THE IMPACT OF LANDUSE ON SOIL ORGANIC MATTER AND SOIL STRUCTURE, IN RELATION WITH TERMITE-ACTIVITY

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Dit rapport is uitsluitend voor intern gebruik. Citeren uit dit rapport is alleen toegestaan na overleg met de begeleider.

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The present study started with a period of fieldwork in the Chuka-South project area of the Training Project in Pedology (TPIP) in Kenya. The fieldwork lasted from November 1985 until March 1986. During this period I cooperated with Jeanine Kools, who studied the biological part of the subject, while I concentrated my attention on the soil scientific part. We recieved a lot of cooperation from the members of TPIP, of whom I would like to mention
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1. Introduction

1.1 General introduction

Termites are important decomposers of plant material in the semi-humid to arid regions of Kenya and as such have a great influence on the recycling of organic material. Several studies have been done to estimate the significance of termite-activity to tropical ecosystems (Lee and Wood, 1971; Wood and Sands, 1978). Most studies were confined to the obvious effect of mound-building species (Arshad, 1981; Pomeroy, 1983). The modifications of chemical properties and the textural redistribution of the soil material in the mounds were emphasized in these studies. The changes in physical properties of the soil, such as structure, stability, bulk-density and water holding capacity, which are likely to accompagny textural redistribution, were recognized, but very few measurements were actually done (Wood and Sands, 1978).

Also sheetings, built by termites over their food source while foraging, recieved little attention so far.

The aim of this study is to get an idea of the impact of landuse on soil organic matter and soil structure, in relation to termite-activity. Therefore not the termite-mounds themselves, but the surrounding soils are the object of study. This field-approach of studying soils and sheetings rather than mounds, was also followed by Bagine (1984). His study area was located in a dry plain with an open bush and grass vegetation in Northern Kenya. This study concentrated on an area with a potentially higher agricultural use.

Through the cooperation of a biologist (Jeanine Kools) and a soil scientist (Nicole Bongers) it was tried to get a better picture of the ecological circumstances. This report will concentrate on the comparison of soil parameters under the various conditions, while the observations of termite-activity, expressed in litter consumption and soil translocation are reported in Kools (1987).

1.2 Study area

The area of study described in this report is part of the project area of the Training Project in Pedology (TPIP), Chuka-South and is located on the footslopes of Mount Kenya. TPIP was a training project of the Agricultural University, Wageningen, for MSc-students, working in close cooperation with the Kenya Soil Survey (KSS), Nairobi. In the framework of the Chuka project a soil survey on a semi-detailed scale (1:25,000) was carried out in part of the project area (Bongers and Pulles, in press). Afterwards the whole area (mapsheets 122/3 and 122/4) was surveyed on a reconnaissance scale (1:100,000) (De Meester, in press).

The location of the Chuka-South project area is indicated in fig. 1.1.

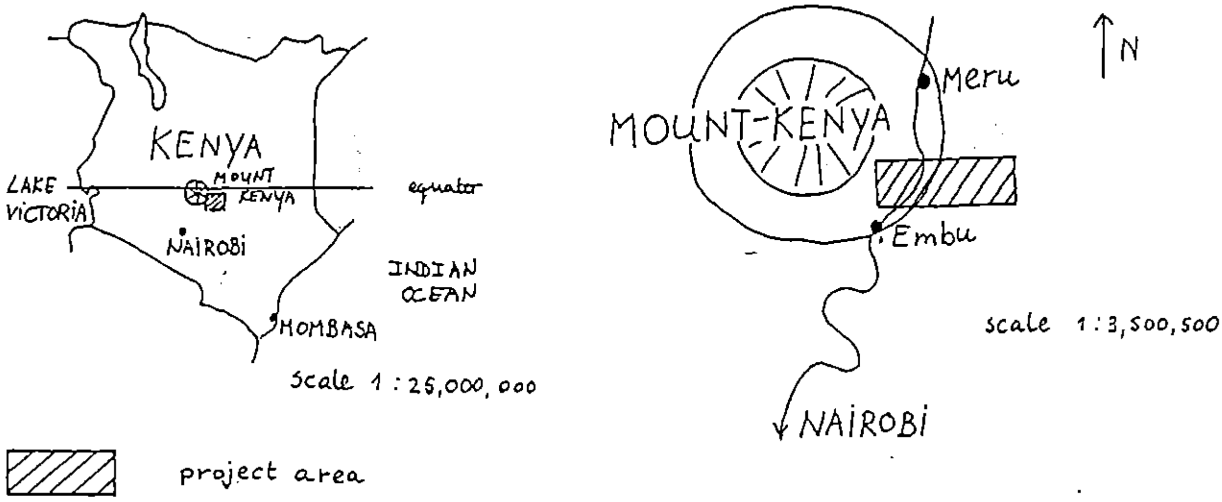

Fig. 1.1: Location of the Chuka-South project area (from Kools, 1987)

The position of the study area on the slopes of Mt. Kenya is such that the altitude changes from about 1800 m in the west to about 1100 m at the escarpment, which forms the transition to the peneplain of the Basement System in the east. The varying altitude causes a change in climatic conditions. While the annual rainfall decreases from about 2200 mm to about 1000 mm from west to east (fig. 1.2), the average annual temperature increases from 16-18 °C to 21-23 °C.

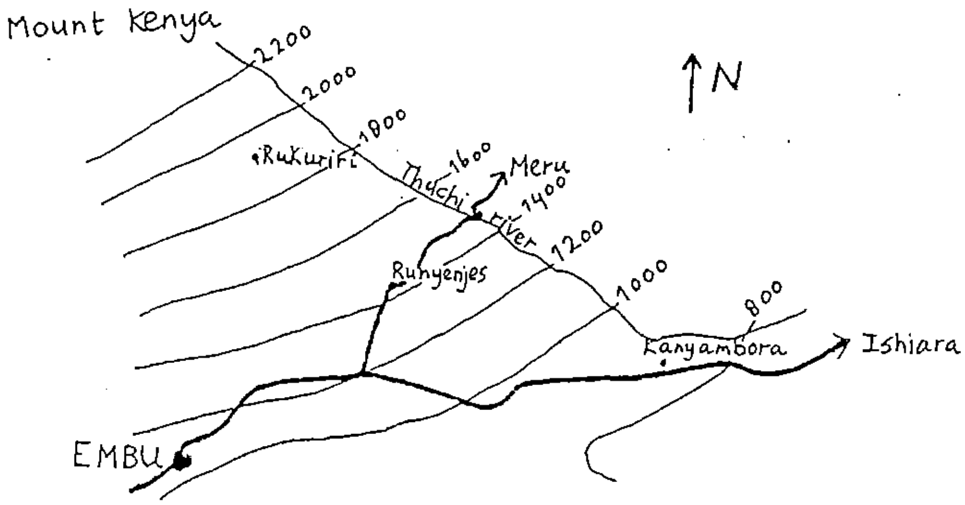

Fig. 1.2: Average annual rainfall in mm in the study area (Jaetzold, 1982)

These climatic condition can be interpreted in terms of agro-ecological zones (Jaetzold et al, 1982), since they influence the success of growing certain crops (fig. 1.3).

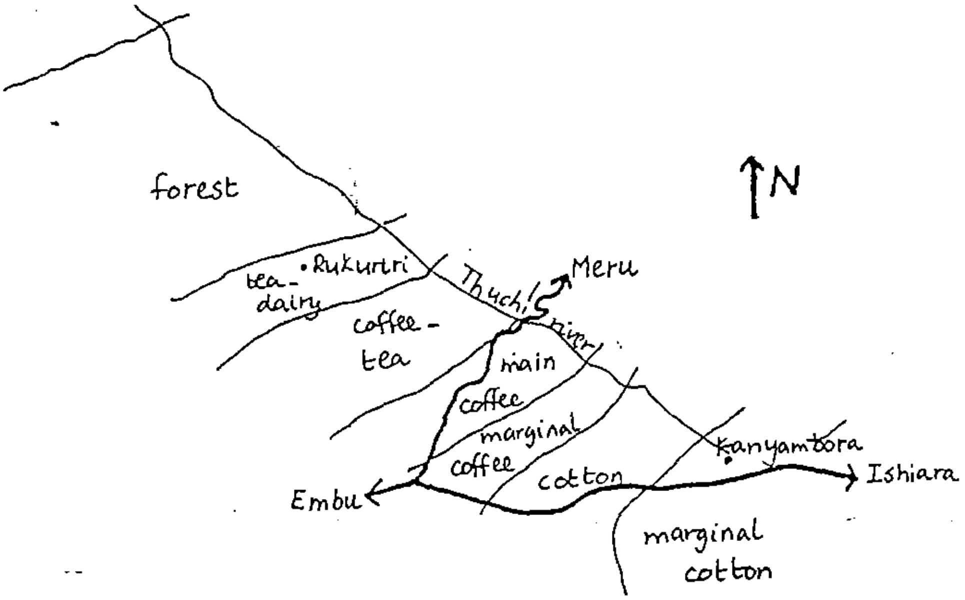

Fig. 1.3: Agro-ecological zone in the study area (Jaetzold, 1982)

For this study the Tea-Dairy zone and the Cotton zone were selected.
In the teazone (as the Tea-Dairy zone will be referred to in this report) most slopes are cultivated with tea. Small plots on the crests remain for houses and shambas (gardens) with foodcrops like maize, yams, beans and potatoes. Close to the houses the cows are kept on zero- or small grazing plots, where they are fed on treeleaves, maize and napiergrass. The manure is used as fertilizer on the shamba. In this zone Mt. Kenya forest has its lower boundary.
The teazone has an average annual rainfall of 1800-2000 mm. The average minimum temperature is 12-14 °C, the average maximum temperature 24-26 °C.
The Cotton zone (or mangozone, as it will be referred to in this report) has a much warmer and drier climate. The average annual rainfall is about 1000 mm and the average minimum and maximum temperature are, respectively 16-18 °C and 28-30 °C (Jeatzold, 1982)
The mangozone is characterized by the many mangotrees and shambas alternating with bananabushes. The shambas are cultivated with cotton and tobacco as cash crops, and maize, millet and beans as food crops. Patches of bushland are used for grazing cattle.

1.3 Approach

In the two zones (teazone and mangozone) 4 sites were selected, each zone having a site with an annual crop (maize) and a site with a standing vegetation

(forest/banana).
Between the zones there is a difference of climate, as mentioned in 1.2, within one zone landuse is the variable factor. Fig. 1.4 illustrates this approach.

