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Titel SEALED RED SOILS IN EASTERN KENYA
their genesis and maintenance in
relation with vegetation and
ways to manage them

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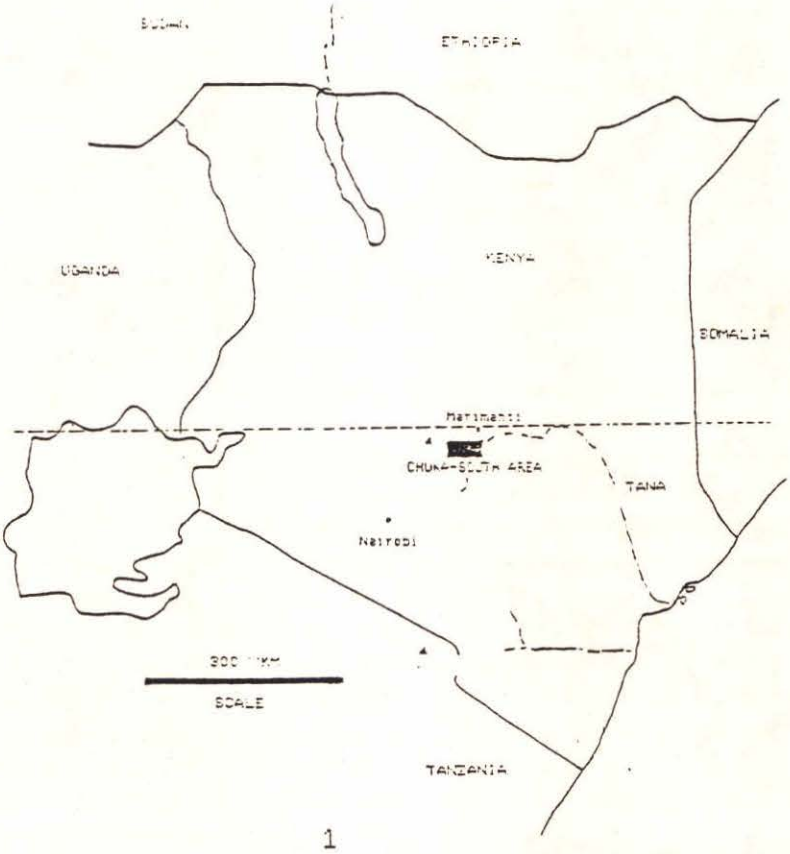
1 INTRODUCTION

During 1985-1986 the Training Project in Pedology (TPIP) of the Agriculture University Wageningen, in cooperation with the Kenya Soil Survey, carried out a soil survey of the Chuka-south area in Eastern Kenya (see figure 1). During this survey the importance of soil surface sealing (capping) was recognised. This phenomenon is common on red soils developed from the Basement System. An approximate 15 percent of these soils in Eastern Kenya is strongly sealed and remains bare throughout the year.

Aim of this study is to get a better insight in the process of sealing and it's ecological consequences. Further to provide information about the frame in which possible solutions can be found. This also fits with the work of the British-Kenyan EMI project on the problems of landuse and land degradation in the semi-arid parts of Embu, Meru and Isiolo districts.

The study was concentrated on EMI's Sheep and Goat project in Marimanti, some 15 km north of the Chuka-south area (see figure 1). We started here two months before the rainy season of october-november 1985 and ended in january 1986.
Elsewhere, both in cultivated land (especially Chuka-south area) and in less disturbed areas (Meru NP and Kora NR), additional observations have been made. These were meant to obtain a better understanding of the origin of sealing and the (im)possibilities of managing sealed soils.

FIGURE 1: LOCATION OF THE CHUKA-SOUTH AREA AND THE MARIMANTI STUDY SITE



2 THE AREA

2.1 CLIMATE

The average amount of rainfall in the study area is indicated in figure 2 (Jaetzold & Schmidt 1983). The soils, where the sealing occurs, are all situated in the semi-arid area, with an average annual rainfall of 900 - 700 mm/yr. Figure 3 shows rainfall and potential evapotranspiration of Tharaka village (see figure 2 for location). In general two rainy seasons are present, one "long" (march, april and may) and one short (october and november), both are only marginal for cropping.
In semi-arid environments average rainfall data do not say much. This is illustrated by figure 4 which shows the fluctuation in rainfall in Marimanti, from a maximum of 1500 mm (1968) to a minimum of 500 mm (1973 and 1983). This variation in time is accompanied by a considerable variation from space to space. As shown in figure 5, half of the monthly rainfall falls within a single day (one large shower). This means that when a particular area misses one or two of these showers it is a dry year for that particular place , while on average it can be a wet year. The topography of the area is likely to cause this variation.

FIGURE 2: AVERAGE ANNUAL RAINFALL DISTRIBUTION IN THE AREA (mm)
(Jaetzold & Schmidt 1983)

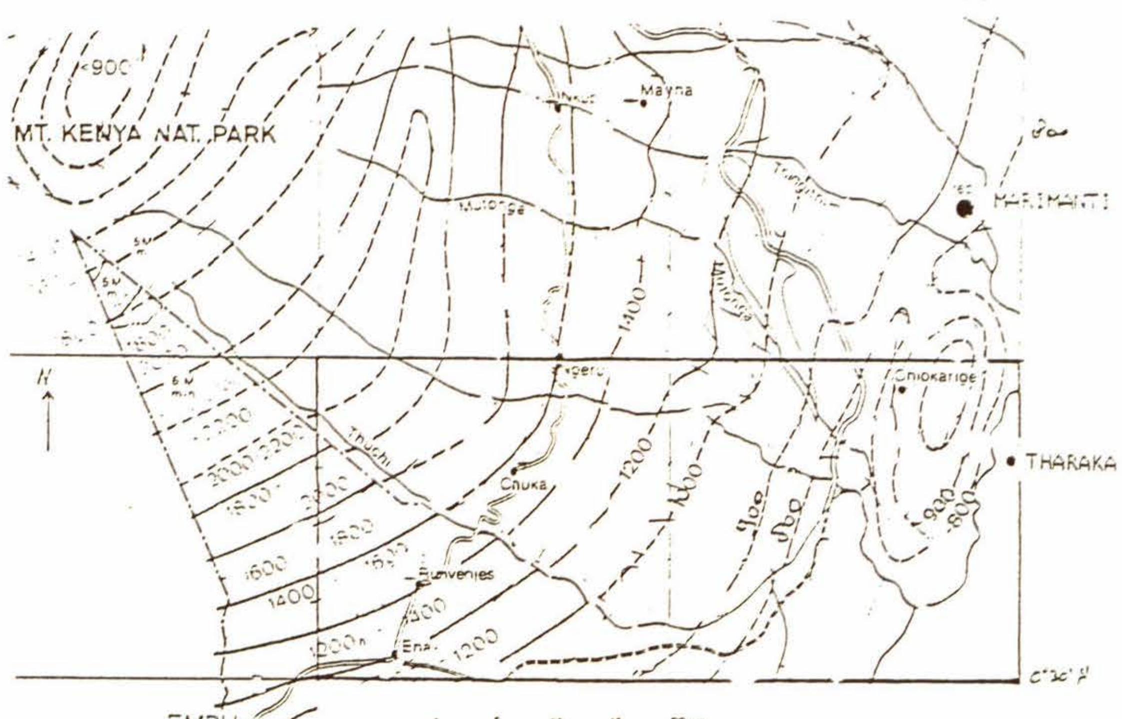


FIGURE 3: RAINFALL AND POTENTIAL EVAPORATION IN THARAKA VILLAGE

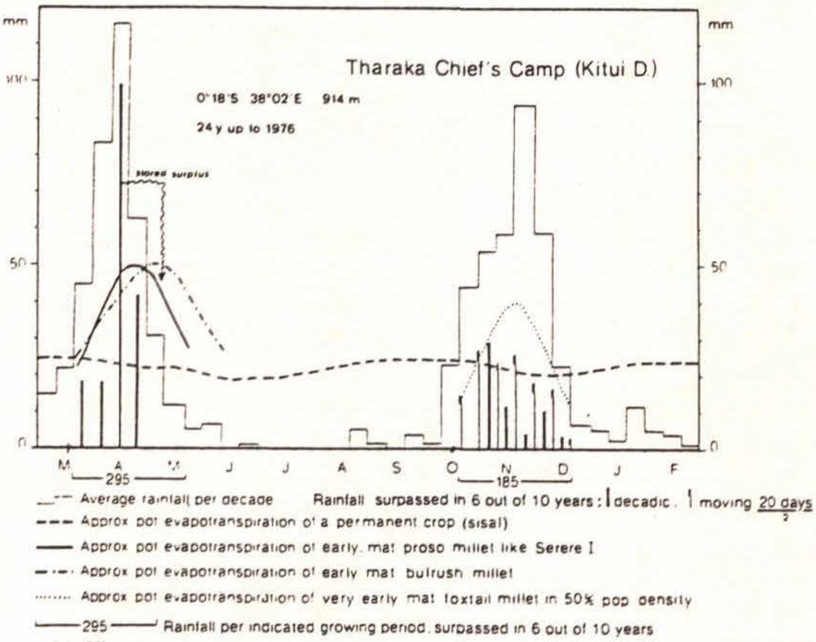


FIGURE 4: VARIATION IN ANNUAL RAINFALL,
Marimanti metereological station

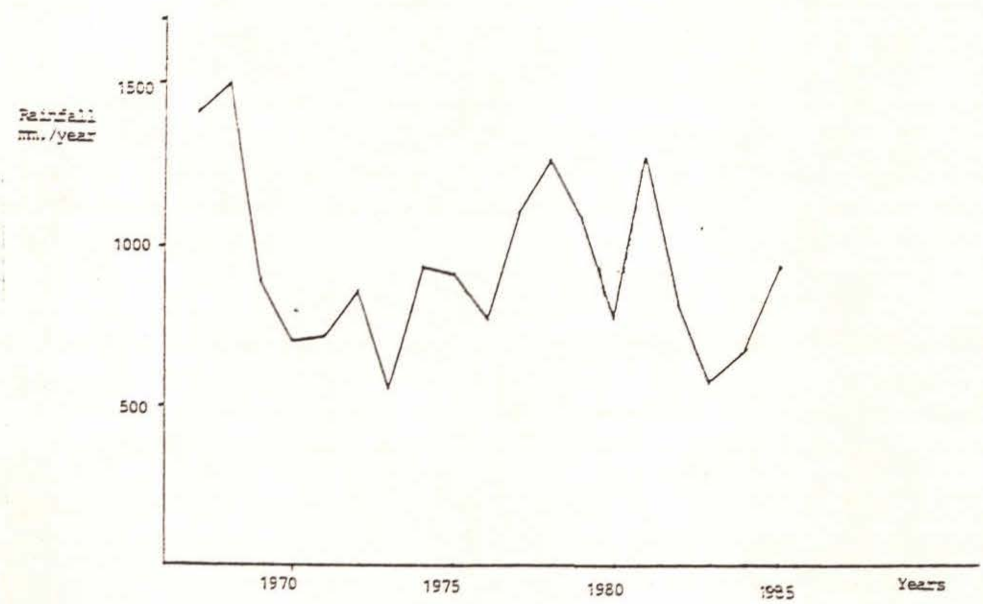
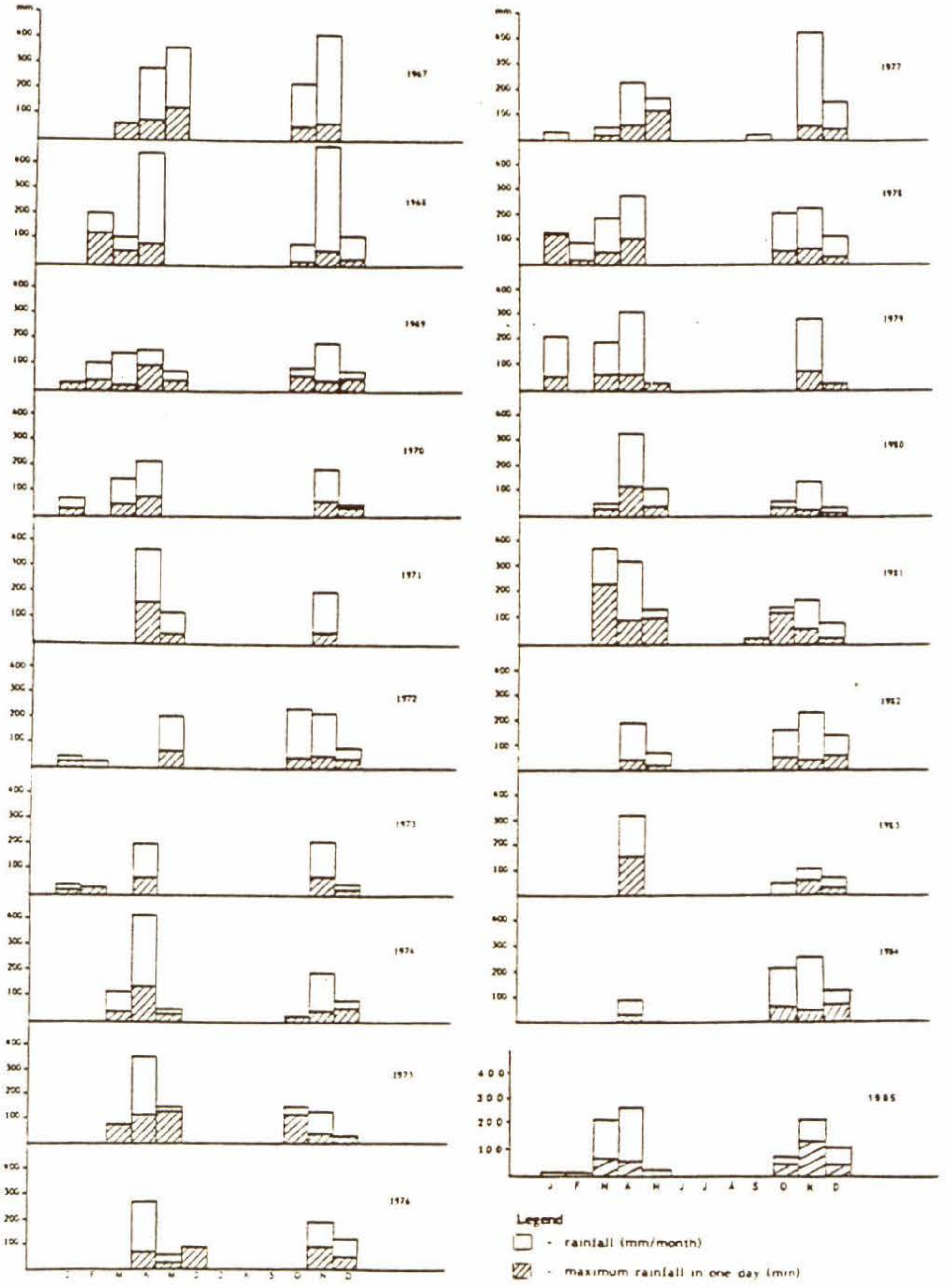


FIGURE 5: INDICATION OF THE IMPORTANCE OF LARGE SHOWERS,
Marimanti metereological station



Source: District Water Officer, Meru

2.2 GEOLOGY AND PHYSIOGRAPHY

Note: In this description all landform classification names are used as defined by the Kenya Soil Survey in their internal communication nr 13, 1978 (Weg, 1978)

The study area is part of the old (precambrian) metamorphic Basement System which covers large parts of Eastern Kenya. The majority of the Basement System consists of various types of gneisses. Especially biotite and hornblende gneisses are common. In these gneisses narrow amphibolite belts ocur. The plagioclase (a feldspar) in the weathering gneisses and amphibolites is the source of calcium in the secondary lime which accumulates locally near streams. Locally the gneisses have been further metamorphised into granulites.

