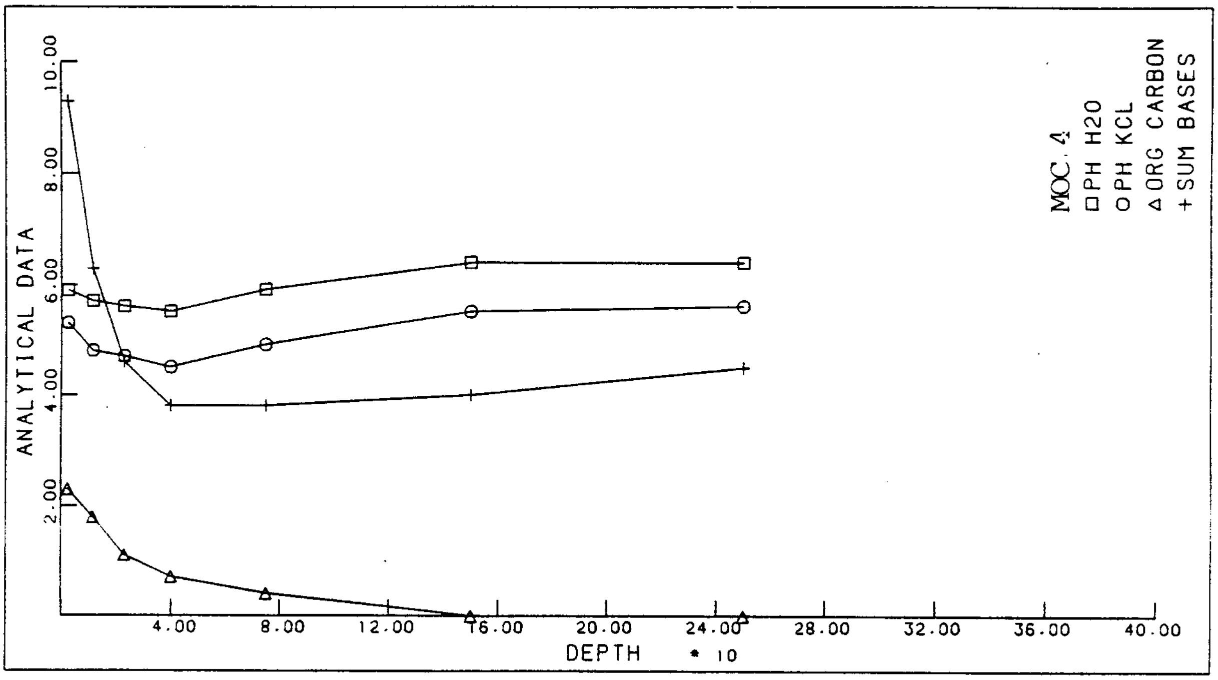
		SAMPLING DEPTH			COARSE SAND			FINE SAND		SILT		CLAY		pH											
1	2	BEG	END	AVE	CS1	CS2	CS3	FS1	FS2	SI1	SI2	AG	DISP	H2O	KCl	H+Al	Al	C	N	C/N	Ca	Mg	K	Na	EC
11	1	0	5	2.5	1.7	8.1	16.9	24.3	11.6	7.3	8.3	21.9	7.0	5.9	5.3	0.02	0.00	2.29	0.13	17.6	4.7	4.2	0.3	0.1	0.06
11	2	5	18	11.5	2.2	8.6	16.1	22.0	11.3	6.0	6.9	26.7	9.5	5.7	4.8	0.02	0.00	1.77	0.10	17.7	3.3	2.8	0.1	0.1	0.03
11	3	18	28	23.0	2.2	8.9	13.6	17.9	8.7	6.1	3.3	39.4	14.4	5.6	4.7	0.07	0.00	1.10	0.07	15.7	2.4	2.0	0.1	0.1	0.03
11	4	30	50	40.0	3.0	7.5	9.7	12.9	6.7	4.1	1.0	55.1	15.2	5.5	4.5	0.15	0.00	0.73	0.07	10.4	1.9	1.7	0.1	0.1	0.02
11	5	60	90	75.0	2.3	5.4	7.8	10.7	5.4	3.4	2.2	62.7	10.2	5.9	4.9	0.04	0.00	0.42	0.04	10.5	2.1	1.5	0.1	0.1	0.01
11	6	125	175	150.0	2.2	5.1	7.7	12.1	6.7	4.4	2.6	59.2	0.5	6.4	5.5	0.00	0.00	0.00	0.05	0.0	2.1	1.7	0.1	0.1	0.01
11	7	225	275	250.0	3.1	4.3	6.8	11.4	7.2	5.5	5.0	56.8	0.0	6.4	5.6	0.02	0.00	0.00	0.03	0.0	2.5	1.8	0.1	0.1	0.02

MOC 4 - Analytical results

Depth (cm)	Si/AG	DIFPH	ECEC	CEC
0-5	.71	.6	9.3	15.9
5-18	.48	.9	6.3	12.9
18-28	.24	.9	4.7	9.7
30-50	.09	1.0	3.9	9.1
60-90	.09	1.0	3.8	8.2
125-175	.12	.9	4.0	7.2
225-275	.18	.8	4.5	7.4

Sample Depth (cm)	elemental composition of the total soil (weight %)											
	Si02	Al203	Fe203	Ca0	Mg0	K20	Ti02	Mn0	P205	Ba0	Ign. loss	
0-5	76.82	7.13	6.96	0.27	0.161	0.05	2.74	0.13	0.03	0.00	6.25	100.53
5-18	75.36	8.80	7.72	0.20	0.16	0.03	2.67	0.12	0.03	0.00	6.06	101.16
18-28	69.92	12.21	8.84	0.14	0.09	0.02	2.29	0.11	0.03	0.00	6.58	100.21
30-50	63.48	16.59	10.20	0.10	0.10	0.02	1.77	0.09	0.03	0.00	7.48	99.86
60-90	59.54	19.86	11.39	0.08	0.09	0.02	1.69	0.08	0.03	0.00	8.25	101.04
125-175	59.16	18.30	11.32	0.08	0.07	0.02	1.88	0.10	0.02	0.00	7.46	98.36
225-275	60.01	19.25	11.94	0.09	0.09	0.02	1.84	0.11	0.01	0.00	7.53	100.89