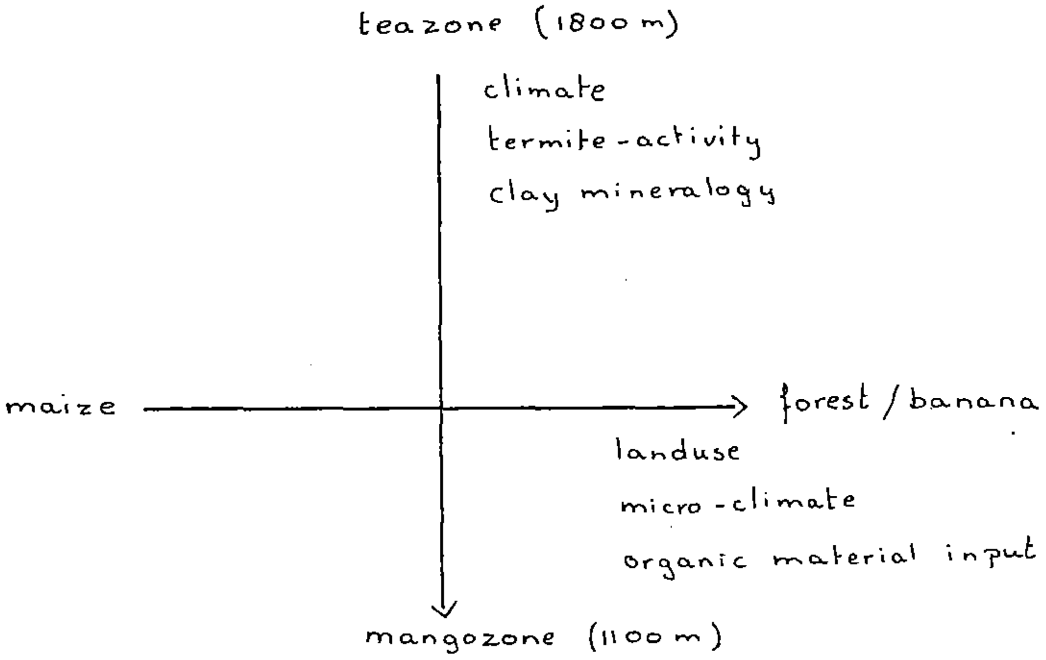

Fig. 1.4: Approach of the subject

Besides the difference in climate between the teazone and the mangozone, we assumed that the clay mineralogy may be different for the two zones as a result of different weathering conditions (Bongers, 1987). This may be expressed in the soil structure and thus should be taken into account. Within one zone differences occur due to landuse. The forest and the banana were supposed to have a more moderate micro-climate than the corresponding maizefields, expressed in a smaller diurnal variation in temperature and a higher humidity. Also the production of litter was expected to be greater in a standing vegetation than in a maize field. Both litter production and micro-climate may be important factors in the formation of soil organic matter.
Termite-activity is favoured by high temperatures, therefore comparing the two maizefields the activity was expected to be higher in the mangozone than in the teazone. Since the amount of food present most likely also will have influence, an even higher activity was expected in the bananabush.
Because the many different species of soil fauna (other than termites) and the complexity of the litter production and consumption, the forest site will be left out of consideration concerning these items.

The interactions of all these parameters together with soil organic matter and soil structure are summarized in fig.1.5. Soil structure and soil organic matter also have again influence on the vegetation and the crops grown, but these influences will be left out of consideration here.

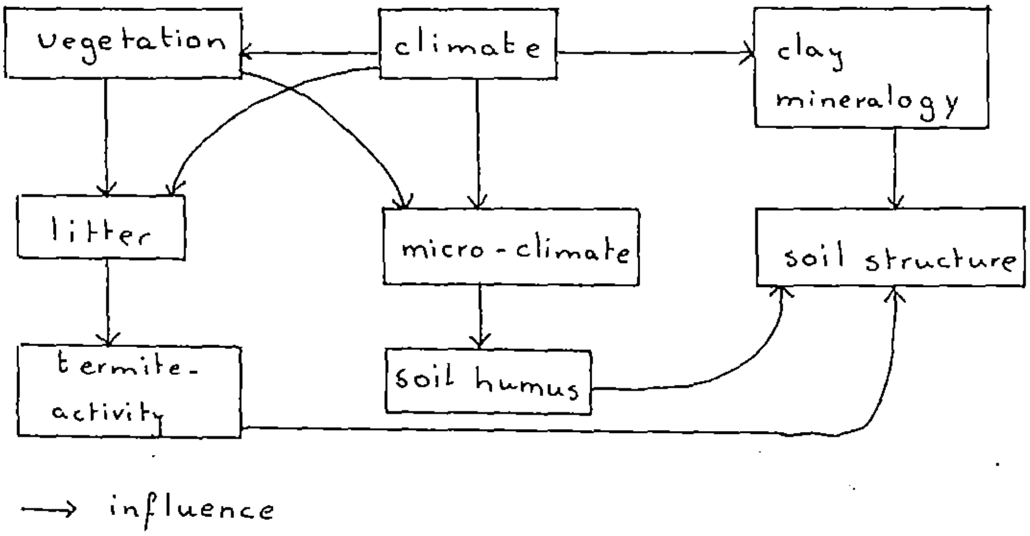

Fig. 1.5: Interactions soil organic matter / soil structure

Soil humus is the resultant of production and decomposition processes of organic material.
The role of termites in the production of soil humus.is assumed to consist of the deminution of litter and of the incorporation into the soil while cementing soil particles together with saliva. The litter production is of course of primary importance for the soil humus.
Soil humus is decomposed by micro-organisms. (Micro-) climatic conditions favouring the activities of these organisms, like high temperature and high humidity, thus enhance higher decomposition rates.
The soil structure can be degradated by the influence of swelling clay minerals, which eventually leads to a compacted internal structure of the soil aggregates. But also the direct impact of rainfall on a dried out topsoil can lead to structural degradation by causing crust formation. Moreover, tillage can distroy a favourable structure. The influence of degradation processes, however, can be diminished by forming a more stable structure by incorporation of humus. Termites could play a role in this process by forming open structures by building galleries, runways and sheetings, and stabilizing these structures by incorporation of humus, while cementing soil particles together with saliva.

2. Material and methods

2.1 Sampling

2.1.1 Profile pits

To get information about the soil under the selected types of landuse a profile pit was dug at each of the four sites. Prior to this study a semi-detailed soil survey was carried out, which enabled us to choose representative sites.
Sites were chosen located on a slope less than 2% and on a well drained position.
Because of the small size of the plots (0.08-0.11 ha) and the limited number of samples that could be taken for analysis, only one profile pit per site could be studied. We assumed that the distance to a termite mound was large enough not to find direct influence of soil washed from its sides and not too large, so the influence of termite-activity would still be noticeable. In a standing vegetation, such as forest and bananabush, a relatively large heterogenity in soil parameters may occur. Especially organic matter is quite concentrated on certain spots where a whole tree was fallen or had been cut down. Related to this concentration of organic material there could be a concentration of biological activity. It is, however, impossible to dig a pit on such a spot. Therefore the data presented here for a soil under forest and under banana should be seen as reflecting a minimum termite-activity.
For chemical and textural analysis samples were taken at the depths of 0-5, 5-10, 15-20, 25-30, 35-40, 50-55 and 95-100 cm in the profile pits. At the same depths pF-samples were taken for study of the soil structure.
Rectangular (8*8*5 cm) undisturbed samples for micromorphological study were taken at the depths of 0-15, 15-30, 30-45, 50-65 and 90-105 cm.

2.1.2 Sheetings

Termites build sheetings over their food source when they are foraging aboveground. It is certain that these sheetings consist of termite-modified soil. Studying the changes in the soil material when it is reworked into sheetings therefore should give an idea about the modifications of the soil by termite-activity in the whole profile.
Sheetings were gathered for chemical and textural analyses. From the texture it might be possible to identify the horizon from which material is used for building sheetings.
Sheeting material was gathered by taking it from the groundsurface with a spoon to avoid mixing with the topsoil.

2.1.3 Litter

The amount and the quality of the litter are important factors in the formation of soil humus.
The amount of litter in the maizefields was measured on small plots of 1 m^2 from which regularly all the litter was removed and weighed. Both maizefields contained 3 of these measuring plots. Removing the litter from more plots was suggested, but the idea was rejected, because of the small size of the maizefields. We expected that removing more litter would influence the total termite-activity.
The amount of litter in the bananabush was estimated, because direct measurement was not possible due to the heterogenity mentioned before. For the estimation of the litter production (Kools, 1987) 15 bananatrees were marked at random. From the marked stems still standing after two months the rate of cutting stems was determined. The total dry weight involved was estimated by sampling and weighing material from a selected trunk and from the leaves. These two estimations together give an idea of the litter production in the bananabush. Because of the even greater complexity of the situation in the forest the litter production was not determined or estimated there.
To determine the quality of the litter samples for chemical analysis were taken in both the maizefields and in the bananabush.

2.2 Methods

2.2.1 Chemical analyses of soil material (Begheijn, 1980)

- Organic carbon by wet combustion
  Digestion of organic carbon by wet combustion in a phosphoric-chromic acid mixture and adsorption of the carbondioxide generated into sodiumhydroxide bariumchloride solution; followed by dissolution of the precipitated barium carbonate by EDTA and measurement of the pH in the final solution.

- Total nitrogen (Kjeldahl)
  Destruction of organic matter with sulphuric acid and selenium mixture. The ammonium (NH_4^+) is measured in a five times diluted solution with a Technicon Autoanalyser.

- CEC and exchangeable bases with Li-EDTA
  Replacement of the adsorbed cations by Li and the chelation of the exchanged Ca and Mg by EDTA. Determination of the exchangeable Ca and Mg by atomic adsorption spectrometry and the exchangeable Na en K by atomic emission spectrometry. Determination of the CEC by flame photometric determination of Li in the extracting solution and in the extracts, respectively.

- pH_{H2O} and pH_{CaCl2}
  Measuring pH in a 1:2.5 dilution of H_2O and 0.01M $CaCl_2$, respectively.

2.2.2 Chemical analyses of plant material

Samples were analysed by the laboratory of the Department of Soil Science and Plant Nutrition, Agricultural University, Wageningen.

After digestion (in a sulphuric selenium salicylic acid mixture with H_2O_2) N-total and P were measured with a spectrometer, and Na and K with a flame photometer (continuous flow measurements). In the destruate Ca was measured also with a flame photometer, and Mg with an atomic adsorption spectrometer (AAS).

2.2.3 Texture analysis

NAL (National Agricultural Laboratories, Nairobi)

Mechanical treatment for removal of cementing agents; overnight shaking with sodium hexametaphosphate and sodiumcarbonate in end-over-end shaker. Measuring silt and clay (< 50 um) with a hydrometer after 40 s and clay (< 2 um) after 6.4 h. The rest represents sand (0.05-2 mm)

Stichting Technisch Centrum voor de Keramische Industrie (De Steeg)

Removing organic matter with hydrogenperoxide; leaving it overnight and boiling until the reaction is finished. Boiling with 1N HCl; followed by three times washing. Finally 0.24N sodium biphosphate is added and boiled. Measuring silt and clay as described above.

2.2.4 Water retention

Determination of mass fraction of moisture in saturated soil and soil after equilibration with sandbox to pF 0.7, 1.0, 1.4, 1.7 and 2.0, and kaolin box (for pF 2.3 and 2.5) and pressure equipment to pF 3.7 and 4.2 (Stakman et al., 1969). For every depth four undisturbed ring samples were determined for pF 0-2.5. Disturbed samples were used for pF 3.7 and 4.2.

2.2.5 Morphology

Soil profiles were described macromorphologically according to the Guidelines for Soil Profile Description (1977) using Munsell colour charts.

The micro-morphological structure description was done according to Beckmann and Geyger (1967). The amount of each type of structure present in the thin section was determined semi-quantitatively with the microscope. On each thin section 30 images (one image is the area of about 1 cm^3, which can be seen at once with the microscope), laid out in a lattice, were counted. When about the whole image in one point of the lattice contained one structure type only, it was counted as such. When the image countained two types of structure each was counted half. In this way 4 thin sections were counted for each profile.

For estimating the amount of pores and filled-in cavities an estimation table was used (Bulluck et al., 1985). The amounts of small fissures were estimated on a relative scale.

3. Results

3.1 Clay mineralogy

In a toposequence on the slopes of Mt. Kenya in this area the clay mineralogic composition of the soil was determined (Bongers, 1987). Although not all samples were taken from the same profiles as studied here, the results can be extrapolated and used in this study.
The results are summarized in Table 3.1. The samples were taken at the depth of 50-70 cm.

Table 3.1: Clay mineralogic composition of soil samples (after Bongers, 1987)

zone	landuse	kaolinite	halloysite	vermiculite	gibbsite
tea	forest	++	+	++++	++++
	tea	++++	+	+	++
mango	maize	++++	+	-	+++

The clay fraction in both the teazone and the mangozone is dominated by the non-swelling kaolinite. Moreover, a good deal of gibbsite and some halloysite is found. In the teazone also vermiculite was found. Striking is the higher content of vermiculite in the forest profile compared with the tea profile.