The landform of the Basement System dominated area are gently undulating to rolling Uplands, dissected by several valleys of perennial rivers with accompanying river terraces. Many small (several metes deep) seasonal streams dissect the land.

Characteristic in the eastern part of the area are granitic Intrusives, Mountains, which rise several hundred meters above the surroundings (Inselbergs). More to the west Intrusives of a different geology (ultramafic hornblende gabbro's and granulites) dominate the landscape.

Quite recently major changes took place due to the forming of the Rift Valley. Mt. Kenya and the Niambeni Range developed and became active volcanoes. Although in our study area hardly any volcanic remnant can be found, this activity has changed it to a great extent, due to volcanic ash deposits, changed drainage patterns etc. The only volcanic remnants still found in the area are formed by flows of basalt of the Niambeni. Nowadays they rise as Plateaus above the surrounding Uplands.

2.3 SOILS

In the Uplands, developed on Basement System rocks, the most common soil types are chromic Luvisols (FAO, 1975), which cover more than 70% of the area. They are moderately deep to deep, have a texture of sandy loam to sandy clay in the topsoil and of sandy clay in the subsoil. The abundant clayskins in the subsoil already indicate the instability of these soils. Only in case of untruncated soil profiles the topsoil is dark red. Usually however it has the same red colour as the subsoil.

Surface sealing is the clogging of the pores in the upper few centimeter of the profile. It is a very common phenomenon in these soils and the most limiting factor for their use. Although the chemical fertility is not high, it is not limiting. Crucial for the stability of these soils is the amount of organic matter which is often very low (< 0.5%!).

Other soil types in the area are calcic Luvisols (FAO, 1975), occuring along the numerous seasonal streams. They cover not more than 10% of the area, but are important for grazing and, to a lesser extent, for farming. In contrast to the chromic Luvisols, they are quite stabile and always have a moderately high infiltration capacity. Their chemical fertility is equal to that of most chromic Luvisols.

2.4 VEGETATION AND LANDUSE

The always available water in the streams flowing from Mt. Kenya to the Tana river has always attracted people. Consequence is a very high cultivation activity, therefore no natural vegetation occurs in the area anymore. Differences in vegetation are a reflection of the period that the land has been left fallow. However the vegetation-landuse map of the Chuka-south area (Oostveen & Scholte 1986), shows differences between these "bush-fallow complexes". Differences in climate and parent material were clear. However on the chromic Luvisols main differences are reflected by stages in the bush-fallow cycle.

In the study area bush-fallow agriculture is the main form of landuse. People start cultivation by clearing a particular bush, usually not more than one ha large. Not all trees are cut, especially Sterculia rhynchocarpa, Delonix elata and Adansonia digitata are spared. Commiphora africana and Acacia senegal trees are often cut at a heigness of one meter. A few months after clearing everything will be burned, usually just before the expected onset of the rains. Then cultivation starts, major foodcrops are millet, sorghum and green grams, major cash crop is cotton. On favourable spots, which receive more moisture and manure (especialy of goats), preferable maize is grown. Usually the gardens are protected against livestock by fences of thorny Acacia senegal or A. tortilis branches. But after the harvest animals are driven in the gardens to graze weeds and millet and sorghum stalks.

After two or three years of cultivation, land is left fallow. The first year only some annual grasses and forbs grow, but they are heavily grazed. Trees which have been spared during cultivation grow out and are the nuclei of a slowly recovering vegetation. Dependent of the amount of depletion of the soil and the grazing pressure, regeneration can occur, or not. In the latter case the land remains bare, the soil surface seals stronger and any regeneration will be very unlikely. Is the grazing pressure lower then dense thickets are formed. Becoming older (>15yr?) trees grow higher and a kind of Scrub forest is formed (7m high). This stage is hardly reached anymore, because before that moment trees are already cut for a new cultivation period.

Nowadays especially the transition from bare soils with outgrowing trees into bushland is hindered. More exhausted soils and a higher grazing pressure are responsible for this and cause a decrease in speed of bush development.

The majority of the time livestock (predominantly local zebu's and goats) grazes in the fallow bush and thicket vegetation. Especially the well developed bushland is an important source of forage in the beginning of the rainy season, later on also the vegetation along the streams is of great importance. In the dry season hardly any ground vegetation is left and the consumed forage consists mainly of litter. It is clear that in this way soils have lost much of their organic matter input. (See Scholte 1986 for more details about the grazing system)

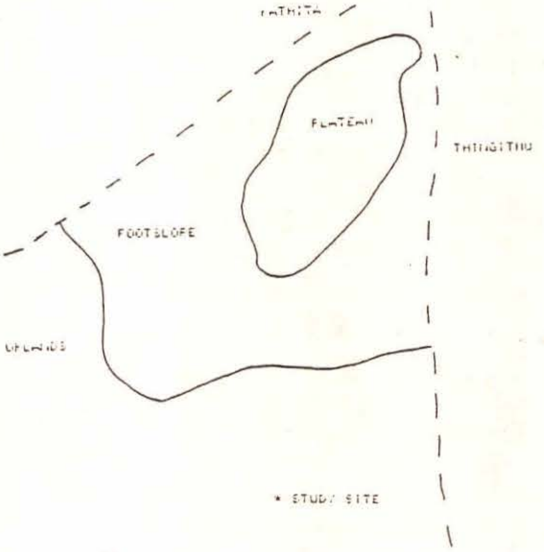
3 THE SITES

3.1 INTRODUCTION

The EMI's Sheep and Goat project was selected as location for the detailed research to the sealed soils. Situated between the perennial rivers Thingithu and Kathita, this area has been intensively cultivated and grazed in the past. In 1982 the British - Kenyan EMI project started here their Sheep and Goat project and fenced the area. Several families had to leave the area and cultivation and grazing was no longer allowed. Therefore at the start of our study two years had passed without cultivation and with only a very low grazing pressure (< 1 goat per acre). No spontaneous rehabilitation of the areas with sealed soils has taken place. Vegetation only growed vertically but did not colonize new places. In this way the contrast between places with and without vegetation has increased.

In figure 6 a schematic physiographic map of the Marimanti area is given. A basalt plateau dominates the area near the joining of both rivers. Uplands, separated from the Footslopes by dissected streams, form the majority of the area.

FIGURE 6: PHYSIOGRAPHIC MAP OF THE MARIMANTI STUDY AREA



3.2 SITE DESCRIPTION

Our research was concentrated on four hectares of strongly sealed soil. The sites are situated in a relatively flat area, somewhat elevated above the other surrounding Uplands. In the past some compounds with their gardens and kraals were situated here.

Scattered trees of medium size (4-8m), Acacia tortilis, Commiphora africana and Boscia angustifolia are present. Patches of dense Boscia coriaceae shrubs (3m) are common. In contrast to the situation with the trees here a dense ground vegetation occurs. Perennial Grassland as well as Annual Grassland occurs often around these trees and shrubs (species see table 2). Half of the area is bare with sealed soils, only very locally some annuals grow (Blepharis linariifolius, Tragus berteronianus).
A special position is taken in by the so called Vegetation Isles which are especially common on slopes. They are remnants of the area around a shrub or tree. Their immediate surrounding has been eroded away so that they represent the former soil level like an isle.

Research concentrated on six kind of places:

1- Bare soil without any vegetation at all
2- Soil under Annual Grassland, often where it borders bare soil
3- Soil under Perennial Grassland
4- Soil under Boscia Shrubs
5- Soil near stems of Trees
6- Soil in Vegetation isles

In three transects both soil and vegetation have been studied, according to the arrangement given above. Figures 7, 8 and 9 show the position of the transects in relation with the vegetation.

In Appendix 1 more detailed characteristics of the three transects are given.

FIGURE 7: VIEW ON TRANSECT 1
for legend see next page

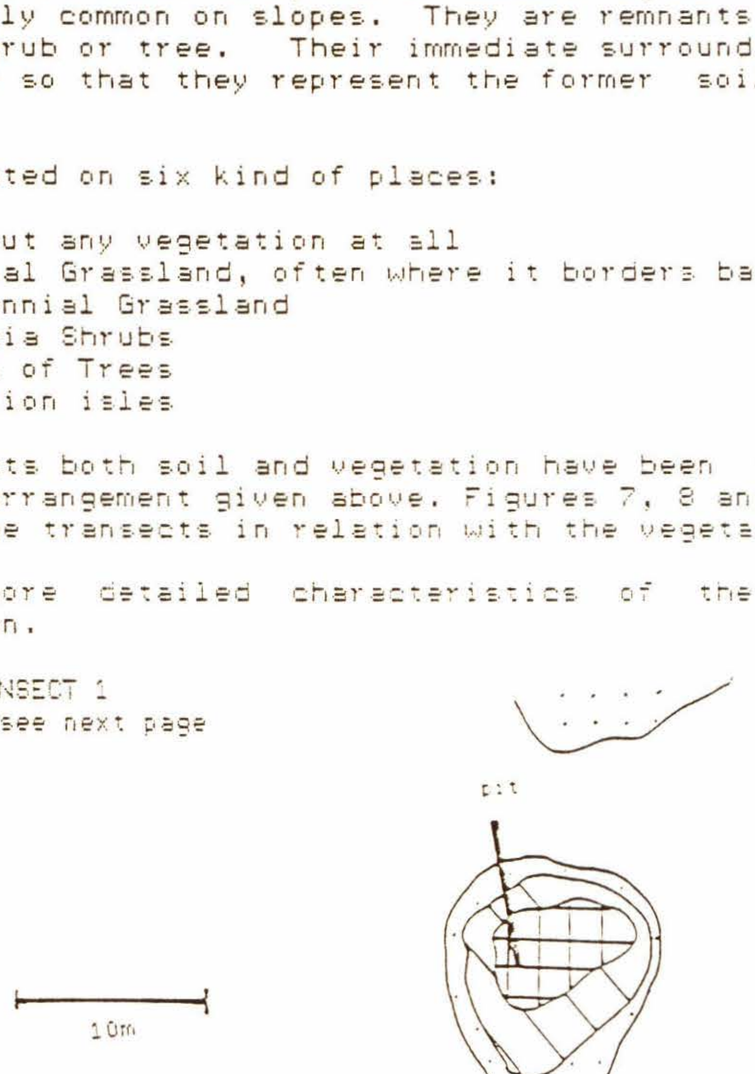
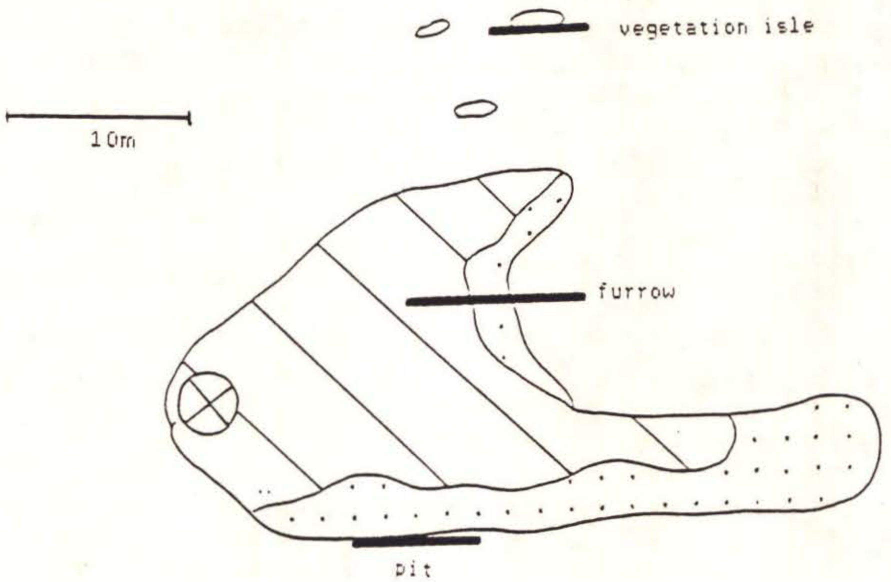


FIGURE 8: VIEW ON TRANSECT 2



LEGEND:

BARE (SEALED) SOIL

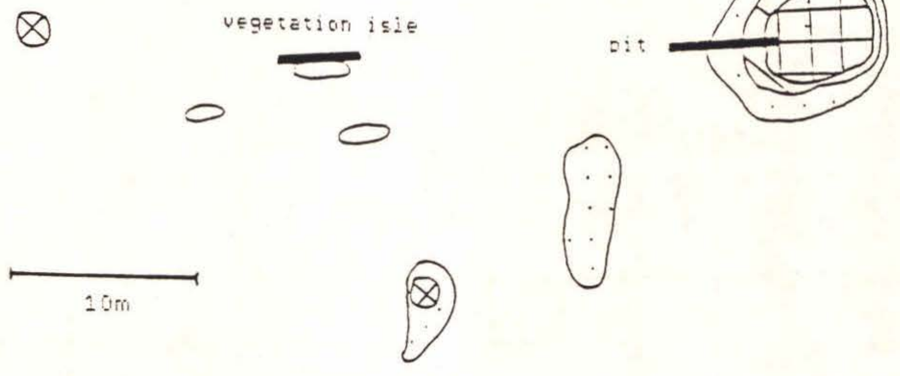
ANNUAL GRASSLAND

PERENNIAL GRASSLAND

SHRUB VEGETATION

TREE

FIGURE 9: VIEW ON TRANSECT 3



3.3 DESCRIPTION OF TRANSECTS

3.3.1 Soil

In each transect a pit has been dug where it crosses as many vegetation types as possible. Their depth was limited by the depth of the rotten rock, 150 - 200 cm. For the location of the pits see figures 7, 8 and 9.

They span:
Pit transect 1: Shrub - Perennial - Annual Grassland - Bare soil
Pit transect 2: Annual Grassland - Bare Soil
Pit transect 3: Shrub - Perennial - Annual Grassland - Bare soil

In addition in transect nr 2 (see figure 8) one furrow has been dug, 50 cm deep, crossing Perennial-Annual Grassland-Bare soil. In both transect 2 and 3 a profile of a Vegetation Isle has been studied (50 cm deep).