Depth (cm)	Mineralogical composition of the clay fraction				
	Kaol	Quar	Gibb	Goeth	Hem
0-5	+++	0-tr		tr-x	tr-x
5-18	+++	0-tr		tr-x	tr-x
18-28	+++	0-tr		tr-x	tr-x
30-50	+++	0-tr		tr-x	tr-x
60-90	+++	0-tr		tr-x	tr-x
125-175	+++	0-tr		tr-x	tr-x
225-275	+++	0-tr		tr-x	tr-x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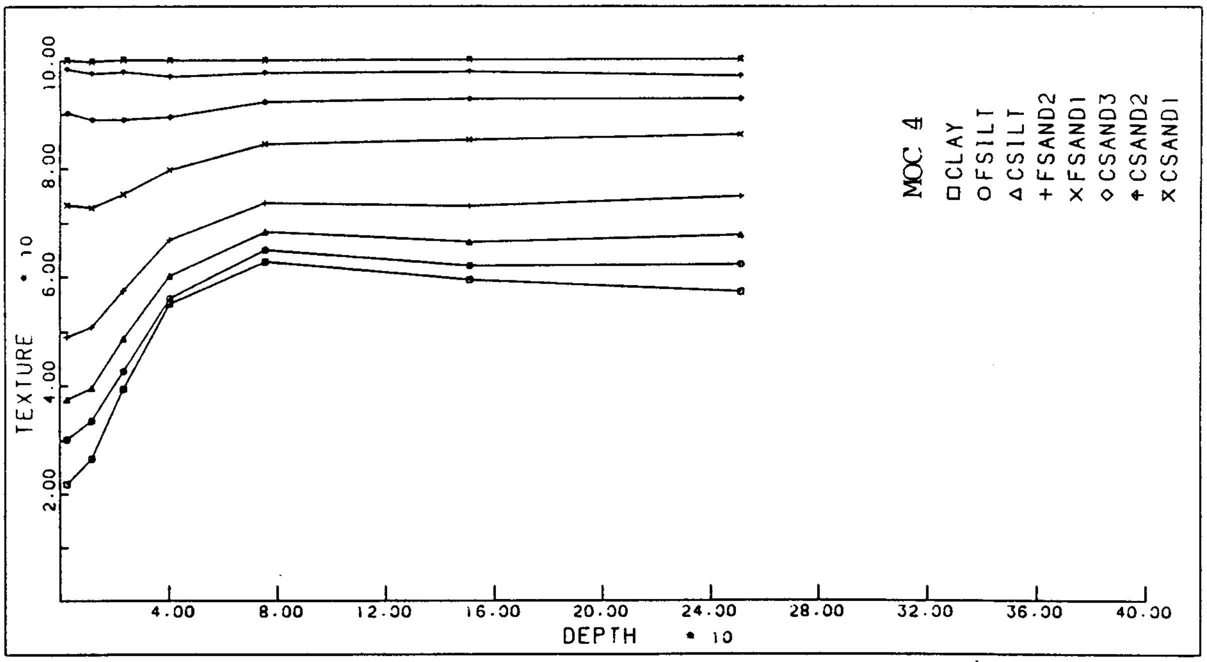
MOC 4
□PH H20
○PH KCL
△ORG CARBON
+SUM BASES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DEPTH * 10
MOC 4
□CLAY
○FSILT
△CSILT
+FSAND2
×FSAND1
◇CSAND3
CSAND2
×CSAND1

Interpretation of the micromorphological data Profile MOC 4

- Clay illuviation occurred over the whole studied zone, in the actual A as well as the B horizon. The quantities fulfill the requirements for an argillic horizon. In the first 12 cm of the A horizon and deep in the B horizon papules are common indicating disturbances by other processes.
- The topsoil of the studied pedon is eroded. Clay illuviation features are present in A horizon and the quantity of coarse mineral material is higher than deeper in the pedon (resulting in a dense porphyric packing contrary to the open porphyric packing in the B horizon) as result of lateral erosion of fine mineral material. Moreover, the mineralogy of the coarse mineral material in the A horizon is more varied (includes pyroxenes and feldspars) than deeper in the pedon, which may be indicative for a kind of transport of coarse mineral material over the surface placing the profile in a lower position in the landscape or they are brought in by human activities.
- Soil fauna plays an important role. Large void systems are produced, often interconnected, which are partly or completely infilled with open packed to slightly welded shaped mineral excrements. Over the whole depth some of these voids have plastered walls, consisting of compact fine-grained mineral material, produced by soil fauna. In the B horizon the animal activity is responsible for the disturbance of clay illuvation features.
- In the A horizon occurs a relatively high quantity of dead organic matter as coarse, dark coloured fragments. The dark colour is an evidence of decomposition by fungal and microfloral attack. Due to the presence of this organic material the A horizon is darker coloured. The occurrence can be a result of animal activity under a shrub vegetation or woodland and/or a result of cultivation practices.