3.2 Termite-activity measurements

Some of the findings in the biological study (Kools, 1987), accompagnying this study (see 1.1) are quoted here. They form important parameters in the comparison of the four sites.

From the full data about temperature and relative humidity the data of some days (both in the wet and in the dry season) were extracted and listed in Appendix A. They serve to illustrate the differences in micro-climate between landuses. The accompagnying results of the soil parameters (watercontent and temperature) are also given in Appendix A.
During the measuring period (nov-april) the air temperature in the bananabush (measured at a height of about 1.2 m) was some degrees lower than in the maizefield in the mangozone, whereas the relative air humidity was higher in the bananabush. The same tendency could be seen in the teazone for forest and maize.
The temperature in the soil usually was some degrees lower than the air temperature. In the maizefields the temperatures at a depth of 5 cm, however, sometimes rose

above the air temperature.
The water content (weight %) in the soil was always higher in the banana than in the maize (mangozone).
These data show that the assumed difference in microclimate (1.3) proves to be true.

The sites were selected on the presence of a termite mound in the surrounding area to be certain of termite-activity. In the mangozone a Macrotermes mound was located in the maizefield and closeby there was a mound of Odontotermes. In the bananabush a Odontotermes mound was found at the onset of the study. During the study a Macrotermes mound developed there. In the teazone no aboveground termite mounds were found. But termites of the Odontotermes and Microtermes species were found in and nearby the maizefield.
The conclusions about termite-activity (Kools, 1987) are not as definite as they were hoped to be.
Comparing the two maizefields, it is clear that the activity is much lower in the teazone than in the mangozone. This difference is expressed both in activity measurements and in litter consumption measurements.
However, a difference in termite-activity due to landuse (banana/maize) in the mangozone could not be downstated. It turned out to be impossible to quantify the termite-activity in the bananabush with the methods used (for methods see Kools (1987)). Still it is assumed that the termite-activity in the bananabush was relatively high. This is concluded from the fact that incidentally very large numbers of termites were foraging, concentrated on an area of only a few square metres.

3.3 Chemical and textural analysis

3.3.1 Profile pits

In Appendix B the results of the chemical and textural analyses are given for the profile pits on each of the four sites.
The texture in the pits in the mangozone shows much lower claycontents and higher siltcontents in the data from De Steeg compared with the data from Nairobi (NAL). This difference in the data about texture from the two laboratories is not found in the teazone. The texture determined in the field was similar for both zones.
The standing vegetation of forest and banana give a high organic carbon content in the (top)soil. But also the % C of the profile in the maize/teazone is quite high. The C:N ratios in all four profiles are relatively low.
The soils under maize have a lower CEC than under standing vegetation, whereas the BS does not exceed 35 % of the CEC. Under banana and forest both CEC and BS are higher, especially under banana.
The contribution from clay and organic matter to the CEC of the soil can be estimated. First the specific CEC of the

clay (mmol(+)/100 g clay) and of the organic matter (mmol(+)/1 g C) is calculated.
The following procedure is followed (Legger, 1987):
For each pit the organic carbon content (g/100 g soil), the clay content (g/100 g soil)(NAL) and the CEC (mmol(+)/100 g soil)(determined at $pH_{Li-EDTA}$) are known. The % C and the CEC can be recalculated into g and mmol(+), respectively per 100 g clay by multiplying with 100/clay content. Assuming the specific CEC of the clay fractions in all samples within one profile is the same, the difference in CEC between the samples of one profile can be attributed to differences in % C.

Table 3.2: Specific CEC of the clay and of the organic matter and their contributions to the total CEC

depth (cm)	% CEC by o.m.	% CEC by clay	$CEC_{o.m.}$ (mmol(+)/1g C)	CEC_{clay} (mmol(+)/100g clay)
Maize/tea			1.55	9.70
0-5	56	44	(r=0.949)	
5-10	53	47		
15-20	49	51		
25-30	31	69		
35-40	28	72		
50-55	21	79		
95-100	22	78		
Maize/mango			4.14	7.09
0-5	67	33	(r=0.939)	
5-10	68	32		
15-20	66	34		
25-30	63	37		
35-40	57	43		
50-55	37	63		
95-100	34	66		
Forest/tea			1.59	12.51
0-5	72	28	(r=0.990)	
5-10	55	45		
15-20	41	59		
25-30	38	62		
35-40	22	78		
50-55	22	78		
95-100				
Banana/mango			3.53	9.90
0-5	77	23	(r=0.967)	
5-10	64	36		
15-20	55	45		
25-30	50	50		
35-40	51	49		
50-55	43	57		
95-100	21	79		

Lineair regression of the CEC versus % C both expressed per 100 g clay then gives:

CEC (mmol(+)/100 g clay) = a + (b * % C (g/100 g clay)), in which a is the CEC_{clay} (mmol(+)/100 g clay) and
b is the $CEC_{o.m.}$ (mmol(+)/g C)

With these values for the specific CECs of clay and organic matter the contributions of each to the total CEC can be calculated by multiplying with its content in each sample and dividing by the total CEC of the sample.
The results of these calculations are listed in Table 3.2.
The specific CEC of the clay in the teazone is slightly higher than in the mangozone. The difference in specific CEC of the organic matter between the two zones, however, is more important.
The contributions of clay and organic matter to the total CEC vary only little between the different profiles. The topsoil of the profile maize/teazone has a lower contribution of the organic matter than the rest. In both profiles in the teazone the contribution of organic matter is decreasing more rapidly than in the profiles in the mangozone.

3.3.2 Sheetings

The results of the chemical and textural analyses of the sheeting material are presented in Appendix C.
In the maizefield in the teazone only one sheeting could be sampled and analysed. In the forest/teazone no measurements of termite-activity were made and therefore no sheetings were gathered.
The sheetings marked with + (first column) were identified as being built by Odontotermes. The other sheetings were built by Macrotermes. There does not seem to be a significant difference in chemistry between the sheetings built by the two species.
The samples marked with V were not taken into account for the determination of the averages, because their contents differed too much from the others.
For the sheetings data about texture only come from De Steeg. The relatively low clay content and high silt content, as could be seen in the profiles in the mangozone, are also visible for the sheetings. This time, however, the same goes for the (one) sheeting from the teazone.
Sheetings from the bananabush have a higher CEC and a higher BS than the sheetings from the maizefields. The same tendency was visible in the profiles.
The importance of building sheetings can be illustrated by the amount of soil replaced by termites in this way. For the maizefield in the mangozone this was calculated for the 24 weeks that the experiment lasted (nov-april). According to this calculation (Kools, 1987) 491 g soil/m^2 was replaced by Macrotermes and 25 g soil/m^2 by Odontotermes.

3.3.3 Litter

In Appendix D the results of the chemical analyses on the litter material are listed.
The first samples were erroneously dried at a temperature of 105 °C, which is a high temperature for drying plant material and might influence for example the nitrogen content. Later we reduced the drying temperature to 70 °C, the normal temperature for drying plant material. Fortunately, there does not seem to be a significant difference in the results of the chemical analyses as a result of different drying temperatures.
The difference between the litter from the two maizefields is the higher content of almost all elements in the mangozone. Two samples with even higher contents were left out of consideration when calculating the averages. The C:N ratio of the litter in the mangozone is also lower.
The banana litter has again a higher content of all elements examined and a lower C:N ratio than the litter in the maize/mangozone.
The amount of litter produced on both maizefields and in the bananabush are given in Table 3.3.

Table 3.3: Litter production on three sites (after Kools, 1987)

landuse	zone	production	period
maize	tea	210 ± 74 g/m^2	24 weeks nov.- april
maize	mango	400 ± 67 g/m^2	24 weeks nov.- april
banana	mango	± 5000 g/m^2	1 year

Assuming, that in the maizefields the litter production during the growing season (nov-april) with the short rains and the short dry season is similar to the litter production during the growing season with the long rains and the long dry season (april-nov), the total litter production per year in the teazone is equal to about 400 kg/ha.yr and in the mangozone about 800 kg/ha.yr. The bananabush is harvested continuously, which makes the applied calculation method possible.

3.5 Water retention

The results from the pF-samples are given in Appendix E. The water retention at each pF-value is indicated in volume %. The bulk density is the amount of dry soil (g) divided by the standard volume of the rings (= 100 cm^3).
The pF-curves of the data are presented in fig. 3.1 - 3.4. In those graphs the measured pF 0 is used instead of the

calculated porevolume (PV), which probably means a small underestimation of the total porevolume. PV is the total volume minus the volume of the solid phase, or 1 minus the volume fraction of the solid phase. The latter is calculated by dividing the bulk density (g/cm^3) by the particle density. The particles density was estimated at 2.70 g/cm^3. The average particle density of soils is 2.65 g/cm^3. For soils with high contents of clay and iron-oxides (p.d. ± 5.0), such as occur in these soils, the particle density is slightly higher.