All profiles have been described according to the FAO guidelines (FAO, 1977) with special attention to the pores and roots in each horizon. In the appendix the complete soil descriptions of the pits, the vegetation isles and the furrow are given.

In table 1 a summary of these data is given, with emphasis on the topsoil. Hardly any difference has been found between the subsoils in the different situations. In addition of the data presented in table 1 all subsoils can be described as follows:
Red (2.5 YR 4/6-8) when moist; slightly gravelly sandy clay with a stone line (quartz) at ± 1m; fine crumb structure and moderate to strong subangular to angular blocky structure; common to abundant clayskins; abundant to few fine pores and common to very few fine roots; pH is quite high (6-7).

The striking differences in character between the soils in the different situations (bare soil, grasslands, shrubs and trees) can not be explained by the observations of the subsoils. However the topsoils show much more differences (see table 1):

Bare Soil: In general they have a sandy clay topsoil with on top of it some sand wash, they are red when moist (2.5 YR 4/6-8), have a porous massive structure and in general many pores which are often closed. Striking is the abundancy of clayskins already in top of the topsoil. The example of the bare soil in the furrow with it's dark topsoil shows that there can be deviations of this generalisation (see discussion).

Soil under Annual Grassland : There exists much variation in depth of the dark red topsoil, from 0 - 40 cm. The upper part of the topsoil is always sandy loam with on top of it sand wash. This becomes gradually more clayey. Structure is single grain, deeper all possible combinations of crumb, subangular- and angular blocky structure occur. Here clayskins also become more common.

TABLE 1: SOIL CHARACTERISTICS OF ALL PROFILES

CHARACTER	PITS IN TRANSECT NR							FURROW		VEGETATION ISLE	
LOCATION	T1		T2		T3			F		T2	T3
SITUATION	2	4	1	2	1	4	1	2	3	6	6
DEPTH DARK TOPSOIL (cm)	40	40	0	0	0	30	20	15	15	12	20
TEXTURE (0-50 cm)	sl scl	scl sc	sc sc	sl sc	sc sc	scl sc	sl sc	sl sc	sl sc	sl sc	scl sc
STRUCTURE (0-20 cm)	sg	gs +cr	cr +pm	sg	cr	cr +gr	cr +ab	cr +b	cr +ab	cr +sb	cr +sb
(20-50 cm) if different	sb +ab	sb +cr	pm	cr +ab		cr +ab					
CLAYSKINS (0-50 cm)	n-c	n-f	a	n-f c	a	n a	n-f c	n-f a	f-c a	f-c a	f-c
PORES (0-50 cm)	m	m	m *	m	m-c *	c	f *	c	m-c	m-c	f coarse
pH (Helliger) (5 cm)	8	7.6	6.3	6.9	5.7	5.7	6	5.5		6	
deeper	7.2			6.6	6.7	6.0		6.5			
DEPTH ROTTEN ROCK (cm)	130	130	150	130	170	200					
STONELINE AT (cm)	90	90	85	90	85	100					
PARENT MATERIAL	biotite augengneiss		hornblende +biotite		biotite gneiss						

LEGEND

Situation:
1 = Bare Soil
2 = Soil under Annual Grassland
3 = Soil under Perrennial Grassland
4 = Soil under Shrub
5 = Soil under Tree
6 = Vegetation Isle

Texture:
sl = sandy loam
scl = sandy clay loam
sc = sandy clay

Clayskins:
n = none
f = few
c = common
a = abundant

Structure :
ab = angular blocky
cr = crumb
gs = granular structure
pm = porous massive
sb = subangular blocky
sg = single grain

Pores : m = many c = common f = few * = closed

Soil under Perennial Grassland: Is intermediar to the soil conditions under annual grassland and shrubs.

Soil under Shrubs: Deep dark topsoil with a texture from sandy clay loam to sandy clay, always a granular structure (+ crumb) in the upper part of the topsoil, deeper also a subangular blocky structure occurs. Only in the subsoil (>50 cm) clay skins can be found.

Soil under Trees: No unequivocal description of the topsoil under a tree can be given. The situation varies between the one of bare soil and that under a shrub.

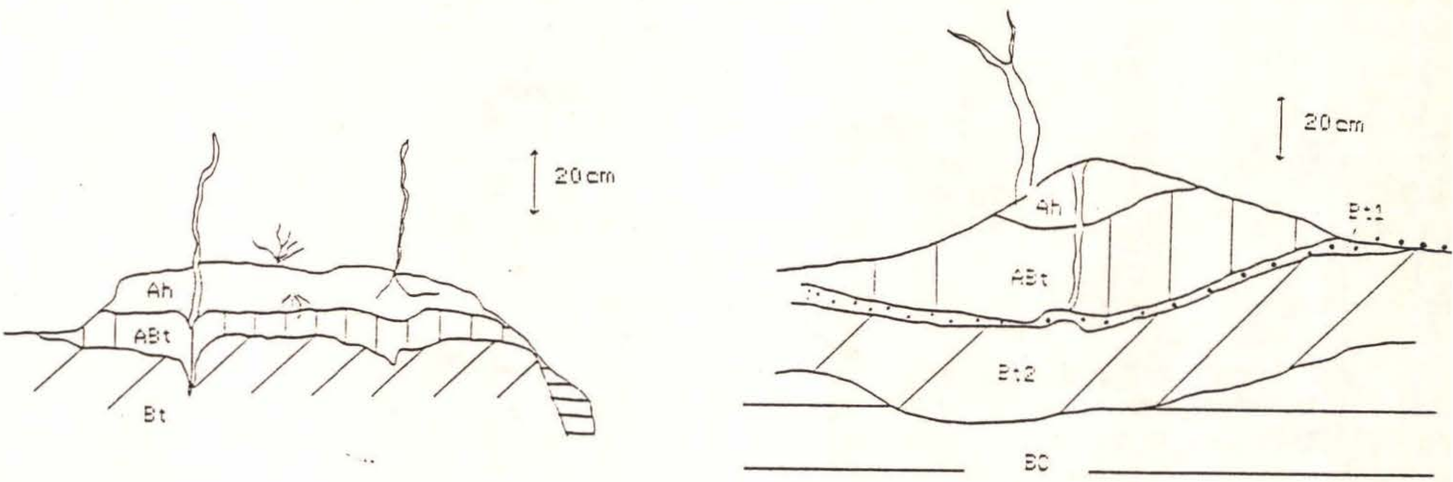
Soil in Vegetation Isles (see also figure 10): Characterised by a moderately deep dark topsoil which changes in texture from sandy loam to sandy clay. The structure is crumb together with some subangular blocky structure. Striking are the very big pores (> 1 cm) which give this soil a spongy like structure. In contrast to the situation under shrubs , clayskins occur already in the topsoil and become common in the subsoil.

General : Striking are the high pH values, already an indication of the instability of these soils (see 7.1).
All soils were classified as chromic Luvisols (FAO/Unesco) or as udic Haplustalfs (Soil Taxonomy).

3.3.2 Vegetation on the sites

As can be observed in figures 7, 8 and 9 an important determining factor of the vegetation is it's distance to bare soil. Figure 11 shows the situation in transect 2 (near the furrow). A plant near the bare area receives much run-on water which is favourable for fast germinating grases like Tragus berteronianus. Within a few weeks these plants can finish their life cycle. Further away from the bare soil less fast germinating species occur. They have a much deeper rooting system and can also use the water which is stoored deeper in the soil. Perennials have the best developed rooting system and, due to their perennial character, can absorb the first rainwater. But although the efficiency of water substraction of fast germinating species is much less than that of perennials, the latter are more susceptible for grazing (especially in the dry season), burning etc.

FIGURE 10: CROSSSECTION THROUGH VEGETATION ISLES



TRANSECT 2 TRANSECT 3

FIGURE 11: PLANT SPECIES IN RELATION WITH DISTANCE TO BARE SOIL

```
           0       1       2       3       4       5       6   METER
           |-------|-------|-------|-------|-------|-------|

           |Eragrostis   |  Rhynchelytrum | Digitaria abyssinica
           |cilianensis  |  repens        |
           |            |               |
          | Tragus       |  Chloris       |
          | berteronianus | virgata       |
           |             |              |  |
BARE SOIL  |            |             |     |
           |          |             |          |
          |           |            |          |
         | Tragus     |  Chloris |  Ocimum basilicum |
          | berteronianus | virgata|                 |
           |             |     |  Endostemon tetericaulis  |
```

As a summary in table 2 the most important plant species of the Marimanti study area and their life strategies as observed there, are given. The consequences of the vegetation dynamics for the origin and maintenance of sealing will be discussed in chapter 5.

TABLE 2: PLANT STRATEGIES OF THE MOST COMMON PLANTS AS OBSERVED IN THE MARIMANTI STUDY AREA

PLANT SPECIES	GERMINATION	DISTANCE to bare soil	MULCH TRIAL*	LITTER#
ANNUAL GRASSES				
Acrachne racemosa	medium	close	some	none
Aristida adscencionis	slow	medium	some	little
Chloris virgata	medium	close	none	none
Eragrostiella cilianense	fast	very close	some	none
Rhynchelytrum repens	slow	close	dominant	little
Tragus berteronianus	fast	very close	some	none
ANNUAL HERBS				
Acanthospermum hispidum	medium	close	common	none
Blepharis linariifolius	medium	very close	none	none
Commelina benghalensis	slow	medium	common	much
Pupalia lappaceae	slow	far	common	little
PERENNIAL GRASSES				
Chloris roxburghiana		medium	none	medium
Digitaria abyssinica		far	none	much
Enteropogon macrostachys		medium	none	little
SHRUBBY HERBS				
Barleria acanthoides		medium	dominant	little
Endostemon tetericaulis		close	none	little
Ocimum basilicum		close	none	little
Tephrosia villosa		medium	none	medium
SHRUBS				
Boscia coriacea		far	none	much
Commiphora africana		medium	none	little
TREES				
Acacia senegal		close	common	little
Acacia tortilis		close	none	little
Boscia angustifolia		medium	none	little
Commiphora africana		close	none	little

* for explanation see paragraph 6.3.2
\# where the plant is germinating

3.3.3. Vegetation production on the sites

On several places in the three transects vegetation biomass and cover determinations have been carried out. In the various annual- and perennial grasslands and under shrubs and trees, this has been done in september 1985 (before the onset of the rains) and in january 1986 (at the end of the growing season). The dry weight of perennial grasses and herbs and the amount of litter (dead leaves and wood) has been measured. Cover has been determined of all plant species in relation with the heighness of the vegetation (see relevee methodology in Oostveen & Scholte 1986). Biomass determinations of shrubs and trees were out of scope. The homogeneous character of the vegetation enabled to sample vegetations comparable to those where the infiltration measurements would be (had been) carried out.

Table 3 shows the cover and biomass determinations before and after the rainy season in the various situations. Biomass is presented for annuals, perennials and litter separately. Cover is presented for ground vegetation (<1 m), shrub and tree vegetation (>1m) and litter separately. Indicated are average values and standard deviations (except for trees).

TABLE 3: BIOMASS AND COVER OF VEGETATION IN THE TRANSECTS

	BIOMASS (g/m^2)						COVER (% real)					
	BEFORE			AFTER			BEFORE			AFTER		
SITUATION	L	A	P	L	A	P	L	H	G	L	H	G
ANNUAL	49 (16)	46 (23)		298 (103)			37 (19)		12 (8)	14 (10)		46 (24)
PERENNIAL	139 (107)	29 (25)	62 (49)	352 -	326 -	172 (141)	27 (5)		33 (28)	2 (3)		57 (28)
SHRUB	255 (110)		90 (79)	638 -	75 -	288 (9)	45 (26)	45 (21)	23 (12)	5 (6)	41 (3)	77 (21)
TREE 1	321			457		59	36	30	1	56	30	10
TREE 2	156			237		73	5	6	4	18	6	40

LEGEND:
L = litter
A = annual vegetation
P = perennial vegetation
H = high vegetation (>1 m)
G = ground vegetation (<1m)
( )= standard deviation
- = only one observation

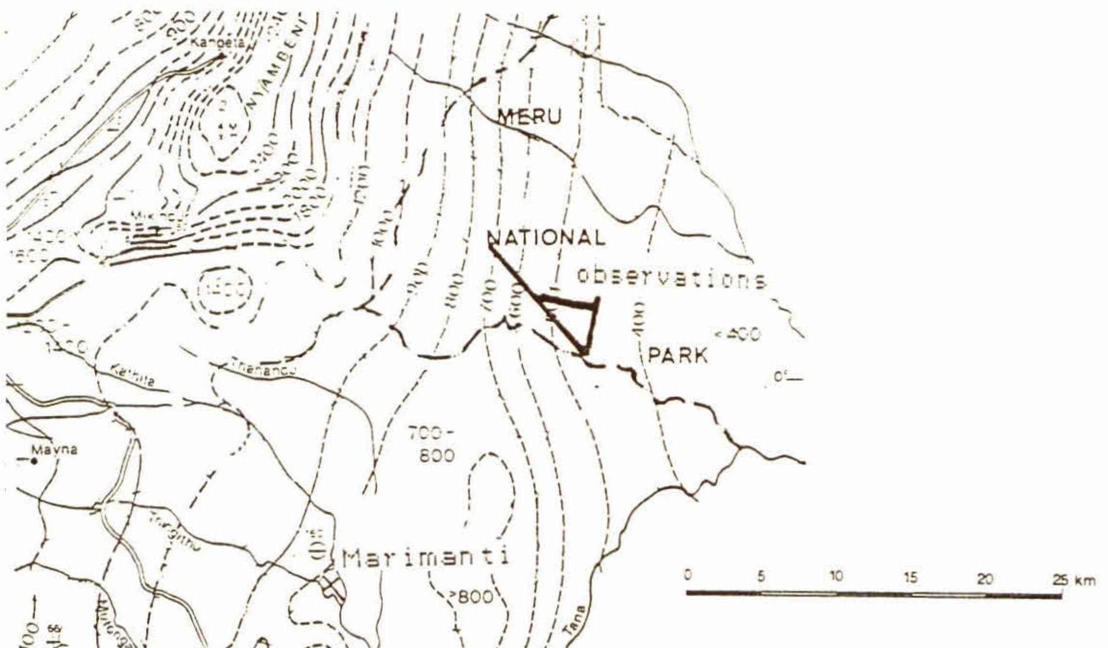
4 OBSERVATIONS IN MERU NATIONAL PARK

Twenty five kilometer north east of Marimanti, Meru National Park is located. In the south-west corner of this park comparable environmental circumstances are found as those in the Marimanti study area. Main difference is landuse. The average annual rainfall ranges from 800 - 400 mm per year (see figure 12, Jaetzold & Schmidt 1983).

Soils are developed on Hornblende-Biotite gneisses and are comparable to the least disturbed soils in the cultivated area (same color- and texture sequence, structure and consistency). Although no certainty exists if the pedological circumstances are equal (e.g. differences in volcanic ash deposits), it is very likely that human influence is the main determining factor for the observed differences.