PROFILE: MOC-5

Date of examination: 23 November 1982 (start of rains); repeat: 13 April 1983 (end of rains)

Authors : J.H. Kauffman, M. Vilanculos

Higher category classification

- (FAO-UNESCO, 1974)
- (Soil Taxonomy, 1975)

Environmental information

Location : Mozambique, Nampula, Monapo, Metochéria

Coordinates : 14°49' S, 40°05' E

Elevation : 180 m

Landform : planation surface, nearly flat to weakly undulating; dissected interfluves

Slope of site: complex, weakly convex, length < 300 m, gradient 1-2%; position: nearly on top of interfluve

Vegetation : dense grass cover with few trees (originally probably dense rich forest)

Land use : at site nearly permanently cultivated plots of small farmers, nearby large cotton estates

Climate : Unimodal, P = 935, Ep = 1425, ± 6 months dry, L.R. = 275 mm (see annex)

General information on the soil

Parent material : mafic rock type, probably gabro (see annex)

Drainage conditions : well drained

Moisture conditions : 0-85 moist, > 85 cm dry

Ground water level : no evidence

Termitaria : dome-shaped mounds, density about < 1/ha

Surface characteristics: in the cultivated land rill erosion is common, mainly on the more sloping terrain towards natural drainage channels

Miscellaneous

Local soil name : -

Brief description of the profile

A deep, well drained, dark reddish brown clay soil, strongly or moderately structured; with a thick dark coloured topsoil; subsoil aggregates fall apart when wetted.

HORIZON CODE	DEPTH	BOUND	COLOUR	TEXTURE	STRUCTURE	CONSISTENCY D	M	W	CUTANS	POROSITY	ROOTS	OTHER CHARACTERISTICS
Ah	0-30	c-s	5YR3/1	C	m vf/f sb+cr	(s)h	vfr	ss/p	-	vm vf/m	m f/m	
AB	30-50	g-s	5YR3/2	C	s/m vf/m sb+ab	h	fr	s/p	c/b p C	m vf	m f	
Bt'''	50-95	g-s	2.5YR3/4	C	s/m f/m sb+ab	h	fr	s/p	c p C	c vf/f	c f	
BC	95-140	d-w	±2.5YR3/5	C	m f sb+ab	h	fr	s/p	c p C	c f	c f	very few to few fine to medium, strongly weathered rock fragments
CB	140-160+		7.5YR5/8 + 2.5YR3/4	mainly rotten rock								

Note

- Soil when dry has a few cracks, width is less than ½ cm.
- Soils clods falls apart in very fine angular aggregates when saturated with water.
- At a depth of about 70-100 cm is present a "stone layer" with a thickness of 5 to 15 cm containing few, fine to medium (iron rich) angular concretions and few quartz gravels; the layer forms no limitation for root development.

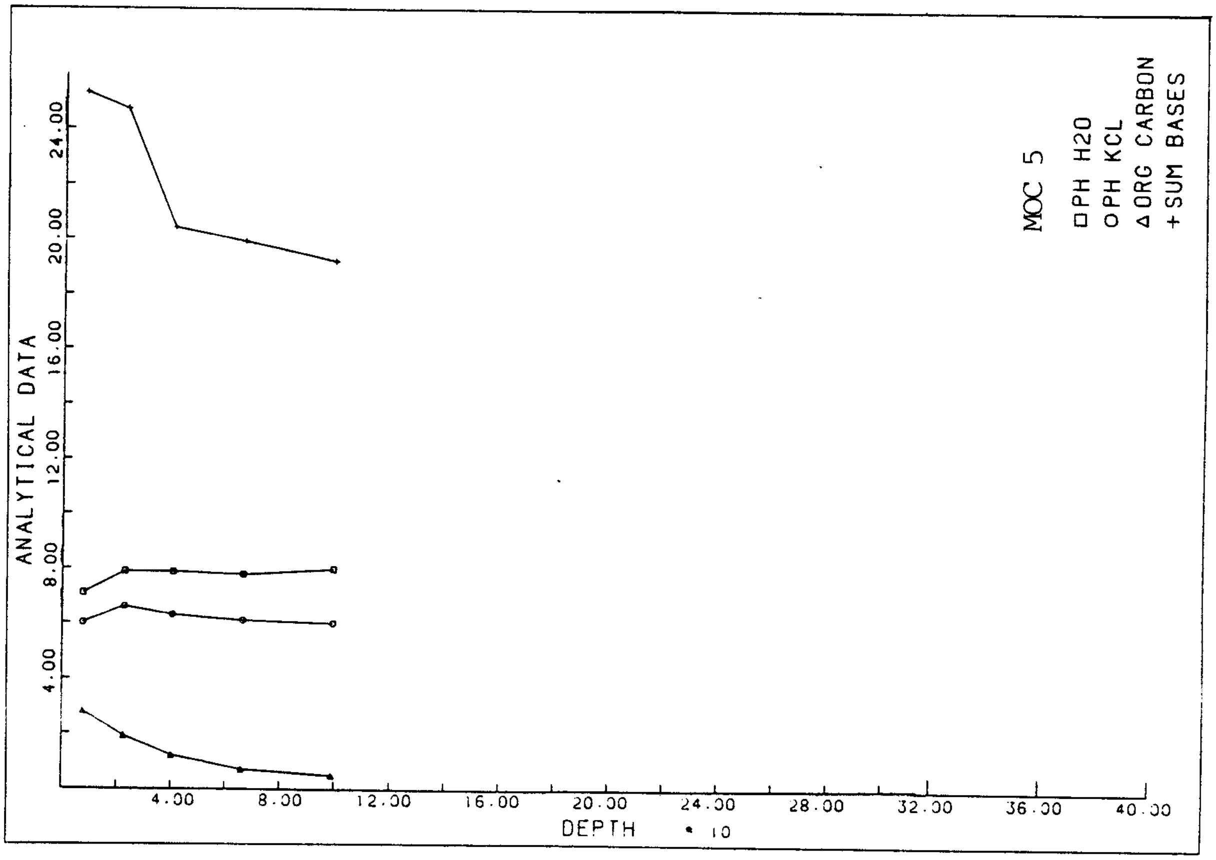
1	2	SAMPLING DEPTH BEG	END	AVE	COARSE SAND CS1	CS2	CS3	FINE SAND FS1	FS2	SILT SI1	SI2	CLAY AG	DISP	pH H2O	KCl	H+Al	Al	C	N	C/N	Ca	Mg	K	Na	EC
15	1	0	15	7.5	1.8	4.6	7.8	12.4	8.5	8.4	15.0	41.4	16.2	7.1	6.0	0.06	0.00	2.81	0.19	14.8	20.5	3.5	1.2	0.1	0.13
15	2	15	30	22.5	0.6	2.8	6.4	10.8	7.5	8.1	15.5	48.3	19.8	7.9	6.6	0.06	0.00	1.92	0.14	13.7	20.9	2.5	1.2	0.1	0.13
15	3	30	50	40.0	0.8	2.3	4.9	9.0	5.2	7.1	11.2	59.5	25.1	7.9	6.3	0.03	0.00	1.18	0.10	11.8	15.1	5.0	0.2	0.1	0.09
15	4	50	82	66.0	0.8	2.2	2.9	4.6	3.3	2.6	6.3	77.3	21.9	7.8	6.1	0.03	0.00	0.74	0.09	8.2	12.5	7.0	0.3	0.1	0.08
15	5	82	125	99.0	1.2	3.5	4.3	6.4	4.6	4.8	8.1	67.1	22.1	8.0	6.0	0.02	0.00	0.51	0.08	6.4	11.4	7.5	0.2	0.1	0.06