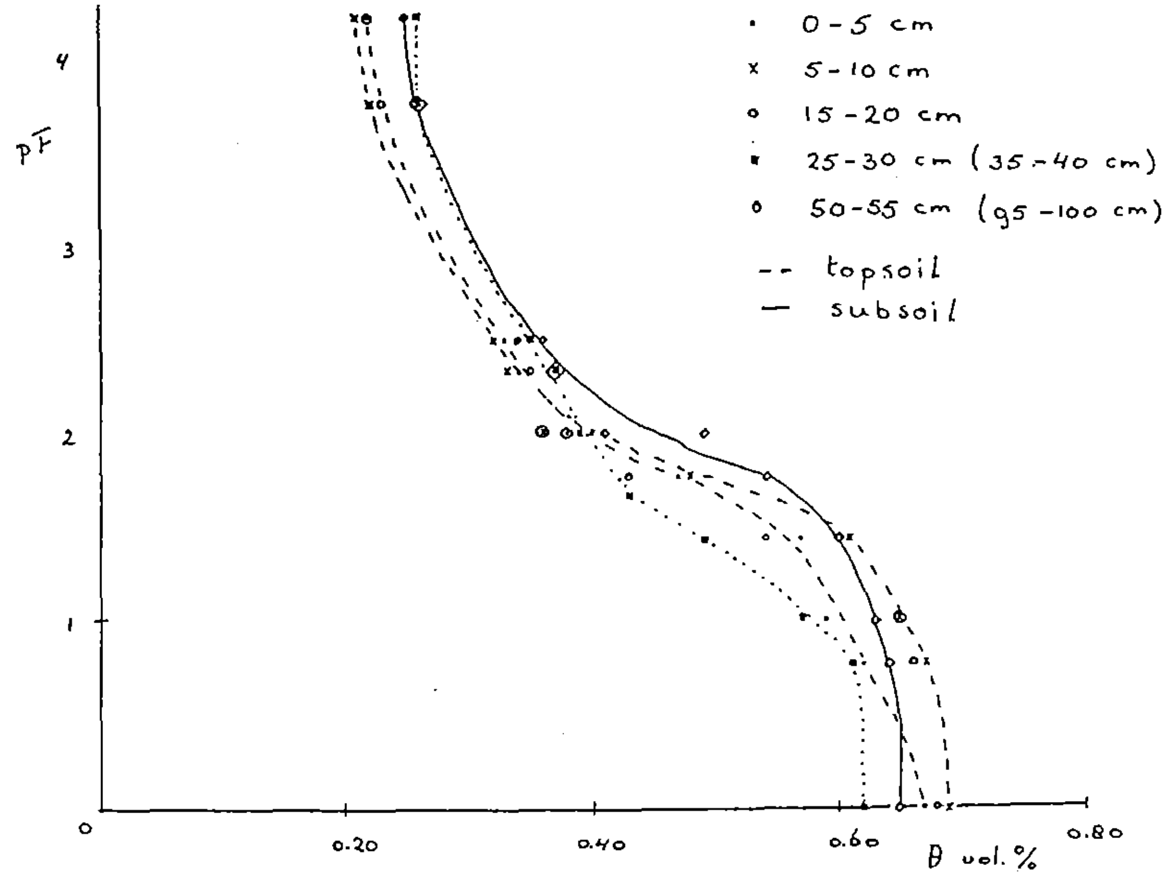

Fig. 3.1: pF-curve of the maize-profile in the teazone

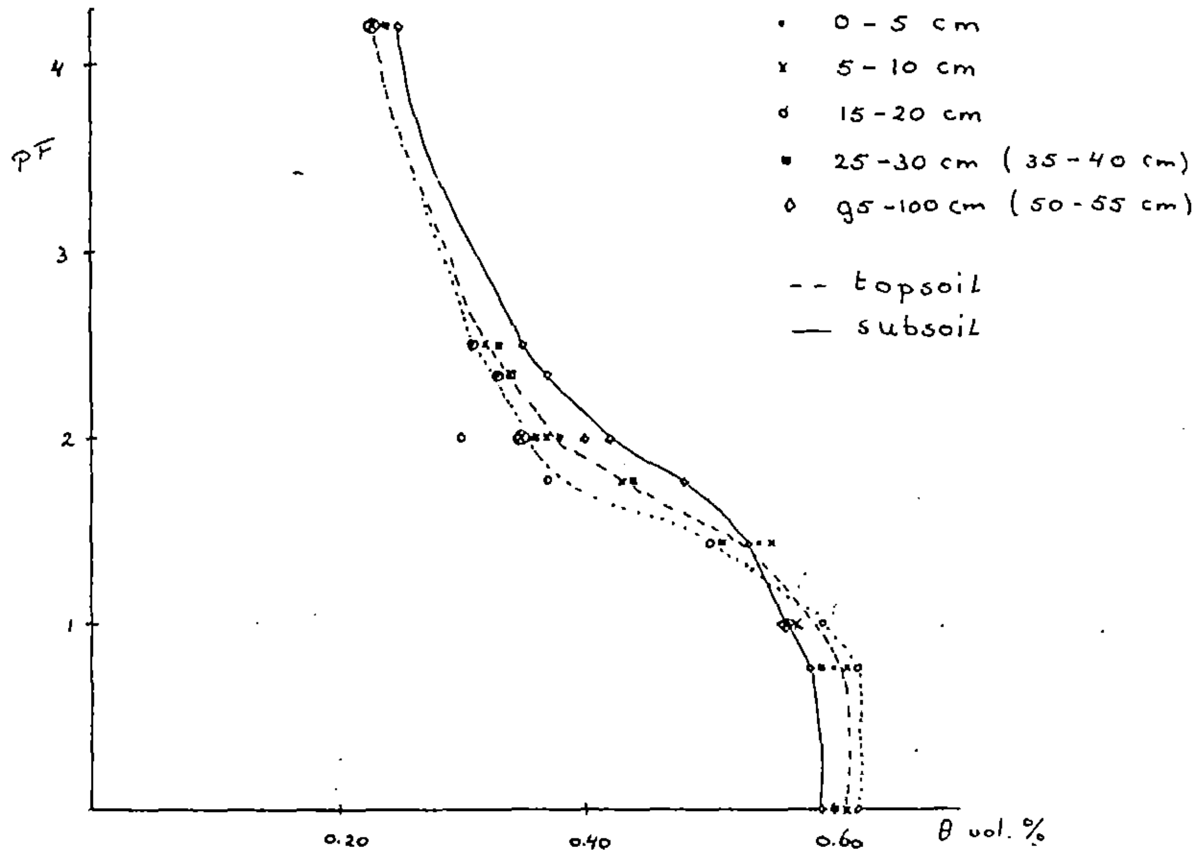

Fig. 3.2: pF-curve of the maize-profile in the mangozone

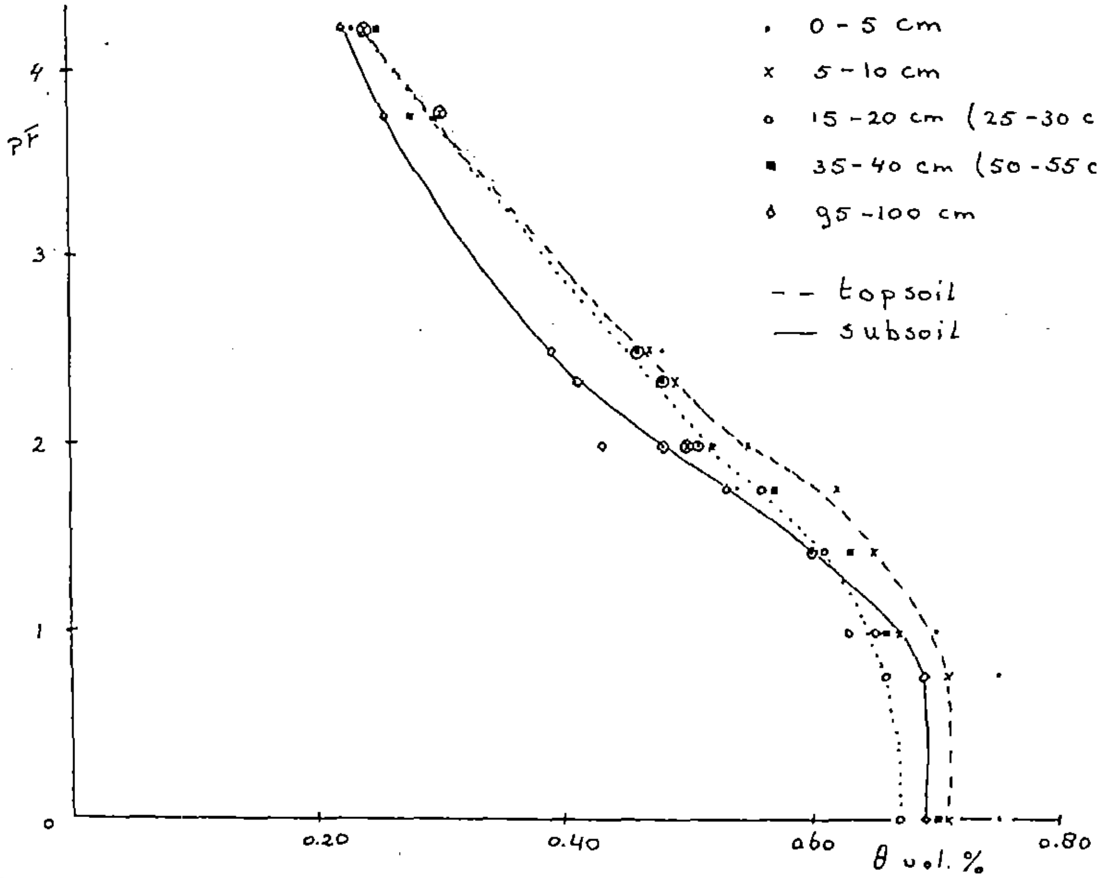

Fig. 3.3: pF-curve of the profile in the forest/teazone

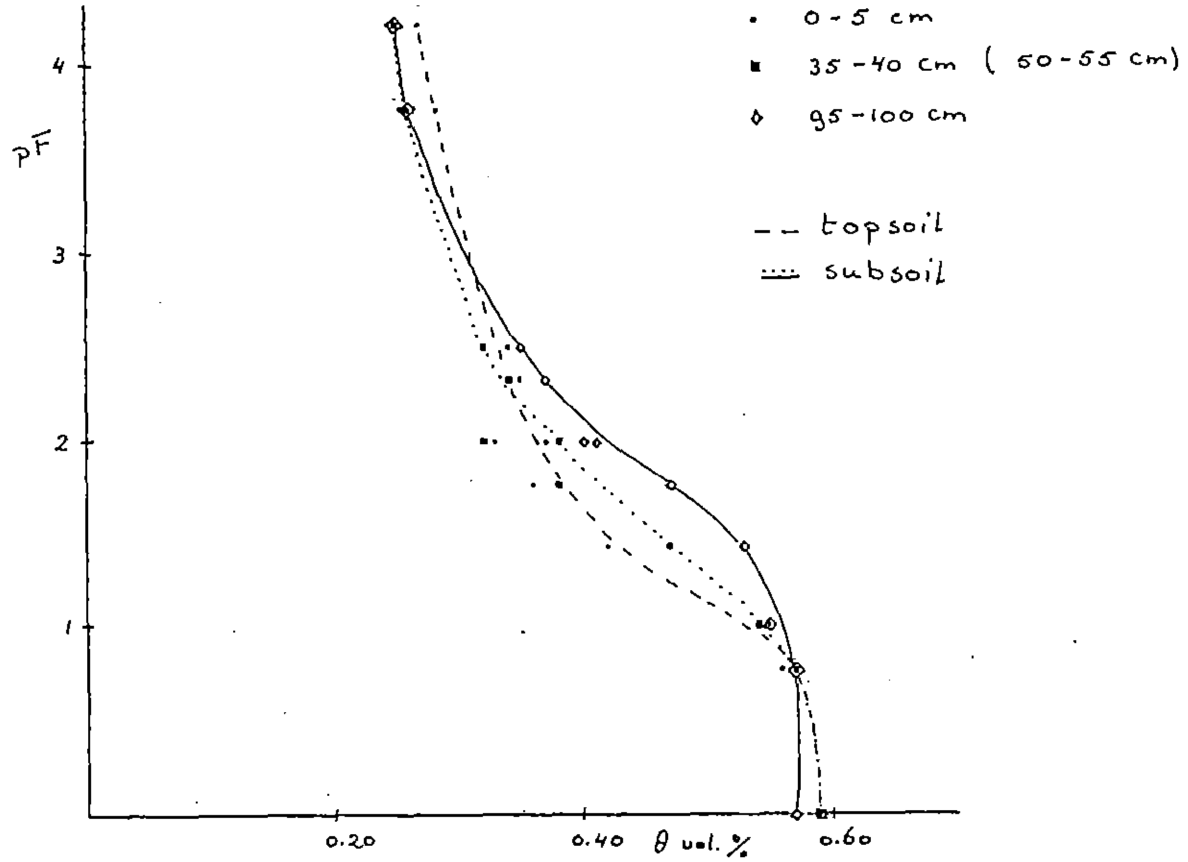

Fig. 3.4: pF-curve of the profile in the banana/mangozone

From the water retention data the contribution of 4 pore-size classes to the total calculated pore volume has been determined. In Table 3.4 the results of these calculations are given.
All four profiles have a high porosity, ranging from 0.65 to 0.75. About 50% of this volume is occupied by pores in the size < 10 μm. In the forest profile this pore-size class contains more than 65% of the total pore volume. This results in a small fraction of large pores (<115 μm), whereas in the banana profile the contribution of this pore-size class is supprisingly large.
The maize profile in the teazone has a larger fraction of pores in class 3 (10-60 μm), but on the average the pore distributions of the profiles in the maizefields from the two zones are similar.

Table 3.4: Pore-size class distributions in the four profiles

\ class	1	2	3	4
depth \ pore-size	>115 um	115-60 um	60-10 um	<10um
maize/tea				
0-5	19	14	20	47
5-10	14	18	23	45
15-20	21	15	12	48
25-30	28	9	12	51
35-40	34	10	16	54
50-55	13	9	28	52
95-100	16	9	22	54
maize/mango				
0-5	21	23	10	50
5-10	15	12	17	49
15-20	24	20	11	45
25-30	22	13	12	53
35-40	19	13	17	52
50-55	16	10	19	56
95-100	16	8	21	56
forest/tea				
0-5	18	8	6	66
5-10	6	4	14	68
15-20	8	8	8	70
25-30	9	7	10	67
35-40	7	9	8	68
50-55	-	7	12	66
95-100	15	10	11	55
banana/mango				
0-5	35	9	4	52
5-10				
15-20				
25-30				
35-40	28	14	10	49
50-55	27	8	18	47
95-100	13	10	20	57

3.5 Soil morphology

The soil structure of the profiles has been described macro-morphologically in the field and micro-morphologically using thin sections. In Appendix F the profile descriptions of the four pits are given.