In the south-west corner of Meru NP 25 augerings and (quick) vegetation relevees have been made in order to make some qualitative comparisons of the soil - vegetation relation in an undisturbed area with the already described cultivated area (see figure 12 for the precise location).

FIGURE 12: AVERAGE ANNUAL RAINFALL MERU PARK (mm)

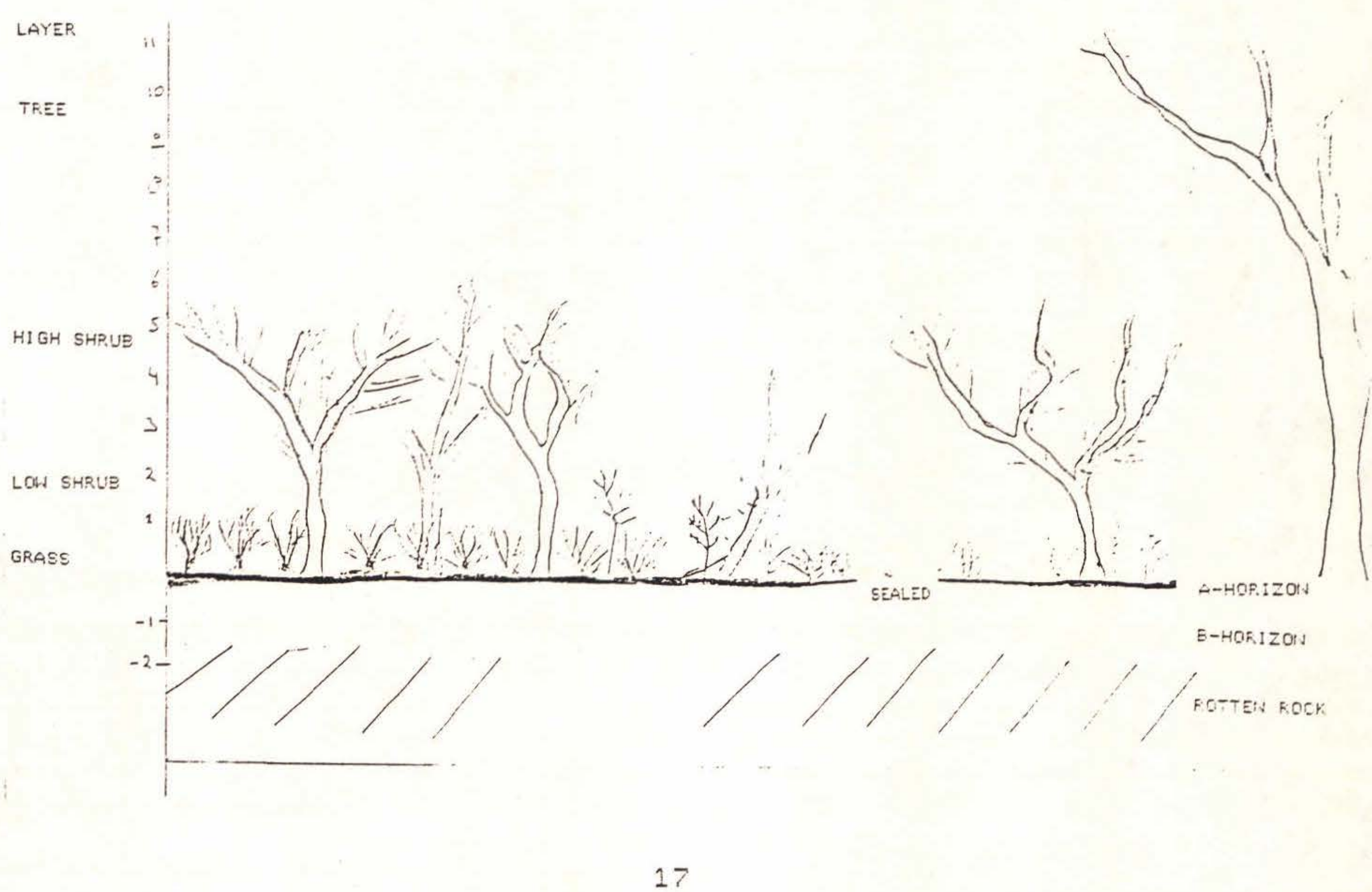


In Meru NP the general vegetation type is a Commiphora africana bushland which differs largely from the C. africana fallow thicket vegetation in the cultivated area. Main difference is the high cover of ground vegetation in the protected area. The cultivated land almost completely lacks such a ground vegetation.

Schematically the situation in Meru NP can be presented as has been done in figure 13. Four layers can be distinguished:

Tree layer, scattered Acacia tortilis trees (± 15 m high) in a low density, less than 1 per ha.
High Shrub layer, predominantly Commiphora africana shrubs (± 6m high, only a few A. senegal trees, cover (external) 30-70 %.
Low Shrub layer, Grewia villosa, G. bicolor, Combretum aculeatum, Bauhinia taitensis and Triumfetta flavescens shrubs (1-2 m high), cover (external) 0 - 20 %.
Perennial Grass layer, Chloris roxburghiana and Enteropogon macrostachys perennial grassland , with a low percentage of annuals and shrubby herbs (Blepharis linariifolius, Tragus berteronianus, Ocimum basilicum and Barleria acanthoides). Total cover of perennial grasses (both species more or less the same perentage) is 80-50% (external), 50-30 % (real). Half of this amount is "dead" material (last season's growth).

FIGURE 13: CROSSSECTION THROUGH DOMINANT VEGETATION-SOIL TYPE IN MERU NP



In general the soil accompanying this vegetation type is deep (> 1m), with a red, slightly gravelly sandy clay subsoil and a 10 - 30 cm deep, dark red (2.5YR 3/4(6), occasionaly 5YR 3/4-6) topsoil with a granular structure.

Although the majority of the area is covered by vegetation, patches of bare sealed soil occur. They always consist of red sandy clay (2.5YR 4/6-8)), similar to the subsoils in places with a vegetation cover. Spots of bare soil are abundant along the roads, but occur also elsewhere. They are always small (< 100 m^2 often only a few m^2) and occur near game tracks or in the direct surrounding of a termite mound.

Only some annuals can grow here (often at the edge of the spots), Blepharis linariifolius, Tragus berteronianus and Chloris virgata are the most common ones. Run-off water flows only a few meters and infiltrates rapidly in the surrounding soil which is covered by vegetation. Only near the roads rill or gully erosion has been observed.

Two augerings and accompanying vegetation relevees show a different picture. One patch of sealed soil showed a dark red topsoil (indicating a high organic matter content?). At another sealed spot the soil was only 20 cm deep, which probably explains the sealing (see 7.1).

In some parts of the studied area recent burning has changed the vegetation structure (management to increase the attractivity of the area). The result is an increase in annual grasses (Aristida adscensionis, the same as found on the fallow lands in the cultivated land), small shrubs and a sharp decline in the cover of higher shrubs. Changes in soil (losses of organic matter, reducing depth of dark topsoil) are likely. However it is difficult to say if this will increase the danger of sealing.

5 METHODS

5.1 RAINFALL

Daily rainfall measurements of the Marimanti metereological field station, at a distance of 2 km from the sites, have been used for the preparation of the climate figures (figures 4 and 5). However more detailed rainfall data were needed on the sites themselves. Therefore a raingauge was installed within 100 meters of the studied transects (in an open area). From the end of september 1985 till december 1985 precipitation was measured and automatically registrated on a time scale. This allowed the calculation of the important rainfall intensity as well.

Not only the amount of rain that falls, but also the amount that actually reaches the soil (and can infiltrate) should be known. Therefore two non automatic rain gauges were installed under different vegetations (Boscia coriaceae shrub with a cover of 70% and under an Acacia tortilis tree with a cover of 20%). These raingauges were used only during a limited part of the rainy season for the sole purpose of estimating the amount of rainfall interception by the vegetation of showers of different intensity. The accuracy of the measurements with these two non - automatic rain gauges is probably much less than with the automatic one. Not only because influences of evaporation can be expected but also because of their rusty reservoirs. No attempts have been made to determine the interception of other vegetation types.

5.2 SOIL DATA

5.2.1 Bulk density

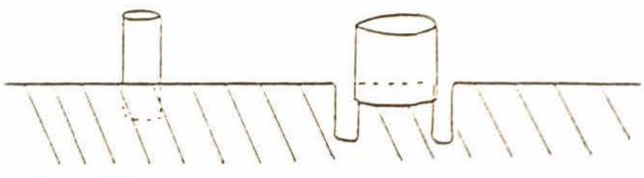
Ringsamples (± 100 cm^3) were taken for bulk density determinations. No problems were encountered by sampling the (exposed) subsoil, however the sandy topsoil could not be sampled properly. Sampling was impossible in case of very porous topsoils with roots (for example the "spongy" structure of the vegetation isles).

5.2.2 Infiltration simulation

In four different situations (bare soil, soil with only annual grasses, soil with also some perennials and soil under shrubs), infiltration has been measured. Close to the stem of trees this was not possible (too many roots and cracks).
Infiltration capacity has been measured by determining the speed at which water infiltrates into the soil. Metal rings with a diameter of 11 cm were slashed into the soil and plastic rings with a diameter of 21 cm were cut into the soil (see figure 14). In case of the plastic rings both the rings and the remaining soil body were treated with grease to prevent water leakage. In the ring a minimum layer of one cm water was kept (indicated by a pebble on the soil surface) and amounts of 0.1 - 1 liter were added (respectively bare soil and soil under shrubs).

In order to get a more detailed idea about the initial infiltration capacity of the soil (what happens with the first intensive rain showers?) the initial amounts were less than later on. When the water reached the limit of 1 cm, new water was poured in the ring and both time and amount of added water were recorded. The measurements were continued till the steady state was reached (infiltration remains constant). The measurements with the small rings were carried out in the dry season, the ones with the wide rings in the middle of the rainy season.

FIGURE 14: METHODS OF INSTALLING INFILTRATION RINGS



5.2.3 Rainfall infiltration by moisture determinations

By measuring the difference in moisture content (on weight basis) before and after a rain shower, the amount of infiltrated rain water on that particular soil - vegetation place can be determined. After correcting these data from weight basis to volume basis (by means of the bulk density), they can be compared with the amount of rainfall, measured by the raingauge (if necessary corrected for interception by vegetation). This finally allows the calculation of the real percentage of infiltrated rain water of the sampled soil - vegetation entity over that particular rainshower.

Immediately after each shower samples were taken, stored in plastic bags which were sealed. They were dried (24 hrs at 110 °C) a few days later.

Before the onset of the rains and after each shower, augerings were made in transect 1 and 2 in all five vegetation situations. Samples were taken at various depths, see table 4.

TABLE 4: DEPTH OF AUGERING SAMPLES

A	0 - 1 cm	F	30 - 40 cm
B	1 - 5 cm	G	40 - 50 cm
C	5 - 10 cm		
D	10 - 20 cm	and in case of deep infiltration:	
E	20 - 30 cm	H	50 - 60 cm
		I	60 - 70 cm

However the majority of the data have been collected in the following way. In the five vegetation situations in all three transects, the depth of the moisture front was measured (by augering). This front is easily detectable shortly after the shower. A mixed sample of the moist soil was taken and after determining the moisture content, the total amount of moisture could be calculated.

6 RESULTS

6.1 RAINFALL

6.1.1 Rainfall in october 1985

The rainfall distribution and intensities in october 1985 as measured by the automatic rain gauge near the transects are presented in figure 15 and table 5 respectively. All moisture determinations were carried out during that period.

FIGURE 15: RAINFALL DISTRIBUTION IN OCTOBER '85 ON THE STUDY SITES

Indicated are the amounts of rainfall per day or part of day, Dates of moisture determinations are indicated by an arrow

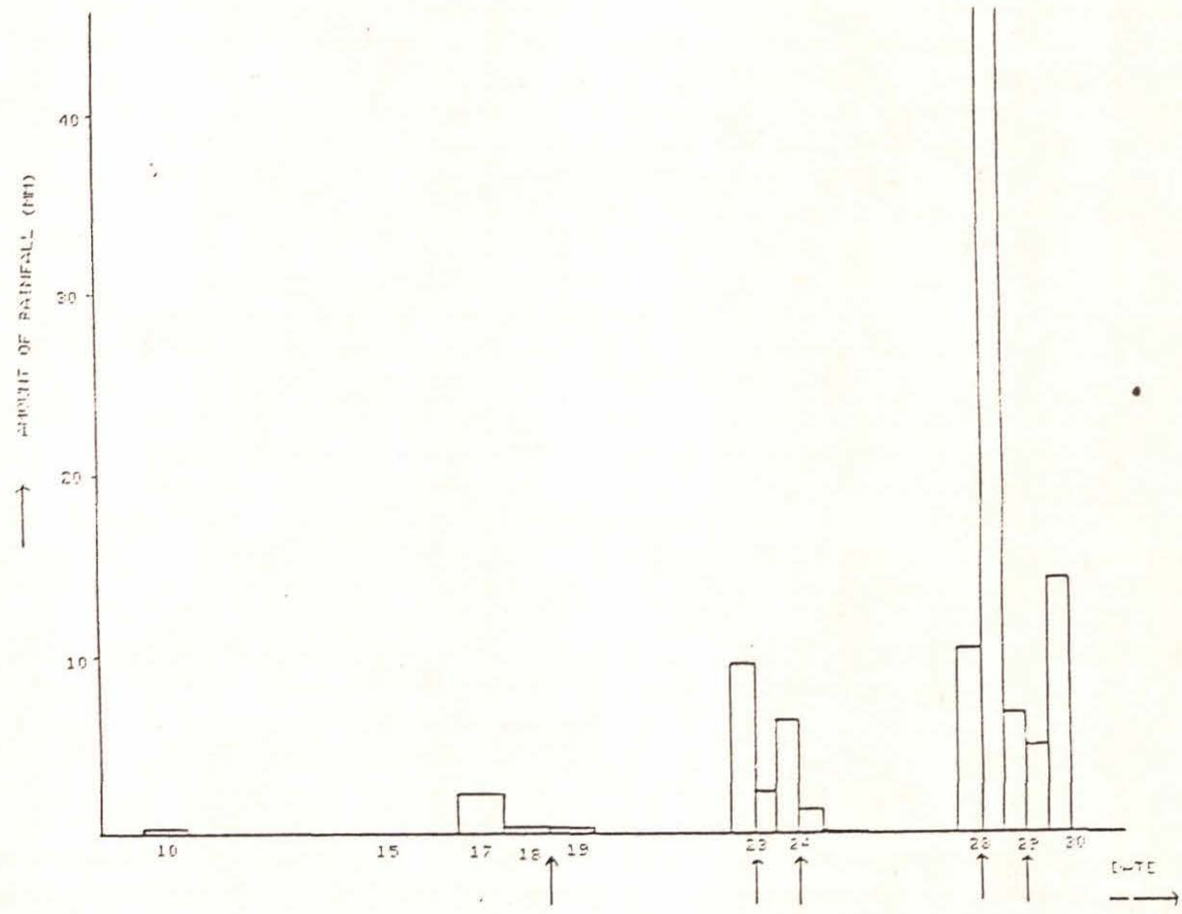


TABLE 5: RAINFALL INTENSITIES OF SHOWERS IN OCTOBER '85 (mm/hr)

DATE (TIME)	AVERAGE WHOLE SHOWER	AVERAGE 1/2 HOUR	MAX. VALUE
23 - 10 (2-3 hr)	10	12	30
24 - 10			
(1 hr)	11	11	33
(4 hr)	17	-	33
28 - 10 (15-16 hr)	57	60	91
29 - 10 (2-4 hr)	15	-	50

6.1.2 Rainfall interception by vegetation

Table 6 shows the amount of rainfall measured under a tree and shrub, given as percentage of the amount measured in an open area (automatic raingauge).