MOC 5 - Analytical results

Depth (cm)	Si/AG	DIFPH	ECEC	CEC
0-15	.57	1.1	25.4	35.3
15-30	.49	1.3	24.8	31.6
30-50	.31	1.6	20.4	27.2
50-82	.12	1.7	19.9	25.6
82-125	.19	2.0	19.2	25.0

Sample Depth (cm)	elemental composition of the total soil (weight %)											
	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	TiO2	MnO	P2O5	BaO	Ign. loss	
0-15	50.30	20.80	10.27	3.61	1.96	0.91	0.81	0.13	0.11	0.04	10.77	99.71
15-30	49.44	21.53	11.09	3.31	1.84	0.75	0.81	0.14	0.04	0.03	10.12	99.10
30-50	47.10	23.77	11.47	2.29	1.49	0.65	0.85	0.12	0.02	0.02	11.95	99.73
50-82	44.75	27.94	11.82	1.37	1.11	0.45	0.73	0.09	0.01	0.01	11.70	100.00
82-125	44.17	26.90	12.67	2.19	1.70	0.33	0.70	0.11	0.02	0.01	10.80	99.60

Depth (cm)	Mineralogical composition of the clay fraction				
	Kaol	Smec	Quar	Goeth	Hem
0-15	+++	+	0-tr	tr	tr
15-30	+++	+	0-tr	tr	tr
30-50	+++	+	0-tr	tr	tr
50-82	+++	tr-+	0-tr	tr	tr
82-125	+++	tr-+	0-tr	tr	tr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MOC 5
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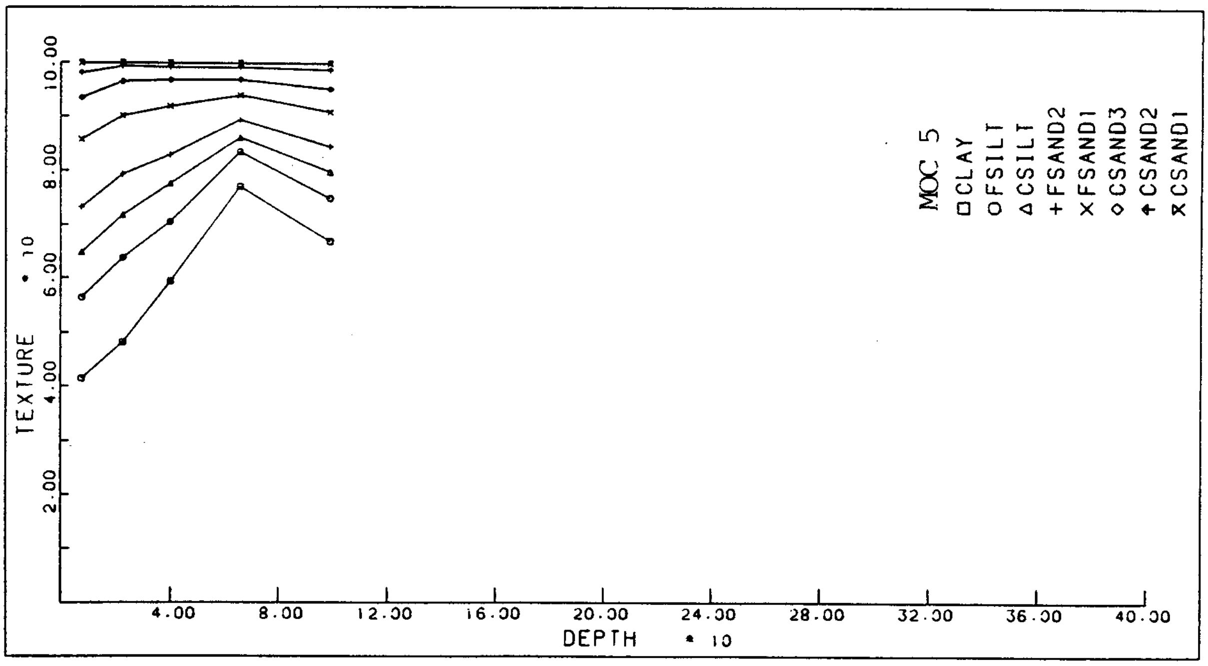
○PH KCL
△ORG CARBON
+SUM BASES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MOC 5
□CLAY
○FSILT
△CSILT
+FSAND2
×FSAND1
◇CSAND3
CSAND2
CSAND1

Interpretation of the micromorphological data Profile MOC 5

- Clay illuviation occured on a minor scale in the upper horizons.
- Till about 32 cm depth the soil material is disturbed, as all clay illuviation features are present as papules, most probably to be attributed to a kind of cultivation practice as the disturbed material has a darker colour due to a higher content on organic matter.
- The effect of the soil fauna on soil structure and porosity is large in the upper section. In the deeper section their impact is considerably less.
- In the deeper section vosepic plasmic fabrics occur along the planar voids surrounding the peds. They indicate a distinct impact of swell and shrink in this horizon.
- In the upper section some evidence of illuviation of shifted soil material can be traced. The impact of this process is low.