Both the profiles under forest and under banana have a topsoil with signs of strong biological activity. In the forest profile this is expressed in a dark colour and many biological pores and infillings. In the profile under banana the structure consists of rounded consolidated fine granulars, whereas the the profile has a very dark topsoil. On the cultivated maizefields biological influence in the topsoil is not so well expressed. The maizefield in the mangozone shows a darker and thicker A-horizon than the maizefield in the teazone.

The structure of the soil under forest is strongly developed in the topsoil, but becomes increasingly more weakly developed with depth. The same tendency can be seen in the profile under banana. In the mangozone the maizefield has a strong structure throughout the profile, whereas in the teazone the structure is weak to moderate.

For the micromorphological analysis, first a general description of the thin sections was made using a lightbox for slides, only after that they were examined under the microscope.

All four profiles show a strong incorporation of organic matter and iron-oxides. Plant remains mostly occur in the topsoil of the maize and banana profiles in the mangozone.

Large cavities, possibly originating from fissures, occur in all profiles, except in the maizefield in the teazone.

In describing the thin section emphasis was placed on structure, because it is the biologically relevant factor varying most in these profiles. Since all structures, which were found, were determined by cavities a subdivision was based on this.

P pore structure
   This a quite compact structure, in which cavities are not interconnected. There are no loose aggregates.

S sponge structure
   This is an more open structure with interconnected cavities. The structure looks like a building of aggregates which cannot be distinguished seperately.

C crumb structure
   This form of structure is so open and loose that single aggregates can be distinguished.

(Beckmann and Geyger, 1967)

The amount of each type of structure present in the thin section was determined semi-quantitatively with the microscope. The results are presented in Fig.3.5.

The topsoil of the bananabush has a special type of structure. It is very open and loose, built up from relatively large, rather compact aggregates. The subdivision used is also based on the internal structure of the particles, therefore these aggregates have been called pore structure, in order to distinguish between the normally occurring structure of loose aggregates, which are usually small and porous (crumb structure).

The topsoils in the forest and in the banana are much more open and loose than in the maizefields, where the sponge (and pore) structure occupy a larger portion.

At a depth of 30-37.5 cm the structure in the maize/teazone profile is dominated by the sponge structure, while the other profiles have more or less equal amounts of sponge and crumb structure.

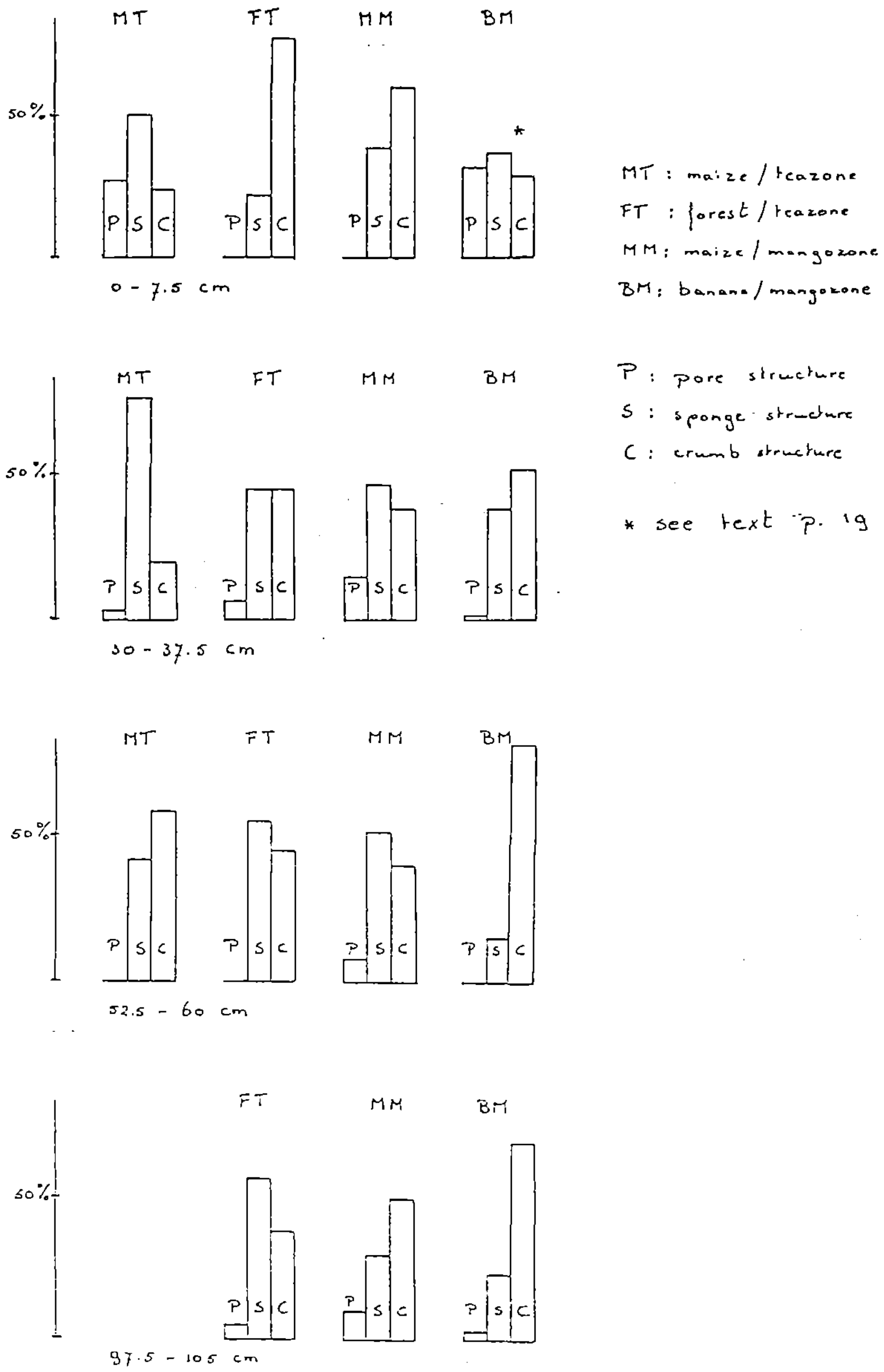

Fig. 3.5: The relative surface area occupied by pore (P), sponge (S) and crumb (C) structure.

The large fraction of crumb structure in the banana profile at a depth of 52.5-60 and 97.5-105 cm is striking.
These structure descriptions show a quite porous structure in all four profiles at each depth, whereas the compact structure only occurs in a significant quantity in the upper centimetres of the maize profile in the teazone, and some of it in deeper layers in the maize profile in the mangozone.

Besides the structure type, also pores, filled-in cavities and small fissures give information about the structure. Filled-in cavities are very open and loose parts, which became filled-in with mostly small rounded particles by the action of termites.
In Table 3.5 estimations of the relative importances of the above mentioned features are given.

Table 3.5: The relative surface area (%) occupied by pores, filled-in cavities and the relative amount of small fissures.

Pores

depth (cm)	maize/tea	maize/mango	forest/tea	banana/mango
0-7.5	5	2	15	20
30-37.5	10	10	5	10
52.5-60	5	5-10	10	10
97.5-105	-	15	5	5

Filled-in cavities

depth (cm)	maize/tea	maize/mango	forest/tea	banana/mango
0-7.5	5	0	30	<2
30-37.5	5	15	20	15
52.5-60	<2	5	5	10
97.5-105	-	2	2	2

Small fissures

depth (cm)	maize/tea	maize/mango	forest/tea	banana/mango
0-7.5	4	1	0	0
30-37.5	4	3	1	1
52.5-60	1	3	1	0
97.5-105	-	2	1	1

The profile under banana shows the highest porosity, followed by the profile under forest. In the topsoil of the maizefields the porosity is quite low, showing an increase at 30 cm. Small fissures (< 1 mm wide) appear most in the profiles under maize. Under the microscope the walls of these fissures appear to be moderately smooth, while under banana and forest the fissure-walls are always rough.
The profiles under standing vegetation, but also the maize profile in the mangozone, have a good deal of filled-in cavities. Except for the topsoil of both profiles in the mangozone where hardly any infillings can be recognized.

4. Discussion

4.1 Chemistry and texture

Comparing the profile pits among each other the expected higher organic carbon content of the soils under standing vegetation is obvious. But the high organic carbon in the maizefield in the teazone, despite the low litter production, indicates that there could also be a considerable difference in decomposition rate of the soil humus between the two zones. Another possible explanation, however, is an inherited high humus content from the time that the soil was covered with forest, some decades ago. But then, if the effect of the forest vegetation is still that clear after some decades of maize cropping, this would also indicate a slow decomposition rate.

Decomposition of organic material under strong influence of soil fauna results in the formation of soil humus with a low C:N ratio. All four profiles show this low C:N ratio.
The specific CEC of the organic matter is determined by the dissociation of COOH-groups and phenolic OH-groups. The much higher specific CEC of the organic matter in the mangozone compared with the teazone, thus should be due to the presence of more of these functional groups. The pH could have some influence on the specific CEC, but the $pH_{Li-EDTA}$, at which the CEC was determined, is only slightly higher in the mangozone than in the teazone, so this influence will be rather small.
Although the C:N ratios in the two zones are only slightly different the soil humus probably differs in functional groups. Whether these differences are due to termite-activity is uncertain.

The slightly higher specific CEC of the clay in the teazone could be explained by the presence of vermiculite in those profiles, because vermiculite has a much higher CEC than kaolinite and halloysite.
The amounts of exchangeable cations in the soils seem to be related with their contents in the litter.

The different data about texture from the two laboratories is probably due to a stronger treatment against cementing agents at NAL (Nairobi), since they must be acquainted with this type of soils. Striking is the underestimation of the clay content not only in the sheetings from the mangozone, but also from the teazone. Although it is only one single observation it points towards a relation between termites and this type of strong cementing material. In Lee and Wood (1971) it was mentioned that problems occurred in dispersing soil from termite mounds (Odontotermes), which was cemented together with excreta. In sheetings saliva are used for cementing particles together, but saliva may contain the same kind of cementing substance present in excreta.

In 2.1.2 it was suggested that the textural analyses of the sheetings might indicate the horizon from which material was used for building sheetings. The difference in texture within the profiles unfortunately is not very definite, which makes it difficult to indicate the right layer.
Both Bagine (1984) and Lee and Wood (1971) suggest that sheetings are built from deeper soil material, but they do not say from which depth or from which horizon the material comes from. From the texture it is assumed that the sheeting material is derived from a depth of about 15-40 cm. This is also in correspondence with the depth at which underground foraging galleries of Macrotermes were found to leave the mound (Darlington, 1984).

The tendencies in the comparison between the sheetings and the profile samples do not seem to go parallel for maize and banana.
In the banana a higher organic carbon content and a comparable nitrogen content is found in the sheetings, whereas in the maize % C in the sheeting is comparable with the profile, but % N is lower, resulting in a much higher C:N ratio. But the litter material from the maizefield also had a higher C:N ratio than the litter from the bananabush.
On both sites the C:N ratio in the sheetings is raised compared with the soil material in the profiles. Lee and Wood (1971) reported the same for soil material from mounds compared with the adjacent soils in Australia. Outside Australia mostly a lower C:N ratio is found in termite modified soil. In literature no explanation could be found for either a higher or a lower C:N ratio in the sheetings compared with the adjacent soil. However, it is known that termites feed on material with a high C:N ratio, while their bodies contain a lot of nitrogen. In order to produce the nitrogen-rich food for the termites the nitrogen is concentrated in the mound by growing fungus (Matsumoto (1976) cited in Wielemaker, 1984). Therefore, it might be possible that the excess of carbon from the feeding material is used in the saliva for cementing purposes.
The high C:N ratio of the sheetings then might be explained by the incorporation of plant tissue into the sheeting or by the use of carbon-rich saliva for cementing the soil particles together.
Concerning the base saturation in the sheetings there is a slight increase in the maizefield and a considerable decrease in the bananabush, although the contents of Ca, Mg and K in the litter from the banana are higher. Sheetings (Bagine, 1984) and termite mounds (Lee and Wood, 1971) usually contain more exchangeable Ca, Mg and K than the adjacent soil, derived from ingested plant tissue.
The pH of the sheetings on both sites is higher than the topsoil and the subsoil of the profiles. A possible explanation for this is a lower acidity as a result of the higher content of Ca and Mg usually found in sheetings (Robinson, 1958).