TABLE 6: MEASURED AMOUNT OF RAINFALL UNDER A TREE AND SHRUB as percentage of automatic raingauge data (open area).

DATE	23-10	24-10	28-10	28-10	29-10
TOTAL RAINFALL (mm)	9.3	6.4	10.2	45.8	6.6
AVERAGE INTENSITY (mm/hr)	10	15	18	57	15
TREE, cover 20% (%)	60	99	62	90	58
SHRUB, cover 70% (%)	40	51	50	93	63

From table 6 it becomes clear that the percentage of intercepted rainfall (100% - measured amount of table 2), is strongly correlated with the intensity of the shower. Under a dense shrub much rain will be intercepted when the rainfall intensity is low (< 10 mm/hr.). This amount of interception decreases till nearly zero in case of high rainfall intensities (>50 mm/hr.). The results under a tree are intermediate and strongly depend on the position under the tree.

The moisture measurements have not been corrected for the amount of rainwater interception by vegetation. The number of data is not high enough to correct the rainfall data under all different types of vegetations.

6.2 SOIL DATA

6.2.1 Bulk density

Table 7 shows the results of the bulk density determinations, necessary for the calculation of moisture on weight basis to moisture on volume basis. The data have been divided in three classes of topsoils (differing significantly) and one subsoil class (differing significantly only with the porous topsoil.

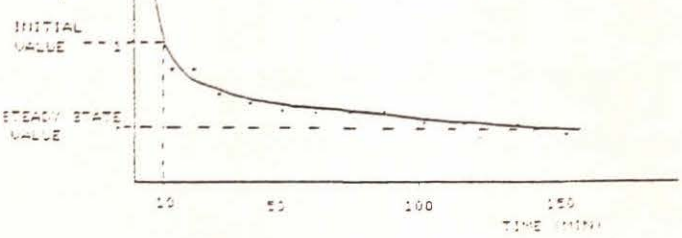
TABLE 7: BULK DENSITY DATA OF SEVERAL LAYERS OF SOIL PROFILES IN THE TRANSECTS

LAYER	CHARACTER	SITUATION	BULK DENSITY	STANDARD DEVIATION
0-5 cm.	porous, loamy sand	Shrub	1.28	0.04
0-10 cm.	compact topsoil	Bare soil	1.69	0.03
0-50 cm.	other topsoils	All other	1.49	0.07
>50 cm.	subsoils	All	1.59	0.07

6.2.2 Infiltration simulation

The results of the 22 infiltration simulation measurements have been reproduced graphically. See figure 16 for an example of a measurement carried out with a wide ring on a soil with perennial vegetation. Comparing the various graphs, two dimensions are important: the final steady state value (comparable to the hydraulic conductivity of a saturated soil), usually reached after 4 hours and the initial infiltration capacity (suction of the topsoil). The latter is especially important but difficult to measure. After interpolating the value at 10 minutes after the start of the experiment was taken for the initial infiltration value.

FIGURE 16: EXAMPLE OF INFILTRATION SIMULATION GRAPH, indicating the initial- and steady state value



In table 8 and 9 the initial and steady state infiltration values are given, determined with the slashed small and cut wide rings respectively.

TABLE 8: INFILTRATION SIMULATION RESULTS, SLASHED SMALL RINGS
upper value is the initial value,
the lower the steady state value

SITUATION	INFILTRATION (mm/min)				AVERAGE (mm/hr)
BARE SOIL	1.0	1.0	1.4	3.0	96
	0.2	0.2	0.7#	0.8#	12
ANNUAL	7	8	8		462
	2.5	1.5	3		138
PERENNIAL	8	6	13	8	525
	3	2.5	6	3.5	225
SHRUB	5.5	5.5			330
	1.5	2			105

: no steady state value, given value reached after 4 hours

TABLE 9 : INFILTRATION SIMULATION RESULTS, CUT WIDE RINGS
upper value is the initial value,
the lower the steady state value

SITUATION	INFILTRATION (mm/min)			AVERAGE (mm/hr)	(ST. DEV.)
BARE SOIL	0.5	0.6		33	(4)
	0.2	0.4		18	(9)
ANNUAL	2.0	1.2			
	0.5	0.4			
				84	(32)
PERENNIAL	1.0	?		26	(3)
	0.4	0.4			
SHRUB	8.5	15	13.5	740	(204)
	6.5	10	9.5#	520	(114)

#: No steady state value, given value reached after 4 hour

The major difference between the values obtained by both methods is the much higher infiltration capacity measured by the slashed ring method. This can be explained by the disturbance caused by this method (especially of importance in case of the bare soil and shrub situation). Therefore they can only be used qualitatively.

The results obtained by the wide ring method are much more reliable. They show the low infiltration capacity of the bare soil, also quantitatively. The initial, but especially the steady state value (saturated topsoil) is much lower than the average rainfall intensity of a heavy shower. In case of the annual and perennial grasslands the initial value (unsaturated topsoil) is comparable to the rainfall intensity. The steady state values are much lower!
Soils under shrubs have such a high infiltration capacity that there is never any risk of run-off. Also striking is the relative high steady state value which is nearly equal to the initial infiltration value.

6.2.3 Rainfall infiltration measurements
Five times soil moisture samples were collected after the showers. In figure 15 the exact dates are indicated. Table 10 shows the amount of rainfall of the specific showers, compared to the cumulative rainfall data.

TABLE 10 : SIZE OF SHOWER COMPARED TO AMOUNT OF RAINFALL ALREADY FALLEN

DATE	INDIVIDUAL SHOWER (mm)	CUMULATIVE RAINFALL previous to shower (mm)
19 oct.	0.4	2.1
23 oct.	9.3	5.5
24 oct.	6.4	14.8
28 oct.	10.3	21.6
29 oct.	52.7	31.9

The showers of 23 and 28-29 october are very suitable for the analysis of the specific influences of those showers. This is caused by the high shower size compared with the amount fallen and so a low disturbance by the previous rains. In this way evaporation can be neglected.

In figures 17 to 21 the results are shown of the augerings made at the various places. Moisture percentages are expressed on volume base. The graphs are based on a very limited number of observations (one augering per site) and are only given as an illustration of the soil moisture change during the first rains under different vegetation types.

Figure 17 shows the situation before the onset of the rains. The behaviour of the soil under perennial grassland differs slightly from the rest. Near trees the subsoil has a slightly higher moisture content than the others.

Figure 18 shows the infiltrated volume of water during the 23-october rainshower (9.3 mm, 10 mm/hr). The bare soil situation shows a remarkable high moisture percentage. The situation of soils under annual and perennial grassland is comparable. The amount of rainwater found in the vicinity of the trees is remarkable high. This is a clear example of steered drip, which is easily infiltrated in these soils with (still) some cracks near the stem (very characteristic of soils near larger trees). The high amount of infiltrated rainwater in the annual grassland can be completely attributed to run-on (run-off of the bare soil).

Figure 19 shows the infiltrated volume of rain water during the shower of 28 october (52.7mm, 57mm/hr). Again only the upper 3 cm of the bare soil site are moistened. Striking in this figure is the high amount of run-on found on the annual grassland. Steered drip in case of trees is no longer found (cracks have been closed).

Figure 20 shows the absolute moisture content of the soil after 84.2 mm of precipitation. Here it is the low percentage infiltrated rainwater on the bare soil sites which is striking. In all other situations the pattern is more or similar, with much run-on in case of the soil under annual grassland.

In figure 21 soil moisture determinations of five other soils, carried out at the same moment as the ones in figure 20, are shown. The same pattern can be seen as in case of the grasslands and shrub situation in figure 20. Only soil nr 1, located at the former kraal (dense perennial grassland and very rich in organic matter) has a much higher moisture content in the topsoil.

FIGURE 17: MOISTURE CONTENT OF SOILS BEFORE THE ONSET OF THE RAINS
(legend see next page)

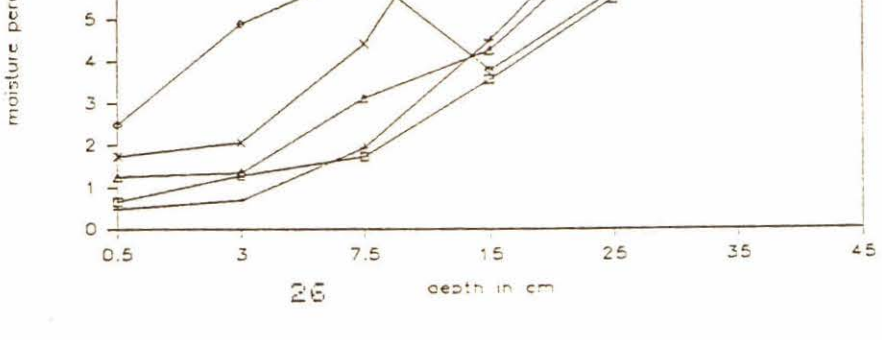
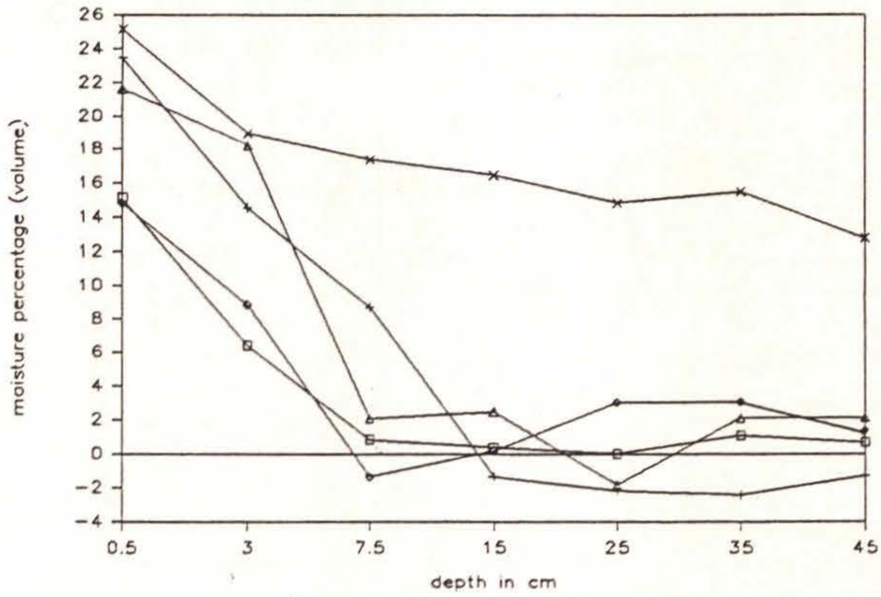


FIGURE 18: INCREASE IN SOIL MOISTURE CAUSED BY SHOWER OF 9.3 MM (10mm/hr)



LEGEND: □ sealed soil
+ soil under annual grassland
◇ soil under perennial grassland
△ soil under shrub
× soil under tree

FIGURE 19: INCREASE IN SOIL MOISTURE CAUSED BY SHOWER OF 52.7 MM (57mm/hr)

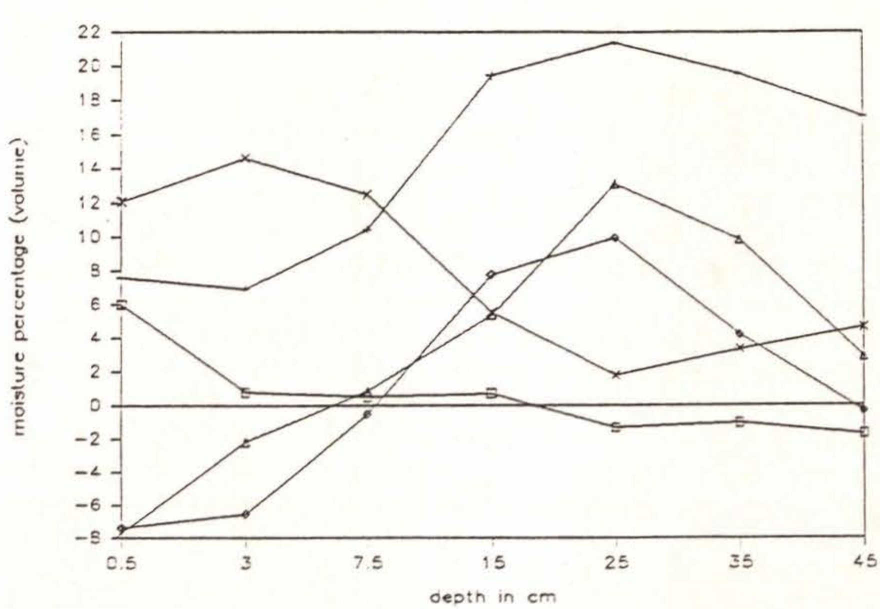
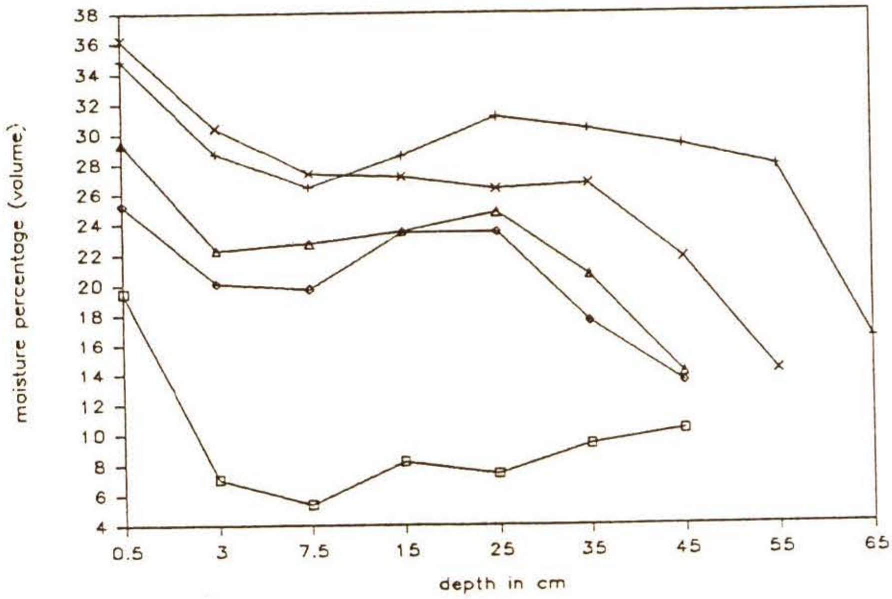
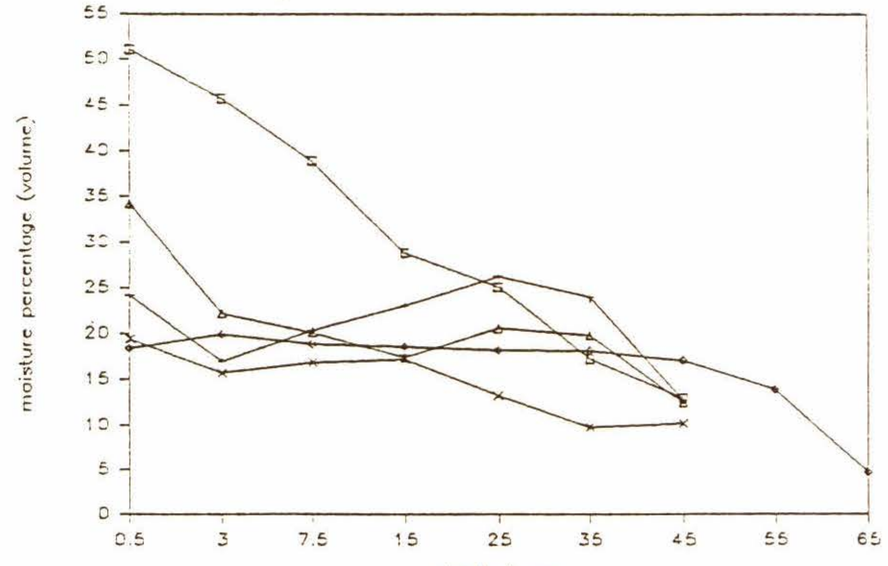