PROFILE: MOC-6

Date of examination: 28 November 1982 (start of rainy season);
repeat: 27 April 1983 (end of rainy season)

Authors : J.H. Kauffman, M. Vilanculos

Higher category classification

- (FAO-UNESCO, 1974)
- (Soil Taxonomy, 1975)

Environmental information

Location : Mozambique, Nampula, Nampula, Nova Chaves
Coordinates : 15°18' S, 39°07' E
Elevation : 450 m
Landform : middle planation surface, (weakly) undulating; irregular interfluves, bare rock inselbergs frequent
Slope of site: straight/irregular, gradient %, length m; position: upper slope
Vegetation : fallow grasses + herbs (see annex)
Land use : shifting cultivation, small farmer, cassave/cashew
Climate : Unimodal, P = , Ep = , about 6 months dry; L.R. = 350 mm (see annex)

General information on the soil

Parent material : Basement; granite (see annex)
Drainage conditions : well drained, 0-120 cm, > 120 cm imperfectly
Moisture conditions : 0-165 cm moist
Ground water level : probably deep subsoil > 150 cm is saturated during some period in rainy season
Termitaria : dome-shaped mounds, medium/large, < 1/ha; also few chimney-shaped mounds present
Surface characteristics: -

Miscellaneous

Local soil name : -

Brief description of the profile

A deep, well drained, yellowish red sandy clay (loam), with a loamy sand topsoil and deeper than 150 cm having a strongly mottled low permeable subsoil.

CODE	HORIZON DEPTH	BOUND	COLOUR	TEXTURE	STRUCTURE	CONSISTENCY D	M	W	CUTANS	POROSITY	ROOTS	OTHER CHARACTERISTICS
Ah	0-21	c-s	10YR3/1	LS	w f/m sb	.	1	ns+np	-	vm f	m vf	
E	21-52	c-s	7.5YR3.5/2	LS	w m[1] sb	.	1	ns+np	-	vm f	m vf	
Bt	52-121	g-s(w)	5YR4/6	SCL/SC	pm-wc	.	vfr	ss+sp	p f C(?)	m vf/f	c vf/f	
Btg	121-165+		2.5YR4/6	SC	w m ab	vh	fr	s+sp	-	m vf/f	f vf/f	many 10YR7/1 + 10YR6/6 mottling

Note

[1] Structure of topsoil can be also described as single grain or massive porous/weakly coherent.
- In topsoil are holes filled with redder coloured subsoil; in subsoil are holes filled with darker coloured topsoil.
- At 90 cm one can observe a slight increase in clay content.
- Termite holes are present, density about $2/m^2$.
- The strongly mottled subsoil is caused by temporarily stagnant water.

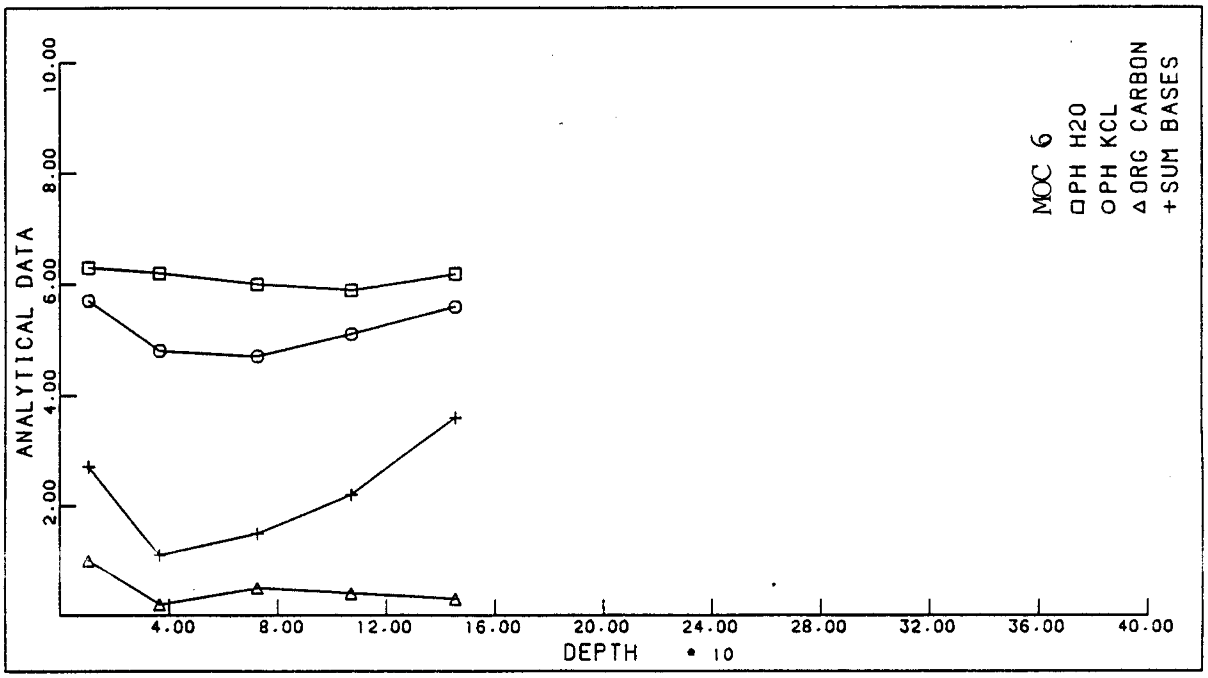
		SAMPLING DEPTH			COARSE SAND			FINE SAND		SILT		CLAY		pH											
1	2	BEG	END	AVE	CS1	CS2	CS3	FS1	FS2	SI1	SI2	AG	DISP	H2O	KCl	H+Al	Al	C	N	C/N	Ca	Mg	K	Na	EC
16	1	0	21	10.5	4.7	16.7	27.6	23.9	6.7	3.7	4.3	12.3	10.2	6.3	5.7	0.00	0.00	1.03	-.10	-.10	2.2	0.4	0.1	0.0	0.05
16	2	21	52	36.5	5.4	19.0	30.2	22.9	5.3	2.4	2.6	12.2	12.4	6.2	4.8	0.10	0.00	0.22	-.10	-.10	0.8	0.2	0.1	0.0	0.04
16	3	52	93	72.5	7.0	21.0	24.7	16.3	4.2	2.2	1.5	23.1	3.4	6.0	4.7	0.10	0.00	0.49	-.10	-.10	1.2	0.2	0.1	0.0	0.04
16	4	93	121	107.0	11.2	15.3	13.2	8.8	3.0	1.9	1.9	44.6	10.8	5.9	5.1	0.10	0.00	0.45	-.10	-.10	1.8	0.3	0.1	0.0	0.04
16	5	131	160	145.5	4.6	8.8	9.2	7.7	3.4	3.3	4.1	58.9	2.3	6.2	5.6	0.00	0.00	0.27	-.10	-.10	3.1	0.5	0.0	0.0	0.03
16	6	275	310	292.5	12.8	15.2	11.7	8.9	4.5	7.0	9.0	30.8	2.5	5.5	5.4	0.00	0.10	0.22	-.10	-.10	0.2	0.8	0.1	0.0	0.03
16	7	325	375	350.0	12.8	12.4	7.7	4.9	2.6	5.3	8.3	46.0	2.0	5.4	4.7	0.20	0.20	0.25	-.10	-.10	0.3	1.1	0.1	0.0	0.04