The calculated amount of sheetings formed on the experimental plot can be compared by the amounts found by other authors. Bagine (1984) found in an arid area in Northern Kenya with 200 mm of annual rainfall 1059 kg soil/ha.yr translocated by Odontotermes. For Macrotermes Lepage (1974, in Bagine, 1984) found 675-900 kg/ha.yr in the sahel savannah in Senegal with a rainfall of 750 mm/yr. In Nigeria in an area with 110 mm annual rainfall Wood and Sands (1978) reported an amount of 300 kg/ha.yr translocated by Macrotermes. It was suggested that there could be a relation between annual rainfall and the amount of sheetings that were built. But also relative air humidity and temperature could be important factors (Bagine, 1984).

The amount calculated in this study for Macrotermes (4910 kg/ha) could well be an overestimation, because the mound was actually located on the experimental plot. The mound of Odontotermes was located a bit away from the experimental plot. When the amount of sheetings calculated for Odontotermes (250 kg/ha) is doubled, assuming that the studied half year (nov.-april) was a representative period for the whole year, the result is about 500 kg/ha.yr. Compared with the other authors this would mean a slightly higher activity on our site.

4.2 Soil structure

Comparing pF-data or pore-size distributions with the structure descriptions of the thin sections it is hard to find the parallels, mostly because the differences are small.

The very open and loose structure found in the banana profile is also expressed in a large fraction of the larger pores (>115 um). Also could the large fraction of the crumb structure in the topsoil of the forest profile be related with a larger fraction of pores >115 um than in the rest of the profile.

The influence of clay mineralogy on soil structure is only of minor importance here. The strongly swelling smectite-type of clay minerals is not found in these soils. Vermiculite might cause some swelling and shrinkage, but the soils in the forest, where it is mostly found, hardly dries out, so its influence will be small. Moreover, there are no definite signs pointing to clay mineralogical influence in the soil structures.

The relation between landuse and soil structure is best expressed in the topsoil. The forest and the banana profiles have a loose structure with many pores. The structures in the topsoil of the maizefields show lower porosity and they are not as loose. At the depth of 30-37.5 cm the structure in the maizefield in the mangozone becomes comparable to the profiles under standing vegetation. In the teazone the maizefield showed less signs of activity, such as filled-in cavities, but also the porosity lags behind.

It is difficult to point out the causes of the occurence or

absence of a certain structure. The absence of many filled-in cavities in the profiles in the mangozone could be a sign of lower activity, but could also indicate a very high activity, which broke up the whole matrix of the soil, so the infillings cannot be differentiated from the matrix anymore..
Another sign of the impact of landuse on soil structure is the high amount of fissures, probably originating from drying out, which occur in the maizefields, but are almost absent in the forest and banana profiles.
These results are corresponding with the micro-climatic data.

5. Conclusions

This study was handicapped by the fact that the assumed differences in termite-activity could not be downstated by measurements and therefore it became difficult to state a definite relation between some aspects of soil humus and soil structure, and termite-activity.
The impact of land use on soil humus is more easily defined. Comparing a standing vegetation (forest/banana) with a maize crop, it is clear that a standing vegetation will have a much higher litter production. This litter will lead to a higher humus content and give the soil a higher CEC and BS.
The high humus content together with probably a higher activity of soil fauna will lead to an open structure with strongly incorporated humus.
But even without the beneficial effects of the standing vegetation the structure in the maizefields is rather good, with a high porosity and a strong incorporation of humus, although the content is lower, and showing little signs of degradation. Is this rather good structure due to termite-activity? In the maizefield in the teazone the measured termite-activity is only small and the signs of present activity are also fewer than in the mangozone. But how could the strong incorporation of the humus into the matrix of the soil be explained otherwise? Could it be that at present the influence of termite-activity in the past is still noticeable?
Other signs of a possible influence of termite-activity are visible in the chemical and textural analyses.
Together with the higher termite-activity, a higher specific CEC of the organic matter and a higher silt content in the textural analysis from De Steeg are found in the mangozone compared with the teazone. Possibly there is relation between these phenomena, although no further evidence can be provided.
Sheetings, which definitely consist of termite modified soil material, show a higher C:N ratio than the surrounding soil. This might be due to incorporation of plant tissue or saliva may consist of a carbon-rich substance, causing a rise in the C:N ratio.
These findings, however, cannot be confirmed with similar results in the literature. But then the approach of the subject, examining sheetings instead of termite mounds, has not been applied much so far.
From the agricultural and ecological point of view it might be interesting to focuss future studies more on the influence termites might have on their entire environment and study the possibly beneficial effects more profoundly.

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Appendix A

(Micro-)climatic data

Maize teazone

date	time	air temp. °C	wet temp. °C	rel. hum. %	temp. soil 5 cm	temp. soil 15 cm
25/11	10.15	19	17	81		
	12.45	20.5	17.5	74	24	20
	15.30	23.5	18	58	24	20
26/11	13.45	23	18	62	26	21
	15.30	23	17.5	57	25	21
10/2	11.45	25	15.5	36	24	20
	12.30	26	15.5	32	27	20.5
	14.15	27	16	31	30	22
	17				33	25

Maize cottonzone

date	time	air temp. °C	wet temp. °C	rel. hum. %	temp. soil 5 cm	temp. soil 15 cm
28/11	8.30	23.5	20	72	21	22
	12.15	25.5	19.5	56	26.5	24
	15.15	27	19	46	31	26.5
	18	23	18.5	65	31	26.5
29/11	7.30	19	17.5	86		
	9.45	23	18.5	65		
	11.30	26.5	20	54		
	14.15	27	19	46		
	16	26	18	44		
10/2	8	22	15	47		
12/2	8.30	25	17	44		
	10	27	18.5	44	20.5	21
	11	29	19	38	21.5	21.5
	12.30	33	19	25	24.5	22
	15	34	20	26	28	23
	16	30.5	18.5	30	28.5	23.5
	17	29.5	18	31	28.5	23.5
	18	28	18	37	28	23

Banana cottonzone

date	time	air temp. °C	wet temp. °C	rel. hum. %	temp. soil 5 cm	temp. soil 15 cm
28/11	9.15	21.5	19.5	84		
	12.30	25	20	63		
	15.45	24.5	19	59		
	17.30	23	18.5	65		
29/11	7.45	18.5	18	95	18.5	20
	12	25.5	20.5	63	19	20
	15.30	26	18	44	20.5	20
	17.45	23	18.5	65	20.5	20.5
10/2	8	20	15.5	63	18	19
12/2	9	23.5	17	52		
	10	26.5	18	43		
	11	28.5	19	40		
	12.30	32	19.5	30		
	15	32	20	32		
	16	30.5	18.5	31		
	17	29.5	18.5	33		
	18	28	18.5	40		

Soil watercontent (%), teazone

date	maize	
	0-20cm	20-30cm
25/11	27.6	23.6
19/12	23.4	27.7
15/1	22.6	26.1
5/2	18.6	21.7
17/2	17.8	13.4
14/3	24.5	23.3
2/4	33.8	34.4

Soil watercontent (5), cottonzone

date	maize		banana	
	0-20cm	20-30cm	0-20cm	20-30cm
9/11	25.3	25.4	28.5	28.1
28/11	21.3	23.4	27.3	26.6
17/12	23.2	23.5	26.0	25.5
16/1	17.3	19.5	-	-
30/1	14.9	17.4	18.1	19.2
19/2	13.9	14.6	16.1	17.7
13/3	17.7	17.1	25.3	23.3
26/3	18.1	18.6	25.0	23.2
10/4	27.6	27.1	27.4	31.1

For the soil watercontent at about 9.30 a.m. samples were taken.

App 3

PROFILE PITS

profile	depth cm	% sand > 50 µm	% silt 2 - 50 µm	% clay ① < 2 µm	% C	% N	C/N	pH_{H_2O} 1 : 2.5	pH_{CaCl_2} 1 : 2.5	Ca^{2+} mmol(+)/100 g	Mg^{2+} mmol(+)/100 g	Na^{+} mmol(+)/100 g	K^{+} mmol(+)/100 g	$pH_{Li.EDTA}$ ②	CEC mmol(+)/100 g	%BS
maize/teazone																
118	0 - 5	20 (3)	21 (40)	59 (57)	4.71	0.65	7	4.8	4.1	1.3	0.5	0.9	0.9	7.0	12.3	30
	5 - 10	20 (3)	21 (40)	59 (57)	4.07	0.54	8	4.5	4.0	0.9	0.2	<0.1	0.1	7.0	13.0	9
	15 - 20	18 (3)	19 (32)	63 (65)	3.82	0.45	8	4.4	4.0	1.0	0.2	<0.1	<0.1	7.1	12.4	9
	25 - 30	10 (2)	11 (23)	79 (75)	2.24	0.28	6	4.3	4.0	1.1	0.2	0.4	1.7 ?	7.3	9.4	36
	35 - 40	12 (2)	7 (28)	81 (70)	1.97	0.24	8	4.3	4.1	0.9	0.1	0.2	0.2	7.4	10.6	14
	50 - 55	12 (3)	9 (24)	79 (73)	1.31	0.31	4	4.3	4.1	1.7	0.3	0.3	0.4	7.4	10.2	26
	95 - 100	12 (3)	7 (27)	81 (70)	1.36	0.25	6	4.2	4.1	1.1	0.5	0.8	0.1	7.4	11.0	33
maize/mangozone																
116	0 - 5	18 (9)	21 (73)	61 (18)	2.44	0.26	9	6.1	5.2	2.8	1.6	0.3	0.8	7.4	15.4	36
	5 - 10	16 (9)	21 (70)	63 (21)	2.31	0.25	9	6.1	5.3	2.6	1.2	<0.1	0.2	7.4	13.9	29
	15 - 20	18 (8)	16 (69)	66 (23)	2.17	0.23	9	5.8	5.0	1.2	1.6	0.1	0.4	7.4	13.3	25
	25 - 30	16 (6)	16 (73)	68 (21)	1.97	0.21	9	5.7	4.9	0.7	1.4	0.5	0.6	7.5	12.8	25
	35 - 40	10 (7)	10 (70)	80 (23)	1.82	0.26	11	5.7	5.0	0.1	1.0	0.4	0.3	7.5	11.3	17
	50 - 55	14 (5)	17 (67)	69 (28)	0.65	0.14	4	5.7	5.2	<0.1	1.0	0.4	0.6	7.6	9.9	20
	95 - 100	12 (6)	9 (68)	79 (26)	0.71	0.09	8	5.7	5.6	<0.1	1.0	0.2	0.1	7.7	7.4	19
forest/teazone																
117	0 - 5	26 (3)	25 (54)	47 (43)	9.67	1.18	8	5.5	5.0	3.0	1.5	0.7	0.8	6.8	21.9	28
	5 - 10	16 (3)	25 (34)	59 (63)	5.73	0.80	7	4.8	4.2	3.7	1.6	0.7	1.1	7.1	15.0	47
	15 - 20	14 (3)	25 (33)	61 (64)	3.31	0.59	6	4.8	4.1	3.5	0.9	0.3	0.4	7.2	14.1	36
	25 - 30	14 (3)	23 (32)	63 (65)	2.99	0.41	7	4.8	4.1	1.6	0.7	<0.1	0.2	7.3	13.0	19
	35 - 40	12 (3)	11 (33)	77 (64)	1.68	0.30	6	4.8	4.1	1.4	0.6	0.6	0.3	7.4	12.6	23
	50 - 55	12 (3)	11 (31)	77 (66)	1.70	0.25	7	4.9	4.2	0.6	0.4	0.3	0.2	7.4	11.6	13
	95 - 100	- (3)	- (29)	- (68)	1.38	0.17	5	4.8	4.2	0.9	0.4	0.5	0.6	7.4	11.9	20
banana/mangozone																
119	0 - 5	20 (7)	27 (63)	53 (30)	4.96	0.51	10	6.9	6.6	7.1	2.9	0.3	1.8	7.0	21.7	56
	5 - 10	20 (8)	23 (63)	57 (29)	2.77	0.35	8	6.8	6.3	6.1	4.0	<0.1	5.4 ?	7.1	17.8	59
	15 - 20	18 (3)	23 (68)	59 (24)	1.97	0.21	9	6.1	5.5	7.8	2.3	<0.1	1.4	7.4	14.8	69
	25 - 30	16 (5)	19 (67)	65 (28)	1.79	0.19	9	5.5	4.8	4.3	2.3	<0.1	<0.1	7.4	12.5	53
	35 - 40	16 (7)	19 (64)	65 (29)	1.93	0.17	11	5.3	4.7	5.8	2.2	<0.1	<0.1	7.4	11.8	68
	50 - 55	16 (6)	19 (72)	65 (22)	1.42	0.17	8	5.3	4.9	4.3	1.4	<0.1	<0.1	7.4	11.3	50
	95 - 100	12 (5)	9 (61)	79 (34)	0.57	0.11	5	4.9	4.7	2.3	1.5	<0.1	<0.1	7.6	8.1	47