FIGURE 20 : MOISTURE CONTENT OF SOILS AFTER 84.2 MM RAIN



LEGEND:
□ sealed soil
+ soil under annual grassland
◇ soil under perennial grassland
△ soil under shrub
× soil under tree

FIGURE 21: MOISTURE CONTENT OF FIVE OTHER SOILS AFTER 84.2 MM RAIN



LEGEND:
□ soil under former kraal
+ soil under Digitaria perennial grassland
◇ soil under perennial grassland (compare transects)
△ soil under Acacia-Commiphora thicket
× soil under annual grassland

The majority of the data has been calculated as absolute moisture percentage per shower. By subtracting the data of the successive days and dividing it by the amount of rainfall, a percentage of infiltration is found (100 % when all rainfall has been infiltrated). See table 11 and table 12 for the results obtained in transects 1+2 and 3 respectively. The data of the vegetation isles are shown in table 13.

TABLE 11: PERCENTAGE INFILTRATED RAINWATER ON FOUR SITES IN TRANSECT 1+2

DATE	INTENSITY	BARE SOIL	BARE SOIL #	ANNUAL	PERENNIAL
23-OCT.	10 mm/hr	28-17%		100-63%	140-99%
24-OCT.	15 mm/hr	13%		172%	18%
29-OCT.	57 mm/hr	3%	63%	55%	286%

#: Bare soil but with influence of lateral water transport (e.g. near gully)

TABLE 12: PERCENTAGE INFILTRATED RAINWATER ON FOUR SITES IN TRANSECT 3

DATE	INTENSITY	BARE SOIL	ANNUAL	PERENNIAL	SHRUB
23 OCT.	10 mm/hr	57-36%	133-87%	130-81%	50-32%
24 OCT.	15 mm/hr	36%	86%	148%	321%
29 OCT.	57 mm/hr	19%	52%	29%	108%

TABLE 13: PERCENTAGE INFILTRATED RAINWATER IN FOUR VEGETATION ISLES

DATE	INTENSITY	VEG.ISLE 1	VEG.ISLE 2	VEG.ISLE 3	ENDOSTEMON*
24-10	15 mm/hr	72%		34%	64%
29-10	57 mm/hr	98%	111%	84%	22%

*: heavily eroded vegetation isle

Bare soil: the results indicate that with intensive showers less than 20% of the rainwater can infiltrate. In several cases only 5% infiltrates. Infiltration increases to 50% with rainfall intensities of less than 10 mm/hr. Locally run-off water collects in small gullies. From there lateral transport of water takes place, including places with surface sealing. So one may find moisture which did not infiltrate through the topsoil.

Soil under Annual Grassland: With low intensity showers much run-on water, up to twice the amount of fallen rain, has been infiltrated. In case of the more intensive showers this amount drops (velocity of run-off too high?) and only half of the fallen amount of rain is found back in the soil.

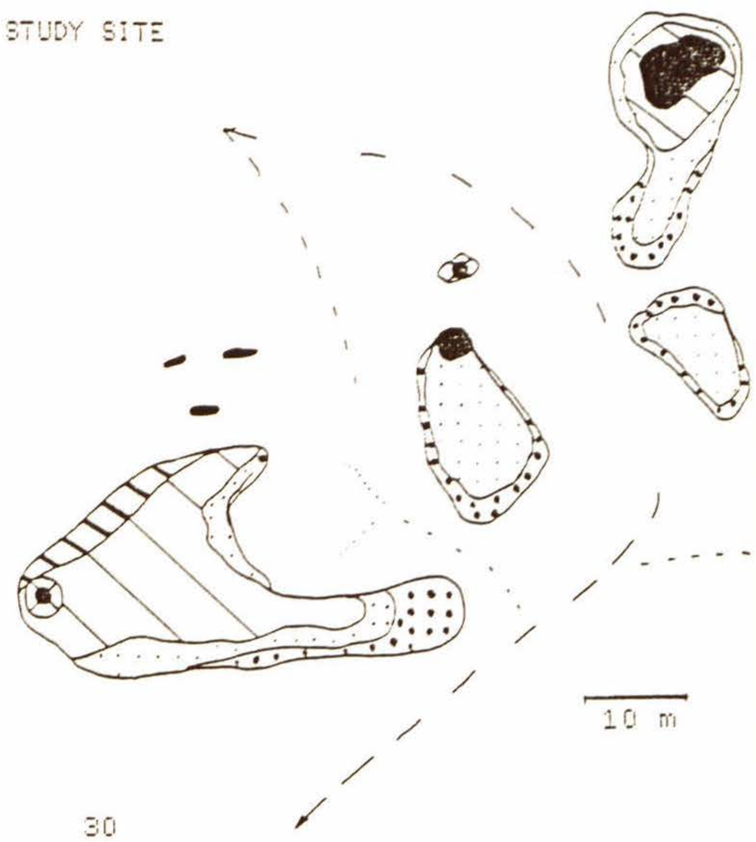
Soil under Perennial Grassland: Much higher differences were found between the data of the various perennial grasslands than those of the other vegetation types. In general the same can be said as for the annual grassland, except the lower amount of run-on.

Soil under Shrubs: The most reliable data, from the shower of 28-10, show an amount of infiltration which is the same as the amount fallen. Locally run-on can occur, but not too such an extent as in case of the grasslands.

Soil in Vegetation Isles: The situation is comparable to that of the soil under shrubs, with a complete infiltration in case of the intensive showers. The Endostemon vegetation isle is heavily eroded and behaves like annual grassland.

FIGURE 22: WATER BALANCE OF THE STUDY SITE

Infilt. (%)	Situation
<20	Bare soil
30	Annual Grassland
>100	Annual Grassland with run on
50	Perennial Grassland
>100	Pernnial Grassland with run on
100	Shrub
>100	Tree, stem
50-100	Tree, rest



In figure 22 a schematic picture is given of the actual infiltration in and around the studied sites. More than half of the fallen amount of rain runs off. A major part is redistributed in the area itself. One third of the rainfall flows out of the area and either flows to the rivers or infiltrates somewhere else.

6.3 MANAGEMENT

6.3.1 Mechanical management combined with reseeding

Disturbance of sealed soils enables rainwater to infiltrate. This principle was already clear on some spots where small pits in the bare sealed soil were dug. Shortly after the onset of the rains annual grasses (especially Tragus berteronianus) germinated and formed the only vegetation on these places.

In september '84 EMI ploughed (with a discplough) a few hectares of sealed soil in furrows of ± 30 cm deep (see figure 23). Eragrostis superba and Cenchrus ciliaris (perennial grasses) were seeded shortly afterwards. They developed well and yielded 8 ton per ha a year later (personal communication Ian Skea, EMI).

FIGURE 22: METHOD OF PLOUGHING SEALED SOILS

Two years later the grass stand has developed even further and a green mat of vegetation covers the area. However hardly any disturbance of the still sealed area between the furrows can be observed. Only in the immediate surroundings of the clumps of grass a loose soil surface is present with some biological activity. In these clumps some darkening of the topsoil can be observed. The present situation is that rainwater runs off the sealed parts and infiltrates where the grass grows.

Just before the onset of the rains in october 1985 a small track of land has been ploughed (by EMI near the road Marimanti-Gatunga) in the same way as described before. The instability of these soils was clearly visible after the shower of 28 october (57 mm/hr). All furrows had been silted up and clear rills had formed. But water had infiltrated (conserved) and planted shrubs and grasses could develop. The area between the furrows remained bare due to sealing which has developed again (after being partly broken by the plough), through the heavy impact of the shower.

6.3.2 Biological management

On several places in the area spots with a dense grass vegetation occur. They are usually correlated with a large amount of dead plant material (often a fallen tree). Striking is the high biological activity. Sheetings cover the wood and the ground surface is very rough due to fallen sheetings and decayed plant material. Based on these observations some trials with mulch as way to rehabilitate the sealed areas were started.

See figure 24 a-e for pictures of the mulch trial.
In august 1985, two months before the onset of the rains, the trials were started. On three spots the surface (± 8x3 m) was covered by tall grasses like Eragrostis superba . On top shrubby herbs (Ocimum basilicum and Barleria acanthoides) and branches of Acacia senegal and Commiphora africana (recently cut) were laid (see fig. 24a).

No changes have been observed during the first two months of the mulch trials (see fig. 24b). However the first shower (only one millimeter) activated termites which came to forage the grass stalks. Within a few days a quarter of the stalks had been covered with sheetings. Odontotermes sp., a well known litter feeder of which a few were catched, was the responsible species (see fig. 24e).

Later in the rainy season termites were still active. About two weeks after the first intensive rains, plants started to germinate on several spots where the termites had been active. This occured much later than in the surroundings, where especially Tragus berteronianus (annual grass) germinated already within a few days after the first large shower (23 october).

The plants developped well and were still green when the surrounding vegetation (mostly annual grasses) was dead already (see fig. 24 c,d).

In table 2 plant species and their life-strategies (3th column), plants are indicated which have been found in the mulch trials in the beginning of the dry season (january '86). Dominating are the slowly germinating grasses and herbs and some shrubby herbs (especially Barleria acanthoides). Only the latter was also present in the mulch material.

No measurements have been carried out to investigate the change in soil characteristics, but they were not significant in the topsoil as a whole. Only the very upper layer (first cm) has changed significantly. There a slightly looser structure and vertical pores have developed. The surface roughness increased considerably (sheetings) (see fig. 24e).

DISCUSSION

7.1 SEALING PROCESSES

All the observed Chromic Luvisols have a very good porous structure in the subsoil, which is sufficient for a rapid permeability of the rainwater. The problem is located in the upper 0 - 15 cm, where the pores are easily clogged by dispersed clay. This instability of the clay can be explained by the high pH (> 6.5) of these soils, and therefore of the distance to the zero point of net charge, causing a decrease in aggregate stability (Legger, 1987).
Especially the violent impact during the first intensive showers and the first wetting cause the dispersion of the clay. It either flows laterally with the run-off water (and causes the red-brown colour of all rivers) or it is illuviated in the soil where it cloggs the pores.

This process of clay dispersion and illuviation can only be observed in those places where the dark red, humous rich, sandy loam topsoil has disappeared and the red sandy clay subsoil is exposed. Obviously the humous containing topsoil prevents sealing. This can be attributed to the stabilising influence of organic matter. This stabilisation factor enables the soil to maintain a very porous structure which, in contrast to the exposed subsoil, is very stable. However it is expected that without the protection of litter and vegetation this topsoil will disappear very rapidly.

This process of sealing dominates in the cultivated land. However in protected areas (Meru NP) also different sealing processes have been observed. Most common is the one associated with termite mounds. Termites build their mounds with subsoil material (Lee and Wood, 1971). This material easily seals when exposed to the impact of rain. In subsequent years run-off water erodes material from the mound. This material covers part of the surroundings where it forms a sealed bare area. After several years the mound itself is completely eroded and only the bare area remains, often slightly elevated above the surroundings. A colonising process, lasting several decades, with a same sequence of vegetation as has been described in 3.3.2, closes the circle.

Comparable phenomena are described by Burtt (1942) and Glover (1964), both quoted in Lee and Wood (1971). Burtt noted that thickets which are confined to areas of soil washed from mounds are composed of species normally found on hardpans. Glover found that the miniature hardpans at the base of mounds were almost bare (Zambia), whereas in Shinyanga (Tanzania) characteristic hardpan plants occured around the base of mounds in Commiphora-Acacia scrub (Lee and Wood, 1971)

Note: No information exists about the possibility of an accumulation of salts in these termite mounds (which is known from other areas), which can also explain these observations.

An other theory explains the sealed surfaces in Meru NP where the soil was only 20 cm deep. Valentin (1985) describes a similar situation in Senegal on places with a very low grazing pressure. " A shallow soil with a subsequent low soil moisture storage capacity causes the collapse of plant communities in dry years. This results, in combination with the meager amount of organic matter, to locally sealing. During normally wet periods these crusted and barren areas are gradually recolonized". The question remains what amount of water can be stored in the rotten biotite gneiss rocks. Observations in the rainy season indicate that this amount is certainly not negligible.

7.2 SOIL AND VEGETATION DYNAMICS

In the past the majority of the semi-arid Basement System Uplands were covered by a vegetation and soil which still can be found in Meru NP (see chapter 4). Only the Mountains and Riverterraces had a different vegetation type (see v.Oostveen & Scholte, 1986). In this more or less natural situation, vegetation and soil conditions were not stable. Most of the expected dynamics can be contributed to the next three causes:

Irregular rainfall distribution. In Tsavo the dominating perennial grasslayer is quite stable and only slightly affected by short term (< 2 yr) variation in rainfall (van Wijngaarden 1985). There is no reason to believe that in the wetter parts of Eastern Kenya with similar geology and plant species the even smaller variability in rainfall will cause more variation in vegetation.