MOC 6 - Analytical results

Depth (cm)	Si/AG	DIFPH	ECEC	CEC
0-21	.65	.6	2.7	5.4
21-52	.41	1.4	1.2	2.5
52-93	.16	1.3	1.6	4.0
93-121	.09	.8	2.3	4.3
131-160	.13	.6	3.6	5.5

Sample Depth (cm)	elemental composition of the total soil (weight %)										
	SiO2	Al2O3	Fe2O3	CaO	MgO	K2O	TiO2	MnO	P2O5	BaO	Ign. loss
0-21											
21-52											
52-93											
93-121											
131-160											

Depth (cm)	Mineralogical composition of the clay fraction				
	Kaol	mi/Ill	Quar	Feld	Goeth
0-21	+++	tr	tr	tr	tr-x
21-52	+++	tr	tr	0-tr	tr-x
52-93	+++	0-tr	tr	0-tr	tr-x
93-121	+++	-	tr	0-tr	tr-x
131-160	+++	-	0-tr	-	tr-x
	+++	-	0-tr	-	-
	+++	-	0-tr	-	-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△ORG CARBON
+SUM BASES
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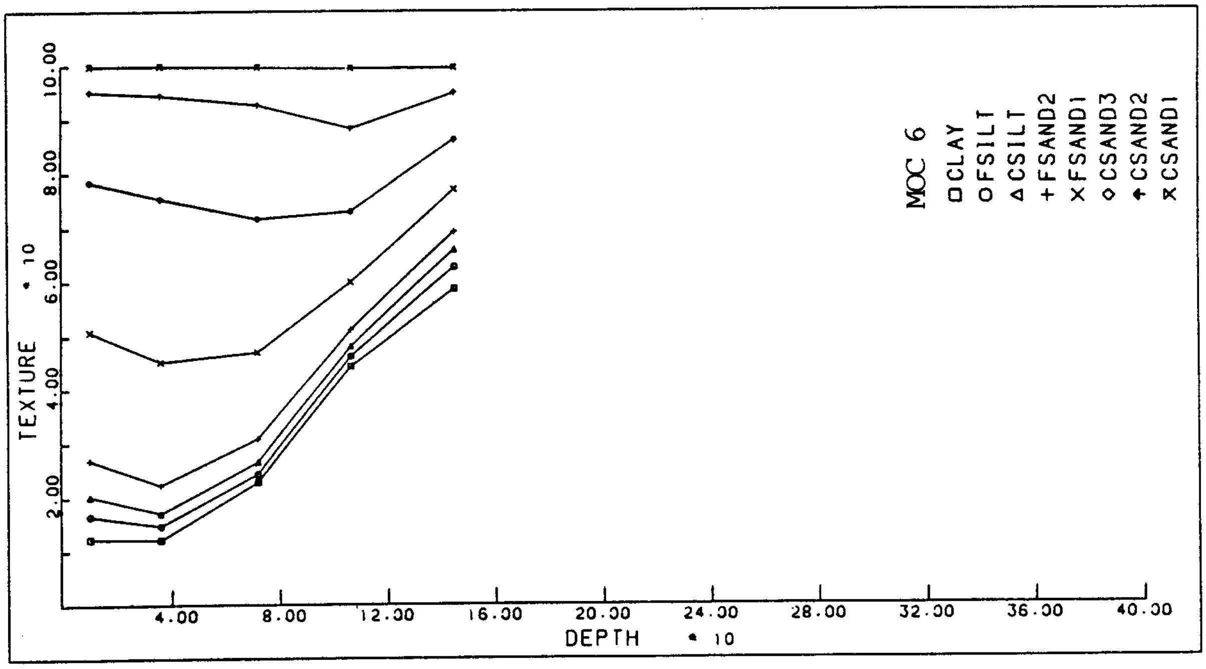
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4.00
6.00
8.00
10.00
4.00
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DEPTH * 10