① Between brackets texture analyses from De Steeg ; others from NAL

② pH of the solution, in which CEC and exchangeable cations were determined

App C

SHEETINGS

	% sand > 50 µm	% silt 2-50 µm	% clay ① < 2 µm	% C	% N. —	C/N	pH$_{H_2O}$ 1 : 2.5	pH$_{CaCl_2}$ 1 : 2.5	Ca^{2+} mmol(+)/100g	Mg^{2+} mmol(+)/100g	Na^{+} mmol(+)/100g	K^{+} mmol(+)/100g	② pH$_{Li\text{-}EDTA}$ —	CEC mmol(+)/100g	% BS
maize/teazone	(2)	(70)	(18)	3.12	0.31	10	4.9	4.2	0.2	< 0.1	< 0.1	0.2	7.4	9.8	4
maize/mangozone	(9)	(68)	(23)	1.47	0.12	12	6.2	5.9	✓ 0.9	✓ 0.4	✓ < 0.1	✓ < 0.1	✓ 7.8	✓ 5.7	✓ 23
				2.12	0.12	18	6.0	6.0	2.2	0.3	< 0.1	0.5	7.7	11.6	26
				1.49	0.13	11	6.2	5.4	2.5	0.7	< 0.1	0.7	7.9	11.5	34
				2.12	0.11	19	6.1	5.4	1.9	0.5	< 0.1	0.3	7.9	10.4	26
+	(10)	(74)	(16)	2.01	0.14	14	6.2	5.5	2.7	0.6	< 0.1	0.5	7.9	11.0	35
				1.95	0.13	15	6.0	5.6	2.1	0.5	< 0.1	0.6	7.9	10.9	29
+				✓ 4.62	✓ 0.28	✓ 17	✓ 6.9	✓ 6.9	✓ 5.5	✓ 1.5	✓ < 0.1	✓ 1.1	✓ 7.9	✓ 16.7	✓ 49
				2.09	0.13	16	6.0	5.3	2.0	0.7	< 0.1	0.3	8.0	11.8	25
average (s.d)				1.89 (0.3)	0.13 (0.01)	15	6.1 (0.1)	5.6 (0.3)	2.2 (0.3)	0.6 (0.2)	< 0.1	0.5 (0.2)		11.2 (0.5)	29 (4.4)
banana/mangozone	(10)	(71)	(19)	3.04	0.27	18	7.1	6.9	4.2	1.7	< 0.1	1.8	7.7	16.6	46
				4.84	0.26	19	7.2	6.9	5.3	1.6	< 0.1	1.2	7.8	19.7	41
				4.67	0.29	16	7.4	7.3	6.2	1.3	< 0.1	2.4	7.9	20.2	49
				3.41	0.21	16	7.1	6.7	3.8	0.2	< 0.1	2.6	7.8	15.0	44
+	(7)	(69)	(24)	2.24	0.16	14	7.2	6.9	3.9	1.0	< 0.1	1.2	7.7	15.3	40
+				3.22	0.19	17	6.8	6.3	3.6	0.6	< 0.1	1.4	7.7	14.2	39
				2.08	0.17	12	6.6	6.2	✓ 1.9	✓ 0.4	< 0.1	✓ 1.6	✓ 7.9	✓ 11.3	✓ 35
				4.64	0.32	15	7.5	7.6	7.5	0.7	< 0.1	2.3	7.9	22.0	48
average (s.d)				3.52 (1.0)	0.25 (0.05)	14	7.1 (0.3)	6.9 (0.5)	4.9 (1.5)	1.0 (0.6)	< 0.1	1.8 (0.6)		17.6 (3.0)	44 (4.0)

① textural analyses from De Steeg

② pH of the solution, in which CEC and exchangeable cations were determined

Appendix D

LITTER

date	drying temperature °C	% C	% N	% P	% K	% Ca	% mg	% Na
maize/teazone								
13/11	105	51	0.86	0.07	0.49	0.13	0.01	–
10/12	105	54	0.86	0.07	0.99	0.10	0.01	0.02
15/1	105	54	1.05	0.05	1.58	0.39	0.11	0.01
15/1	105	53	0.96	0.04	0.27	0.28	0.01	0.02
26/2	70	64	0.83	0.06	1.76	0.15	0.13	0.08
26/2	105	55	0.41	0.04	1.81	0.18	0.13	–
19/3	70	55	0.42	0.03	0.66	0.18	0.07	–
19/3	105	54	0.42	0.02	0.69	0.54	0.08	–
2/4	70	56	0.42	0.04	1.11	0.14	0.09	–
2/4	105	56	0.41	0.01	1.16	0.16	0.18	–
average (s.d)	C/N = 82	54 (1.5)	0.66 (0.27)	0.04 (0.02)	1.05 (0.54)	0.23 (0.14)	0.08 (0.06)	0.01 (0.02)
maize/mangozone								
8/11	105	54	0.45	0.01	0.53	0.17	0.13	0.01
11/12	105	46	✓ 2.25	✓ 0.16	2.36	0.70	0.44	0.03
16/1	105	51	0.78	0.05	0.89	1.14	0.07	–
16/1	105	51	✓ 1.71	✓ 0.07	✓ 2.51	✓ 2.70	✓ 0.24	–
27/2	70	55	0.67	0.01	1.30	0.48	0.34	0.01
27/2	105	55	0.70	0.02	1.43	0.60	0.41	0.01
13/3	105	54	0.65	0.02	0.51	0.35	0.17	0.01
19/3	70	55	0.89	0.07	1.15	0.33	0.24	–
19/3	105	55	0.61	0.02	0.71	0.30	0.25	–
10/4	70	58	0.75	0.03	0.51	0.06	0.12	0.01
10/4	105	56	0.96	0.03	0.52	0.13	0.12	–
average (s.d)	C/N = 75	54 (3.2)	0.72 (0.15)	0.03 (0.02)	1.13 (0.73)	0.43 (0.32)	0.23 (0.12)	0.01 (0.01)
banana/mango zone								
8/11	105	54	0.92	0.07	1.47	1.08	0.36	0.04
11/12	105	46	1.06	0.08	0.44	1.40	0.12	–
16/1	105	52	1.79	0.18	3.74	0.69	0.21	0.02
16/1	105	53	0.83	0.06	0.48	1.50	0.38	0.01
27/2	70	53	1.31	0.09	2.66	0.84	0.33	0.02
27/2	105	54	1.55	0.10	1.44	0.91	0.33	0.13
26/3	70	54	2.03	0.12	1.77	0.71	0.20	0.01
26/3	105	55	1.72	0.11	1.83	0.71	0.25	–
10/4	70	54	0.75	0.03	0.95	1.31	0.41	0.02
10/4	105	54	0.86	0.03	1.32	1.20	0.42	0.02
average (s.d)	C/N = 41	53 (2.6)	1.28 (0.46)	0.09 (0.04)	1.61 (1.00)	1.04 (0.31)	0.31 (0.10)	0.03 (0.04)

profile	depth cm	soil g	pF
maize/teazone			
118	0 - 5	81.81	0
	5 - 10	79.62	0.
	15 - 20	77.00	0.
	25 - 30	85.54	0.
	35 - 40	87.28	0.
	50 - 55	82.40	0.
	95 - 100	83.37	0
maize/mangozone			
116	0 - 5	91.06	0.
	5 - 10	93.87	0.
	15 - 20	92.07	0.
	25 - 30	97.09	0.
	35 - 40	97.06	0.
	50 - 55	99.24	0.
	95 - 100	101.24	0.
forest/teazone			
	0 - 5	73.21	0.
	5 - 10	83.41	0.
	15 - 20	90.81	0.
	25 - 30	89.45	0.
	35 - 40	87.65	0.
	50 - 55	87.49	0.
	95 - 100	80.69	0.
banana/mangozone			
	0 - 5	94.35	0.
	5 - 10		
	15 - 20		
	25 - 30		
	35 - 40	95.48	0.
	50 - 55	92.54	0.
	95 - 100	104.11	0.

App. 5

pF - data

profile	depth cm	soil g	pF 0	pF 0.7	pF 1	pF 1.4	pF 1.7	pF 2.0	pF 2.3	pF 2.5	pF 3.7	pF 4.2	PV
maize/teazone													
118	0 - 5	81.81	0.67	0.62	0.59	0.57	0.47	0.38/0.40	0.34	0.33	0.22	0.22	0.70
	5 - 10	79.62	0.69	0.67	0.65	0.61	0.48	0.36/0.39	0.33	0.32	0.22	0.21	0.71
	15 - 20	77.00	0.68	0.66	0.65	0.54	0.43	0.36/0.38	0.35	0.34	0.23	0.22	0.71
	25 - 30	85.54	0.62	0.61	0.57	0.49	0.43	0.38/0.40	0.37	0.35	0.26	0.26	0.68
	35 - 40	87.28	0.63	0.62	0.60	0.55	0.48	0.43/0.42	0.39	0.37	0.27	0.27	0.68
	50 - 55	82.40	0.65	0.64	0.63	0.60	0.54	0.48/0.41	0.37	0.36	0.26	0.25	0.69
	95 - 100	83.37	0.63	0.62	0.60	0.58	0.52	0.47/0.42	0.39	0.37	0.26	0.26	0.69
maize/mangozone													
116	0 - 5	91.06	0.61	0.59	0.56	0.52	0.37	0.32/0.35	0.33	0.30	0.25	0.23	0.66
	5 - 10	93.87	0.61	0.61	0.57	0.55	0.43	0.35/0.37	0.34	0.32	-	0.23	0.65
	15 - 20	92.07	0.62	0.60	0.58	0.50	0.37	0.30/0.35	0.32	0.30	-	0.23	0.66
	25 - 30	97.09	0.58	0.57	0.55	0.50	0.42	0.36/0.39	0.36	0.34	0.26	0.25	0.64
	35 - 40	97.06	0.59	0.58	0.56	0.52	0.44	0.38/0.38	0.34	0.33	-	0.24	0.64
	50 - 55	99.24	0.60	0.60	0.58	0.53	0.47	0.39/0.40	0.37	0.35	0.27	0.24	0.63
	95 - 100	101.24	0.59	0.58	0.56	0.53	0.48	0.42/0.40	0.37	0.35	-	0.25	0.63
forest/teazone													
	0 - 5	73.21	0.75	0.75	0.70	0.60	0.54	0.48/0.51	0.49	0.48	-	0.23	0.73
	5 - 10	83.41	0.71	0.71	0.67	0.65	0.62	0.55/0.50	0.49	0.47	0.30	0.24	0.69
	15 - 20	90.81	0.67	0.66	0.63	0.61	0.56	0.51/0.50	0.48	0.46	0.30	0.24	0.66
	25 - 30	89.45	0.66	0.66	0.63	0.61	0.56	0.51/0.48	0.45	0.45	0.29	0.24	0.67
	35 - 40	87.65	0.70	0.69	0.66	0.63	0.57	0.52/0.51	0.48	0.46	0.27	0.25	0.68
	50 - 55	87.49	0.71	0.71	0.68	0.64	0.59	0.52/0.50	0.47	0.45	0.28	0.25	0.68
	95 - 100	80.69	0.69	0.69	0.65	0.60	0.53	0.48/0.43	0.41	0.39	0.25	0.22	0.71
banana/mangozone													
	0 - 5	94.35	0.59	0.56	0.55	0.42	0.36	0.33/0.37	0.35	0.34	0.28	0.27	0.65
	5 - 10												
	15 - 20												
	25 - 30												
	35 - 40	95.48	0.59	0.57	0.54	0.47	0.38	0.32/0.38	0.34	0.32	0.26	0.25	0.65
	50 - 55	92.54	0.59	0.56	0.54	0.48	0.43	0.34/0.37	0.33	0.31	0.25	0.24	0.66
	95 - 100	104.11	0.57	0.57	0.55	0.53	0.47	0.41/0.40	0.37	0.35	0.26	0.25	0.61