Grazing of natural animal populations. In combination with grazing it is much more likely that changes will occur. A consumption of more than 45 % of the biomass leads to a decrease in the cover of perennials with after some time even a risk of loss of perennials and sealing of the soil surface (van Wijngaarden 1985). This is often accompanied by an increase of tree and shrub vegetation.

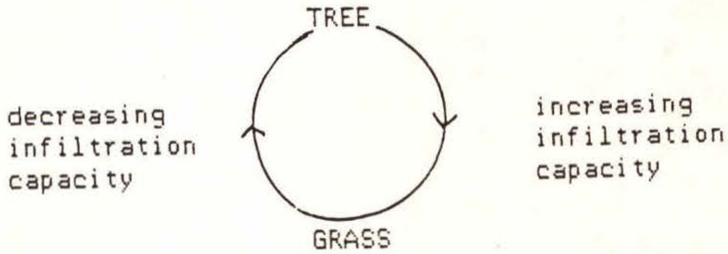
Fire, has a large influence especially on the tree vegetation. The amount of groundvegetation should be large enough to form a combustable layer. A tree- shrub layer of 50% aerial cover is probably the maximum under which this is possible.

This all shows the competition for moisture between trees, shrubs, perennial- and annual grasses and herbs. Generally the depth of the moistened soil is less than 70 cm (this study) and is available for both trees, shrubs and perennial grasses. Only locally, where water is stored deeper e.g. near dry rivers, some trees (especially Acacia tortilis) can obtain water unreachable for others.

This continuous competition can be expressed as shown in figure 25. Each decrease in cover of grasses or woody plants will result in the stimulation of the other and cause a shift in the circle.

Not only the vegetation changes but also the soil. As has been shown the infiltration capacity increases under a dominating (perennial) grass layer. Characteristic is however that all changes are reversible!

FIGURE 25: TREE-GRASS RELATION IN A NATURAL SITUATION



In the East Africa ecosystem the equilibrium Tree - Grass is largely determined by the elephant density (van Wijngaarden, 1985). By the destructing activity of elephants, trees no longer dominate the vegetation at elephant densities of more than 0.5 per km^2.

The described equilibrium between grasses and trees has been disturbed. The dominating fallow vegetation in the cultivated land is either a dense thicket or bare land with only a few annuals. Assumpted that the Meru NP situation represents the former situation of the cultivated land, two theories can be formulated which explain this shift in vegetation and soil.

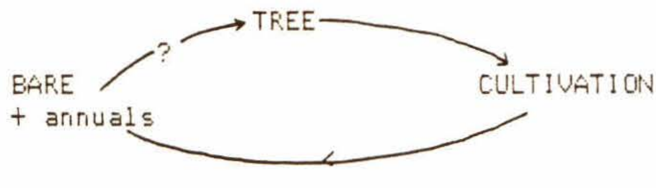
Overgrazing by cattle and goats: A continuous high exploitation of the perennial grasses, especially in the dry season causes a decrease in the grass layer. Usually this would lead to an increase in the amount of trees and shrubs (see circle). But if the grazing pressure (especially of goats) is high, regeneration does not occur anymore and bare land remains. Is that grazing pressure (browse pressure) lower but high enough to keep pressure on the grass layer, regeneration of trees and shrubs takes place and dense thickets are formed.

Combination of agriculture and grazing by cattle and goats: Clearing of the vegetation with subsequent years of cultivation, exposes the humous rich topsoil to the impact of rain and intensive sunshine. Perhaps one bush-fallow circle is already enough for a complete loss of the topsoil if, because of a high grazing pressure in the fallow period, not a complete recovery is reached. The resulting exposed subsoil is easily sealed as has been shown in previous examples. This sealing causes much run-off, locally trees and shrubs can utilize it. Perennial grasses can not develop because of their shallow root system. In case of a high grazing pressure, especially of goats, no regeneration of trees and shrubs takes place at all.

The latter theory is the most likely one, although there used to be pastoralists in the area, their number was too small to cause such a degradation. It is more likely that the much larger numbers of cultivators started this landdegradation. As shown for the natural Meru NP ecosystem not much pressure is needed for a removal of the fertile topsoil.

The system can no longer be depicted by a circle as it was in the past, but by an ellips, see figure 26.

FIGURE 26: TREE - GRASS - BARE LAND RELATION IN CULTIVATED LAND



Is the system still closed or is it open, with other words are the processes still reversible? Interesting is a report written in 1938 (!) by Maher, a soil conservation officer, who made a four week field study of Embu district. He writes about the semi-arid Basement System Uplands:

"Bare granitic rocks and scanty sands in semi-arid country situated at low altitudes reflect back a pitiless sun. Stunted animals and poverty-stricken inhabitants seek sustenance in a barren semi-desert where all hope of progress is futile and where famine is ever waiting at the door - the most promising method of dealing with these people appears to be to move them, lock, stock and barrel, leaving their present land to regenerate to bush and to become once again the haunt of the elephant, the rhinoceros and the buffalo-abandonment of the land to the slow but sure healing of Nature is the only practicable remedy." (Maher, 1938, quoted by Brokensha and Riley, 1980)

Nowadays, nearly fifty years later, the situation seems to be much the same! Although such a quotion is no proof it does indicate that a new equilibrium has been formed. The sealing of large tracks of land causes much run-off water which runs-on locally. There trees and shrubs can utilise this water and reach much higher productions than in case of an evenly distributed rainfall. Such systems might be quite stable. Condition is however that sealed land can regenerate (speed is probably less important).

In the cultivated land, dynamics in vegetation and soil are either caused by an irregular rainfall or by changes in the bush-fallow cultivation and grazing practise. In contrast to the past, irregularities in rainfall are now extremely important. Due to the entire dependancy of annual crops, one bad rainy season which would have had hardly any influence in the past, can now be catastophal for man.

Differences caused by a change in bush-fallow cultivation practise are especially correlated with the shorter fallow period which nowadays is being practised. One such a difference is a decrease in time in which cleared bush remains on the land. In the past people cut the shrubs and trees and let them on the land for half a year or more. Nowadays the bush is cleared three months before the expected onset of the rains and burned just before the onset of the rains. The results of the mulch trials show that this change in landuse means a decrease in infiltration capacity of the soils (termites hardly forage fresh material at the end of the dry season). This also means a decrease in organic matter content of the soils. (See also 7.5.2)

7.3 INFILTRATION CAPACITY IN RELATION WITH VEGETATION AND SITE

All data clearly indicate the correlation of infiltration capacity with the vegetation cover and biomass on that particular spot. A factor 20 difference exists in infiltration measured on sealed soil and soil under shrubs (wide ring method). Kelly (1973) found on sandy loam soils on bare sealed and littered areas, infiltration rates differences in the order of 1:9 (measured with double ring method). Values from Tsavo indicate comparable infiltration rates as we found, from 20 mm/hr for bare areas till 140 mm/hr for totally covered grounds (van Wijngaarden, 1985).

The steady state infiltration rates as measured with the rings are classified (Weg, 1978) as moderately slow (bare soil) to very rapid (shrub situation). A classification based on the initial infiltration rate would put the bare soil situation in a lower class which describes better what is going on during the rains.

What is the relationship between biomass and the infiltration capacity of the soil? Is it a high infiltration capacity which causes a high biomass or causes the high biomass the high infiltration capacity? The results of the mulch trials show that the latter statement is (at least sometimes) valid. An input of organic matter causes a high termite activity which is, together with the other mulch advantages (see 7.5.2), responsible for a higher infiltration capacity. This higher infiltration capacity is at it's turn responsible for a higher biomass production, the circle is closed again.

The moisture measurements show that not only the condition of the soil determines the total amount of infiltrated rainwater. The position in the landscape determines if and to what extend run-off water runs on and can supply an additional source of moisture. To what extend run-on water can infiltrate depends partly also on the roughness of the surface. Also the various sealed bare areas, which already have great variation in infiltration capacity (dependant on the degree of clogging) can receive an additional supply of moisture, for instance laterally out of rills.

7.4 CONSEQUENCES OF SEALING

The strong sealing of ± 15% of the land and the sealing at a lower degree of the remaining land, means a severe loss of land. The high population pressure results in a shortening of the fallow periods which on the contrary should be lengthened because of the effects of sealing. A part of the strongly sealed land will be difficult to restore. Especially where in the past homesteads were situated severe gully erosion has taken place.

On the majority of the sealed soils sheet erosion dominates. This is not experienced as a major problem for landuse because the soils are quite deep. However in the future problems can be expected. In downstream areas problems already occur, especially the water reservoirs have a high risk of being silted up. The great majority of the sediment load of the Tana river comes from these unstable Basement System soils.

Another problem, more directly felt by people, is encountered on the cultivated land. During one or two years of cultivation with it's high offtake (harvest and to a lesser degree grazing) land remains bare and easily seals during the rains.
Usually no tillage is practised and seeds are planted one week before the expected onset of the rains. If the soil is heavily sealed, land preparation is necessary and people have to choose between leaving the land or to plough it. Ploughing however has the disadvantage that it is only possible after the surface soil is wetted. This means that the seeds can germinate only after an important part of the rains has already fallen. In already marginal land for cultivation this often means the complete failure of the harvest.

7.5 REGENERATION OF BARE AREAS

7.5.1 Mechanical methods combined with reseeding

Mechanical methods give satisfying results. For this area this has been shown by the experiments carried out by EMI. Elsewhere in Kenya (especially Baringo with comparable circumstances) much experience has been gained (see Bogdan & Pratt 1967). The results show however, that succes depends fully on the presence of a proper management once the land has been rehabilitated. The failure of numerous reseeding programmes show that this requirement is usually not met.

One has to realise that chosing for a mechanical rehabilitation of these denuded areas means a choice for rangeland as main landuse. Although ecologically perhaps preferable, the high population pressure (± 50/km^2) makes abandoning of agriculture not realistic.

7.5.2 Biological methods

Protecting the area as has been tried in Marimanti, revealed a very slow regeneration of the bare areas. A regeneration time of at least ten years with complete protection is necessary. This means an unrealistic long withdrawal of badly needed land and a nearly impossible task to motivate people to keep their animals out of the protected area.

Covering the land with mulch shows clearly the possibilities of this locally available material. A combination of several factors contribute to this succes:

- 1 Improvement of micro-climate
- 2 Stimulation of biological activity
- 3 Increase of surface roughness
- 4 Interception of seeds

ad 1: Both evaporation and soil temperature decrease under influence of the mulch cover.

ad 2: Organic matter stimulates termites (Odontotermes sp.) to forage in these places. This results in an increase of the porosity in the upper few centimeters and in an increased surface roughness caused by the sheetings.

ad 3: Surface roughness is further increased by the litter material itself and intercepted material (most often sand). As a result the infiltration rate increases. An other result is an increasing amount of run-on water that can be intercepted.

ad 4: On bare soil seeds are either blown or flown away. Now these seeds are intercepted.

Covering the land with mulch is sometimes mentioned as a way of speeding up regeneration (Bogdan & Pratt 1967). Cisse (1982) describes mulch trials which have been carried out with wood on denuded loam soils in Mali. The obtained succes (a productivity of 300, 1500 and 3000 kg/ha after respectively 1, 2 and 3 years) is explained by the accumulation of sand on the contact points of soil and wood. This increased the surface roughness and so the interception of run-on water. Termites were at least in the first years not active. Not very surprising because most trees are very resistent against termite attacks. In the first months of our trials only the grass stalks and parts of the shrubby herbs had been attacked by termites. Elsewhere in the area observations showed that cut Commiphora africana trees were attacked by termites very soon (a few weeks after cutting if the other conditions are suitable). However trees like Acacia senegal are very resistent and not attacked within a year.

The coverage of all bare, sealed areas with litter would mean a destruction of other areas for a rehabilitation of the worst parts.

However the results of this study indicate the importance of groundcover and input of organic material on these soils. No solutions for a regeneration of the bare sealed areas will be given here. Only a few ideas which give a frame for possible solutions. They have to be intensively examinated in the area itself, both ecological as socio-economical. Essential is that they form part of the existing bush-fallow farming system which has to change but can not be abandoned.

Going back to the past and keeping the cleared bush longer on the land, at least one rainy season. First question that has to be answered is why the people left this practise. They will have had a good reason for it (increased landpressure, problems with a not complete burning of the material etc.)

Putting cleared bush on a neighbouring plot which will not be cultivated immediately. This has the advantage of a complete recycling of the organic material. Disadvantages are loss of fertility when starting with cultivation (no input of ash) and problems with animals who can hide near the plots (especially weaver birds).

After abandoning the land of cultivation (and perhaps also after harvest) a no grazing period should be installed till the land is covered again by vegetation and a main part of the shrubs has grown out of reach of goats (two years?). The thornbush fences maintained during cultivation can be used for this.
It is however clear that without an alternative for these grazing lands (which are important in crucial periods, see Scholte, 1986) such a practise is not realistic. An alternative might be the creation of small grazing reserves only to be used during that particular time.

More emphasis on perennial crops in the farming system. A perennial cover prevents sealing during the rainy season and keeps the land more intact. But all major foodcrops are annual plants and no alternative ones are available.

With extra inputs like fertilisers, possibilities exist to create a more permanent agriculture which can permit putting a part of the annual biomass production in maintenance of the soil structure. However doubts exist about the economical and practical possiblities for this.

8 CONCLUSIONS/SUMMARY

All observations show the extreme susceptibility of the chromic Luvisols ("red" soils) of the wetter semi-arid parts in Eastern Kenya to surface sealing. The result is a decrease in infiltration capacity to such an extent that locally only 5 percent of the rain water can infiltrate. Although the climate is suitable for cultivation this becomes impossible on these sealed soils.x

This sealing has been caused by the removal of vegetation cover by which the original topsoil, rich in organic matter, used to be protected. Once eroded away the exposed subsoil lacks the stabilising influence of organic matter and easily seals.

The only practicle way to prevent soils from sealing is by keeping their surface covered, with a vegetation cover and litter. However the existing farming system makes use of annual crops and livestock grazes much litter.

Some ideas are given which may contribute to solve the problem. They are based on the existing bush-fallow system but require a thorough management of the fallow lands and labour both to maintain thornbush fences and to use the cleared bush.

Technically rehabilitating these sealed soils, either mechanically or biologically is no problem. The biological method (mulching) can be fit in a bush-fallow cultivation system. A mechanical way of rehabilitating these areas can also fit in such a bush-fallow system, for instance by the creation of grazing reserves. However one has to realise that grazing, although important, is a side-activity to cultivation and can only remain that with the present population pressure.

Management of these strongly sealed areas has no use if considered separately from the other land use activities. It should be part of an integrated management plan of the whole area. Only then succes can be expected.

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APPENDIX 1: CHARACTERISTICS OF TRANSECTS AND PROFILE DESCRIPTION OF PITS, VEGETATION ISLES AND FURROW.