Interpretation of the micromorphological data Profile MOC 6

- In the studied pedon clay illuviation occurred and still occurs. From about 50 cm onwards their quantities (just) fulfill the requirements for an argillic horizon. Clay illuviation is an old process in this pedon as other processes are superimposed, e.g. iron depletion and accumulation and faunal impacts. Besides clay illuviation also gibbsite is formed deeper in the soil (88-103 cm) in specific locations, namely large originally completely infilled faunal voids, where it occurs along the walls of nearly all secondary formed small interconnected voids. Deeper in the pedon (137-152 cm) seggregation of iron occurs, zones of depletion and accumulation are present adjoining each other. All these processes not only indicate weathering of primary minerals as feldspars and mica's, but mainly a desintegration of the clay in the fine material.
- The soil fauna plays an important role. The structure and porosity is largely determined by their activity. They also transport soil material in the pedon from A horizon to B horizon and reverse. Due to their compact excrements and compacted zones and coatings around voids they also form a stabilizing agent of the soil material, especially in the upper horizons (10-25 cm, 50-65 cm). The soil fauna consists of several species including worms, termites and mites.
- At about 19 cm depth a burried surface occurs detectable from the presence of a horizontally layered, compacted groundmass material. The material on top of this surface is derived from the same type of soils.
- Below and above this burried surface the quantities of coarse mineral grains in the groundmass are higher but of the same origin and grain-size distribution as deeper in the pedon, indicating an overall loss of fine-grained material. As only a minority of this material can be traced as illuviated dark coloured laminated clay, most material must have been removed by lateral erosion. The occurrence of clay illuviation features in situ till the top of the burried surface and the isolated fragments of them above this surface strengthen the importance of lateral erosion.
- Below the burried surface, as well as above a large part of the voids packing voids and charcoal fragments are common, indicating cultivation of the soil.

<u>Mineralogical classification of rock samples</u>

No	CLASSIFICATION	RESISTENT MINERALS			FELDSPARS				MICAS						
		quartz	mag	ilm	micro	oli	and	lab	mus	biot	horn	aug	apa	sph	others
MOC 2	Leucocratic diorite	1			3		74			5		14			
MOC 3	Quartzitic diorite	5	1		1		64			13		16	1		
MOC 4	Amphiobolic gabro	0	<1					38			26	35			
	Amphibolized gabro norite		<1				56				12	31	<1		
MOC 5	Gabro norite	0		1				64			2	19	1		15 hypersthene
MOC 6	Granite	32		1	35		30(p)		<1	1			<1		

mag = magnetite
ilm = ilmenite
micro = microcline (K-feldspar)
oli = oligoclase (Na>Ca feldspar)
and = andesine (Na≥Ca feldspar)
lab = labrador (Na≤Ca feldspar)
(p) = plagioclase (Na+Ca feldspar)

mus = muscovite
biot = biotite
horn = hornblende
aug = augite
apa = apatite
sph = sphene (titanite)

Mineralogical composition of the sand fraction (50-500µ)

Prof. No.	Depth	Op	Qu	Zi	Tu	Ru	Mu	Di	An	Si	Ap	Gr	Fe	Ho	Au	Hy	unknown
		WEATHERING STABILITY															
		very stable					stable			moderate			unstable				
A2	30- 45	14.0	80.5	3.3		0.5			0.2				1.6	<			
A2	130-145	16.0	80.8	2.0		0.3			0.1	<			0.8				<
A2	400-460	16.1	78.9	2.8		0.4			0.1				1.6				
L1	30- 50	9.3	89.2	0.6	<	<		<		<	<		0.9				
L1	240-270	8.9	80.4	0.6		0.1	8.1		<				0.9			<	
L1	550-560	4.3	80.2	0.1			14.3			<			0.9			<	
L2	30- 60	39.7	51.8	0.8		<	6.0						1.8			<	
L2	330-390	31.3	56.7	2.0		<	7.3						2.7				
C1	30- 50	7.3	92.5	0.1	<	0.1				<	<	<		<			
C1	125-175	7.4	92.3	0.2	<	0.1				<	<	<		<		<	<
N2	30- 50	3.7	19.0			0.4						0.8	63.5	5.5	1.8	4.8	
N2	82-125	2.5	14.3									0.5	60.8	9.5	2.7	9.0	
N3	30- 50	0.9	98.9	0.1		<				<				<			
N3	110-150	1.4	98.4	0.1		<			<								
N3	325-375	2.3	97.2	0.2	<	<											

Op = opaque 1)
Qu = quartz
Zi = zircon
Tu = turmaline
Ru = rutile

Mu = muscovite
Di = disthene
An = anatase
Si = sillimanite
Ap = apatite

Gr = garnet
Fe = feldspar
Ho = hornblende
Au = augite
Hy = hypersthene

< = less than 0.1%

1) mainly ilmenite and magnetite

ANNEX 4A - Summary of abbreviations and procedures for exchange properties

Summary of analytical procedures to determine exchange properties

Solution (extractant)				
buffer	pH	salt	Measured cations	Terminology and/or abbreviation used
No	f*	KCl	Hydrogen and aluminium	exchangeable acidity
No	f*	NH_4Cl	Ammonium	ammonium ions retained
Yes	7	NH_4Ac	Ca, Mg, Na and K	sum of bases
Yes	7	NH_4Ac (NaAc)	Ammonium (or sodium)	cation exchange capacity = CEC 7 (NH_4Ac)
Yes	8.2	BaCl -TEA	Hydrogen and Aluminium	extractable acidity = (H+Al)8.2

* pH is nearby pH of soil in the field (f)