Appendix F

PROFILE DESCRIPTION 118 MAIZE/TEAZONE

Date/ season : 10-2-'86
Sheet-observation no : 122/3-118
Coordinates :
Elevation : 1790 m
Authors : Jeanine Kools, Nicole Bongers
Soil mapping unit :
Soil classification (FAO, soil taxonomy) : dystric Nitisol
Geology : Mt. Kenya series
Local petrography (Parent material) : lahar/phonolite
Physiography : mountain footridges
Macro-relief : mountainous
Slope (length, shape and pattern) : straight, regular
Slope gradient : 2%
Position on slope : summit
Meso- and micro-relief : nil
Vegetation/ Landuse : annual crop cultivation and fallow
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : slow
Surface sealing/crusting/cracking : nil
Drainage class : well drained
Flooding : nil
Groundwater level (actual) : always deep, > 2m
Presence of salts/ alkali : nil
Soilfauna influences : moderate influence; two old nests in the profile pit (Odontotermes?)
Expected rooting depth : > 1.50 m, very deep

Horizons:

Ap 0 - 10 cm: Dark reddish brown (2.5YR 2.5/4) when moist; clay; weak very fine granular structure; loose when dry, very friable when moist, non-plastic and non-sticky when wet; clear and smooth transition to:

AB 10 - 15 cm: Dark reddish brown (2.5YR 2.5/4) when moist; clay; moderate very fine angular blocky structure; friable when moist, slightly plastic ans slightly sticky when wet; patchy thin clayskins; clear and smooth transition to:

B 15 - 150 cm Dark red (2.5YR 3/6) when moist; clay; weak subangular blocky structure; friable when moist, slightly plastic and slightly sticky when wet;

continuous thin clayskins, shiny pedfaces.

Pore-distribution[1]:

		Ap 0-10 cm	AB 10-15 cm	B 15-150 cm
very fine	< 1mm :	very porous between granulars of varying size	common	many
fine	1-2mm :		few	common
medium	2-5mm :		few	few
coarse	> 5mm :		few	few

Root-distribution[2]:

		Ap 0-10 cm	AB 10-15 cm	B 15-150 cm
very fine	< 1mm :	very frequent	frequent	common, decreasin with depth to few
fine	1-2mm :	common	common	very few
medium	2-5mm :	-	-	-
coarse	> 5mm :	-	-	-

---

[1] pore-distribution

many	>200 /100 cm^2
common	51-200 /100 cm^2
few	1-51 /100 cm^2

[2] root-distribution

very frequent	5-10 mm apart
frequent	10-20 mm apart
common	20-50 mm apart
few	50-100 mm apart
very few	> 100 mm apart

PROFILE DESCRIPTION 116 MAIZE/MANGOZONE

Date/ season : 31/1/1986
Sheet-observation no : 122/3-116
Coordinates : 37° 42′E / 0° 28′S
Elevation : 1155m
Authors : Nicole Bongers, Jeanine Kools
Soil classification (FAO, soil taxonomy) : humic Acrisol
Geology : Mt. Kenya series
Local petrography (Parent material) : lahar / phonolite
Physiography : plateau
Macro-relief : hilly
Slope (length, shape and pattern) : straight, regular
Slope gradient : 2%
Position on slope : upper slope
Meso- and micro-relief : nil
Vegetation/ Landuse : shifting cultivation of annual crops (millet, maize, beans, cotton).
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : slow
Surface sealing/crusting/cracking : nil
Drainage class : well drained
Flooding : nil
Groundwater level (actual) : always deep, > 2m.
Presence of salts/ alkali : nil
Soilfauna influences : termites; strong influence
Expected rooting depth : very deep

Horizons:

Ap 0 - 19 cm : Dark reddish brown (5YR 3/2) when moist; clay; strong, fine to medium granular structure; soft when dry, friable when moist, slightly sticky and slightly plastic when wet; clear and smooth transition to:

AB 19 - 34 cm : Dusky red (2.5YR 3/2) when moist; clay; strong, fine subangular blocky structure; few thin clay (with organic matter) cutans; hard when dry, friable when moist slightly sticky and slightly plastic when wet; gradual and smooth transition to:

Bu1 34 - 62 cm : Dark reddish brown (2.5YR 3/4) when moist; clay; strong, fine subangular blocky structure; common thin clay cutans; hard when dry, friable when moist slightly sticky and slightly plastic when wet; gradual and smooth transition to:

Bu2 62 - 145+ cm : Dark red (2.5YR 3/6) when moist; clay; strong, fine subangular blocky structure; common thin clay cutans; slightly hard when dry, friable when moist, slightly sticky and slightly plastic when wet.

Pore-distribution[1]:

		Ap 0-19 cm	AB 19-31 cm	Bu1 34-62 cm	Bu2 62-145+ cm
very fine	< 1mm :	many	many	many	many
fine	1-2mm :	common	common	common	common
medium	2-5mm :	few	few	few	few
coarse	> 5mm :	few	few	few	few

Root-distribution[2]:

		Ap 0-19 cm	AB 19-31 cm	Bu1 34-62 cm	Bu2 62-145+ cm
very fine	< 1mm :	very freq.	common	very few	very few
fine	1-2mm :	frequent	few	very few	very few
medium	2-5mm :	few	very few	very few	very few
coarse	> 5mm :	few	very few	very few	very few

[1,2] see profile 118

PROFILE DESCRIPTION 117 FOREST/TEAZONE

Date/ season : 7-2-'86
Sheet-observation no : 122/3-117
Coordinates :
Elevation : 1810 m
Authors : Jeanine Kools, Nicole Bongers
Soil mapping unit :
Soil classification (FAO, soil taxonomy) : humic Nitisol
Geology : Mt. Kenya series
Local petrography (Parent material) : lahar/phonolite
Physiography : mountain footridges
Macro-relief : mountainous
Slope (length, shape and pattern) : convex, regular
Slope gradient : 2%
Position on slope : summit
Meso- and micro-relief : nil
Vegetation/ Landuse : forest
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : slow
Surface sealing/crusting/cracking : nil
Drainage class : well drained
Flooding : nil
Groundwater level (actual) : always deep, >2 m
Presence of salts/ alkali : nil
Soilfauna influences : strong influence, many species
Expected rooting depth : > 1.50 m, very deep

Horizons:

A 0 - 4 cm: clay; strong very fine to fine angular blocky structure; friable when moist, slightly plastic and slightly sticky when wet; continuous moderately thick clayskins; many biological pores and infillings; abrupt and wavy transition to:

Bu1 4 - 55 cm clay; moderate fine subangular blocky structure; friable when moist, slightly plastic and slightly sticky when wet; continuous moderately thick clayskins; diffuse and smooth transition to:

Bu2 55 - 150 cm clay; weak very fine to fine subangular blocky structure; very friable when moist, slightly plastic and slightly sticky when wet; continuous moderately thick clayskins, shiny pedfaces.

Pore-distribution[1]:

		A 0-4 cm	Bu1 4-55 cm	Bu2 55-150 cm
very fine	< 1mm :	many	many	many
fine	1-2mm :	few	common	common
medium	2-5mm :	common	few	few
coarse	> 5mm :	few	few	few

Root-distribution[2]:

		A 0-4 cm	Bu1 4-55 cm	Bu2 55-150 cm
very fine	< 1mm :	frequent	common	very few
fine	1-2mm :	frequent	few	very few
medium	2-5mm :	common	common to few	very few
coarse	> 5mm :	few	very few	very few

[1,2] see profile 118

PROFILE DESCRIPTION 119 BANANA/MANGOZONE

Date/ season : 12-2-'86
Sheet-observation no : 122/3-119
Coordinates :
Elevation : 1200 m
Authors : Jeanine Kools, Nicole Bongers
Soil mapping unit :
Soil classification (FAO, soil taxonomy) : humic Acrisol
Geology : Mt. Kenya series
Local petrography (Parent material) : lahar/phonolite
Physiography : plateau
Macro-relief : hilly
Slope (length, shape and pattern) : straight, regular
Slope gradient : 0%
Position on slope : summit
Meso- and micro-relief : termite mounds
Vegetation/ Landuse : perennial crop cultivation; banana bush
Erosion : nil
Rock outcrops : nil
Surface stoniness : nil
Overwash : nil
Surface runoff : slow
Surface sealing/crusting/cracking : nil
Drainage class : well drained
Flooding : nil
Groundwater level (actual) : always deep, > 2 m
Presence of salts/ alkali : nil
Soilfauna influences : strong influence; many microterme
A-horizon; 13-18 cm: small (3
larvae chambers (?); 45-55 cm: krc
Expected rooting depth : >1.50 m, very deep

Horizons:

A1 0 - 8 cm: Dark reddish brown (5YR 2.5/2) when moist; clay; termite structure consisting of rounded consolidated fine granulars; loose when dry, friable when moist, slightly plastic and slightly sticky when wet; continuous thin clay- and humusskins; abrupt and smooth transition to:

A2 8 - 55 cm: Dark reddish brown (2.5YR 2.5/4) when moist; clay; strong fine subangular blocky structure; loose when dry, friable when moist, slightly plastic and slightly sticky when wet; common thin clayskins; abrupt and wavy transition to:

B 55/60 - 150 cm Dark reddish brown (2.5YR 3/4) when moist; clay;

porous massive structure; loose when dry, friable when moist; slightly plastic and slightly sticky when wet; common to few thin clayskins.

Pore-distribution[1]:

		A1 0-8 cm	A2 8-55 cm	B 55/60-150 cm
very fine	< 1mm	many	many	many
fine	1-2mm	many	many	common
medium	2-5mm	common	common	few
coarse	> 5mm	few	few	few

Root-distribution[2]:

		A1 0-8 cm	A2 8-55 cm	B 55/60-150 cm
very fine	< 1mm	frequent	common	very few
fine	1-2mm	common	common	very few
medium	2-5mm	few	few	very few
coarse	> 5mm	very few	very few	very few

[1,2] see profile 118