Abbreviations used for Cation Exchange Capacities (CEC)

ECEC or "effective CEC" = "sum of bases plus exchangeable acidity; or
ECEC = "me of NH -ions retained by unbuffered NH Cl solution"
CEC(7) = CEC determined with NH_4Ac buffered at pH 7
CEC(8.2) = CEC calculated from sum of bases plus extractable acidity (8.2)

Abbreviations for different Base Saturation percentage calculations

$$\text{BS (7)} = \frac{\text{sum of bases}}{\text{CEC 7}} \times 100$$

$$\text{BS (8.2)} = \frac{\text{sum of bases}}{\text{CEC 8.2}} \times 100$$

$$\text{BS (f)} = \frac{\text{sum of bases}}{\text{ECEC}} \times 100$$

ANNEX 4B - Summary of the exchange properties criteria used in ST and FAO

SOIL TAXONOMY

Oxic horizon

- ECEC $\leq$ 10 me/100 g clay (for both analytical procedures)
- CEC(7) $\leq$ 16 me/100 g clay

Ultisol

- BS (8.2) < 35% at a depth of (about) 180 cm
- Often used is the assumed correlation: 35% BS (8.2) $\approx$ 50% BS (7)

Mollic epipedon

- BS (7) > 50%

Oxic subgroup

- CEC(7) $\leq$ 24 me/100 g clay in the major part of the argillic horizon

Acri (sub)group

- CEC < 1.5 me/100 g clay (for both analytical procedures)

Haplustox

- BS (7) < 50% when clayey
- BS (7) < 35% when loamy

FAO

Mollic horizon

- BS (7) > 50%

Oxic horizon

- ECEC < 10 me (for both analytical procedures)
- CEC(7) < 16 me

Acrisols and dystric subgroups

- BS (7) <50% in at least a part of the B horizon within 125 cm of the surface

ANNEX 5 - Analytical Methods

Particle size distribution

About 20 g of soil (fine earth, < 2 mm) was treated with 15% H_2O_2. It is left for one night in the cold (in waterbath at room temperature) and then heated to 80°C on the waterbath. Small increments of H_2O_2 were added until completion of the treatment. Dispersion was effected by overnight shaking in a reciprocating shaker after adding sodium pyrophosphate. The resulting suspension was sieved through a 50 µm sieve. The fraction passing through the sieve was washed by sedimentation and siphoning, followed by centrifuge washing. Clay and silt were determined with the pipette method. Sand, washed out on the 50 µm sieve was dried and fractionated by a range of sieves on a mechanical vibrator.
In some cases parallel sample was treated similarly but deferration was applied after the peroxide treatment (Mehra and Jackson, 1960).
Water dispersable clay was determined with the pipette method after shaking 20 g of soil (fine earth) overnight (16 hrs) with demineralized water, omitting any other treatment.

pH

The pH-H_2O was measured in a 1:2.5 air-dry soil:water (wt/wt) suspension after overnight mechanical shaking.
The pH-KCl was similarly measuring using a 1 N KCl solution instead of water.

Carbon

Organic carbon was determined according to the Walkley Black method.

Nitrogen

Total nitrogen was determined with the micro-Kjeldahl technique.

Free iron oxides

To determine different forms of "free" iron oxide, extractions were made with three different extractants (reviewed by Andriesse, 1979).
Dithionite (Holmgren, 1967): 2 g of air-dry fine earth was shaken overnight with a sodium citrate/sodium dithionite mixture and then centrifuged.
Pyrophosphate: similar to the dithionite extraction, but 200 ml 0.1 M $Na_4P_2O_7.10\ H_2O$ solution was used.
Oxalate: 2 g of air-dry fine earth was shaken for 4 hours in 200 ml Tamm's solution (0.2 M ammonium oxalate, pH 3, i.4. acidified with ca. 20 g oxalic acid per liter) and then centrifuged.
In all cases superfloc was added prior to centrifugation. Fe was determined by Atomic Absorption Spectrophotometer (AAS).

Exchangeable cations

Percolation of 5 g fine earth with 1 N ammonium acetate (pH 7). Determination of Ca, Mg, K, and Na in leachate by AAS.

CEC

Above NH_4-saturated sample was leached with 1 N sodium acetate (pH 7) and washed free of salts. The sample was then leached with 1 N ammonium acetate (pH 7) and Na was measured in leachate by AAS.

Exchangeable acidity (H and Al)

Percolation of 5 g fine earth with 1 N KCl solution. Hydrogen is determined in leachate by titration with NaOH to pH 7.5. Aluminium is determined in leachate by AAS.

Electrical conductivity

Measured with EC-meter in the 1:2.5 pH-H_2O solution.

Elemental composition

By X-ray fluorescence analysis. Samples are ignited at 900°C, then 0.6 mg sample is molten with 2.5 lithium tetraborate at ca. 1200°C. The obtained tablet was analyzed on a Philips XRF assembly.
For elemental analysis of the clay fraction, clay was separated as indicated for particle size analysis (without addition of pyrophosphate), after centrifuge washing and freeze-drying the sample was further treated as above.

Clay mineralogy

Clay was separated as indicated for particle size analysis (without addition of pyrophosphate). Approximately 10 mg clay was brought onto a porous plate by suction and the specimens were analysed on a Philips diffractometer. For beter identification of the non-phyllosilicates Guinier photos were taken.

Sand mineralogy

Separation of the light and the heavy fraction (50-500 µm) was done in bromoform, after deferration. Determination was done microscopically.

Moisture characteristics

pF curves were constructed by equilibrating undisturbed ring samples at different suction values (up to 1 bar or approximately pF 3) in individual tempe pressure cells (adapted from Soil Moisture Equipment). High suction (15 bar or approximately pF 4.2) values were obtained from disturbed samples in high pressure cells.
Bulk density was obtained from dry weight of ring sample.