Transect nr 1:	Shrub vegetation - Grassland with perennials - Annual grassland - Sealed soil
Date/season:	november '85
Coordinates:	38.00 E 0.10 S
Elevation:	800 m
Author:	Paul Scholte
Soil classification:	chromic Luvisol
(FAO, Soil Taxonomy)	udic Haplustalf
Geology:	Basement System
Local petrography:	gneisses: Augengneiss,
(parent material)	Biotite- and Feldspar gneiss
Physiography:	Uplands
Macro-relief:	undulating
Slope:	<100m, convex, irregular
Slope gradient:	1%
Position on slope:	top
Meso-and Micro-relief:	nil
Erosion:	severe sheet erosion, moderate rill erosion
Rockoutcrops:	very few
Surface stoniness:	very few stones
Overwash:	nil
Surface run-off:	very slow - medium
Surface sealing:	none to weak (annual grassland) and strong more than a 5 cm thick cap (bare soil)
Drainage class:	well drained
Flooding:	nil
Groundwater level:	always very deep
Presence of salts and: alkali	nil
Soil fauna influence:	large influence of termites, more than one fungus comb per square meter
Expected root depth:	very deep
Rock particles:	all soil horizons are at least slightly gravelly; this gravel consists of quartz particles with a diameter of 2-4 mm

Shrub site (transect 1):

Ah1	0 - 20 cm	Dark reddish brown (5YR 3/4) when moist; slightly gravelly sandy clay loam; moderate, fine granular structure and fine crumb structure; very friable when moist, sticky and non plastic when wet; many very fine, discontinuous, random, exped, tubular and simple pores; abundant, very fine, fine and coarse roots; strong effervescence with HCl, pH 6.5; clear and wavy transition to:
Ah2	20 -40 cm	Dark reddish brown (2,5YR 3/4) when moist; slightly gravelly sandy clay ; moderate fine subangular structure and moderate fine crumb structure; friable when moist, slightly sticky and slightly plastic when wet; few thin clay skins; many very fine and common fine and medium, discontinuous, random, exped, tubular and simple pores; frequent, very fine,fine medium and coarse roots; pH 6; gradual and wavy transition to:
Bt	40 -90 cm	Red (2,5YR 4/6) when moist, slightly gravelly sandy clay moderate to strong angular blocky structure; friable to firm when moist, slightly sticky and slightly plastic when wet; common thin clay skins; common very fine, few fine and medium, discontinuous, random, exped tubular and simple pores; common fine, medium and coarse roots; clear and smooth transition to:
BC	90-130 cm	Red (2,5YR 4/6) when moist; very gravelly sandy clay loam; strong medium angular blocky structure; friable to firm when moist; slightly sticky and slightly plastic when wet; common thin clay skins; common, fine, medium and medium and coarse roots; quartz particles and gneiss; gradual and wavy transition to:
R	130-160+cm	Rock, Augengneiss and some Biotite gneiss.

Annual grassland site (Transect 1):

Ah1	0 - 10 cm	Dark reddish brown (5YR 3/4) when moist; slightly gravelly sandy loam; single grain structure; very friable when moist, slightly sticky and non plastic when wet; many, very fine, discontinuous, random, exped, tubular and simple pores; frequent very fine and fine roots; strong effervescence with HCl, pH 7; clear and wavy transition to:
Ah2	10- 20 cm	Dark reddish brown (2,5YR 3/4) when moist; slightly gravelly sandy clay loam; moderate strong fine subangular blocky structure; friable when moist, sticky and slightly plastic when wet; many very fine and common fine and medium, discontinuous, random, exped, tubular and simple pores; common very fine to fine roots; pH 6; clear and wavy transition to:
Bt1	20- 40 cm	Dark red (2,5YR 3/6) when moist; slightly gravelly sandy clay loam; moderately strong, subangular to angular blocky structure; firm when moist, slightly sticky and slightly plastic when wet; common thin clay skins; common very fine to fine, discontinuous, random, exped, tubular and simple pores; frequent, fine to medium roots; pH 5.5; gradual and wavy transition to:
Bt2	40- 85 cm	Red (2,5YR 4/6) when moist; gravelly sandy clay; moderate to strong fine angular blocky structure; firm when moist; slightly sticky and slightly plastic when wet; abundant thin clay skins; many fine, discontinuous, exped tubular and simple pores; frequent to common fine and medium roots; quartz particles with a diameter of 5- 50 mm; abrupt and wavy transition to:
BC	90-130 cm	Red (2,5YR 4/6) when moist; very gravelly sandy clay moderate to strong medium angular blocky structure; firm when moist; slighly sticky and slightly plastic when wet; abundant thin clay skins; common, fine, discontinuous, exped, tubular and simple pores; common fine to medium roots; clear and wavy transition to:
R	130-160+cm	Rock: Augengneiss and some Feldspar gneiss.

Transect nr 2:	Tree - Shrub - Grassland with perennials - Annual grassland - Sealed soil
Date/season:	november '85
Coordinates:	38.00 E 0.10 S
Elevation:	800 m
Author:	Paul Scholte
Soil classification:	chromic Luvisol
(Fao, Soil Taxonomy)	udic Haplustalf
Geology:	Basement System
Local petrography:	gneisses (Hornblende-Biotite-, Granitoid-)
Physiography:	Uplands
Macro-relief:	undulating
Slope:	<100m, convex, irregular
Slope gradient:	2%
Position on slope:	top
Meso-and micro-relief:	nil
Erosion:	severe sheet erosion, moderate rill erosion
Rockoutcrops:	very few
Surface stoniness:	very few stones
Overwash:	nil
Surface run-off:	slow-medium/rapid
Surfacesealing:	none to places with a strong cap of more than 5 cm thick
Drainage class:	well drained
Flooding:	nil
Groundwater level:	always very deep
Presence of salts/alkali:	nil
Soil fauna influence:	large influence of especially termites, more than one fungus comb per square meter
Expected root depth:	very deep
Rock particles:	all soil horizons are slightly gravelly, this gravel consists of quartz particles with a diameter of 2-4 mm.

Annual grassland site (Transect 2):

A	0 - 5 cm	Red (2,5YR 4/6) when moist; slightly gravelly sandy loam; single grain structure; loose when dry, loose when moist, non sticky, non plastic when wet; many very fine, discontinuous, vertical pores; abundant very fine roots; pH 7; abrupt and smooth transition to:
ABt	5 -25 cm	Red (2,5YR 4/6) when moist; slightly gravelly sandy clay; fine crumb and moderate fine subangular blocky structure; slightly hard when dry, friable when moist, sticky slightly plastic when wet; few thin clayskins; many very fine and fine discontinuous and continuous random, exped, tubular and simple pores; frequent very fine and fine roots; pH 6; clear and wavy transition to:
Bt1	25-90 cm	Red (2,5 YR4/8) when moist; slightly gravelly sandy clay; fine crumb and moderate to strong fine subangular blocky structure and moderate to strong angular blocky structure; hard when dry, firm when moist, sticky and slightly plastic when wet; common thin clayskins; many very fine and fine continuous and discontinuous random, exped, tubular and simple pores; common fine and medium roots; clear and wavy transition to:
Bt2	90-100 cm	Red (2,5YR4/8) when moist; gravelly sandy clay; fine crumb structure, strong fine angular blocky structure and strong fine subangular blocky structure; hard when dry, firm when moist, sticky and slightly plastic when wet;common thin clayskins; common fine and medium contiuous and discontinuous random, exped, tubular and simple pores; common fine and medium roots; quartz particles with a diameter of 5-50 mm; clear and wavy transition to:
BC	100-130cm	Red (2,5YR4/8) when moist; slightly gravelly sandy clayloam; fine crumb and moderate fine angular blocky structure hard when dry, firm when moist, sticky and slightly plastic when wet; abundant thin clayskins; comon, fine and medium, continuous and discontinuous, random, exped, tubular and simple pores; few, fine roots; clear and broken transition to:
R	130-150+cm	Rock: Hornblende - Biotite gneiss and (less) Granitoid gneiss.

Sealed soil site (Transect 2):

ABt 0 - 25 cm	Red (2,5YR 4/6) when moist; slightly gravelly sandy clay fine crumb and strongly coherent porous massive structure; very hard when dry , firm when moist, slightly sticky and slightly plastic when wet; abundant thin clayskins; pH 6; many , medium, discontinuous, random, exped, tubular and simple pores; common, very fine and fine roots; quartz particles; clear and wavy transition to:
Bt1 25-85 cm	Red (2,5YR 4/8) when moist; slightly gravelly sandy clay; fine crumb and strongly coherent porous massive structure; very hard when dry, firm when moist, slightly sticky and plastic when wet; abundant thin clayskins; many, very fine, fine and medium, discontinuous random, exped, tubular and simple pores; common very fine, fine and medium roots; clear and wavy transition to:
Bt2 85-95 cm	Red (2,5YR 4/8) when moist; gravelly sandy clay; very fine and fine crumb structure and strongly coherent porous massive structure; hard when dry, friable when moist, slightly sticky and slightly plastic when wet; abundant thin clay skins; many very fine, fine and medium, discontinuous, random, exped, tubular and simple pores; few roots; quartz particles with a diameter of 5- 50 mm; clear and wavy transition to:
Bt3 95-110 cm	Red (2,5YR 4/8) when moist; slighly gravelly sandy clay; very fine and fine crumb structure and strongly coherent porous massive structure; hard when dry, friable when moist, slightly sticky and slightly plastic when wet; abundant clay skins; many very fine, fine and medium, discontinuous, random, exped, tubular and simple pores; few roots; clear and wavy transition to:
BC 110-150 cm	Red (2.5YR 4/8) when moist; gravelly sandy clay loam; moderate strong angular blocky structure; clear and wavy transition to:
R 150-170+cm	Rock: Hornblende and Biotite gneiss and (less) Granitoid gneiss.

Vegetation isle (Transect 2):

Ah	0 -12 cm	Dark red (2.5YR 3/6) when moist; slightly gravelly sandy loam; moderate fine granular structure and fine crumb; slightly hard when dry, friable when moist, slightly sticky and non plastic when wet; few thin clay skins; pH 6; many to common, very fine, fine medium and coarse, continuous and discontinuous, exped tubular and simple pores; clear and irregular transition to:
ABt	12-20 cm	Red (2.5YR 4/6) when moist; slightly gravelly sandy clay loam; fine crumb and moderate fine subangula blocky structure; hard when dry, friable to firm when moist,slightly sticky and slightly plastic when wet; common thin clay skins; common to few, very fine, fine, medium and coarse, continuous and discontinuous, random, exped, vesicular and simple pores; abrupt and wavy transition to:
Bt	20-50+ cm	Red (2.5YR 4/8) when moist; slightly gravelly sandy clay; fine crumb and moderate to strong fine angular and subangular blocky structure; hard when dry, friable to firm when moist, slightly sticky and slightly plastic when wet; abundant thin clay skins; pH 6; few fine and medium, discontinuous, random, exped, tubular and simple pores.

Furrow Transect 2

Sealed soil site:

Ah 0 -10 cm	Dark reddish brown (2.5YR 3/4) when moist; slightly gravelly sandy loam; single grain structure and moderate fine subangular blocky structure; hard when dry, friable when moist, sticky and non plastic to slightly plastic when wet; few fine discontinuous, random, exped, tubular and closed pores; common to few, fine and medium roots; clear and smooth to wavy transition to:
ABt 10-20 cm	Dark reddish brown (2.5YR 3/4) when moist; slightly gravely sandy clay loam; fine crumb structure and moderate fine angular blocky structure; hard when dry, friable when moist sticky and slightly plastic when wet; few thin clay skins; pH 6; common fine and medium, discontinuous, random, exped, vesicular and simple pores; common medium roots; clear and smooth to wavy transition to:
Bt 20-50+ cm	Red (2.5YR 4/6) when moist; slightly gravelly sandy clay; fine crumb structure and moderate fine angular blocky structure; hard when dry friable when moist, sticky and slightly plastic when wet; common thin clay skins; pH 5.5; common fine and medium, discontinuous, random, exped, vesicular and simple pores; common medium roots.

Annual grassland site:

Ah1 0 - 5 cm	Dark reddish brown (2.5YR 3/4) when moist; slightly gravelly sandy loam; single grain structure and moderate fine crumb structure; slightly hard when dry, very friable when moist, slightly sticky and non plastic when wet; pH 5.5; common very fine, fine and medium, mostly discontinuous, horizontal, exped, tubular and simple pores; abundant very fine and common fine roots; clear and wavy transition to:

Ah2	5 -15 cm	Dark reddish brown (2.5YR 3/4) when moist; slightly gravelly sandy loam; single grain structure and moderate fine crumb; slightly hard when dry, very friable to friable when moist, sticky and slightly plastic when wet; few thin clay skins; pH 6; common very fine, fine and medium, discontinuous and continuous, random, exped, tubular and simple pores; abundant fine roots, very frequent very fine roots; clear and wavy transition to:
B	15-50+ cm	Red (2.5YR 4/6)when moist; slightly gravelly sandy clay; fine crumb and weak to moderate fine angular blocky structure; very friable when moist, sticky and slightly plastic when wet; abundant to common thin clay skins; pH 5.5; common, mostly medium, very fine and fine, continuous and discontinuous random, exped, tubular and simple pores; very frequent to frequent fine and medium roots.

Dense grassland with perennials near dead wood site:

Ah	0 -10 cm	Dark reddish brown (2.5YR 3/4) when moist; slightly gravelly sandy loam; moderate fine crumb structure and single grain structure; very friable when moist, slightly sticky and non plastic when wet; few thin clay skins; many to common, fine, discontinuous, random, exped, tubular and simple pores; very frequent very fine, fine and medium roots; abrupt and smooth transition to:
ABt	10-15 cm	Dark reddish brown (2.5YR 3/4) when moist; slightly gravelly sandy clay loam; fine crumb structure and moderate fine subangular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; common thin clay skins; many to common, fine, discontinuous, random, exped, tubular and simple pores; very frequent very fine, fine and medium roots; abrupt and smooth transition to:
Bt	15-50+ cm	Red (2.5YR 4/6) when moist; slightly gravelly sandy clay; fine crumb structure and moderate fine angular blocky structure; slightly sticky and slightly plastic when wet; abundant thin clay skins; common fine discontinuous, random, exped, vesicular and simple pores; frequent to common fine, medium and coarse roots.

Transect nr 3:	Shrub vegetation - Grassland with perennials - Annual grassland - Sealed soil
Date/season:	november '85
Coordinates:	38.00 E 0.10 S
Elevation:	800 m
Author:	Paul Scholte
Soil classification: (FAO, Soil Taxonomy)	chromic Luvisol udic Haplustalf
Geology:	Basement System
Local Petrography: (parent material)	Biotite gneisses
Physiography:	Uplands
Macro-relief:	undulating
Slope:	<100m, convex, irregular
Slope gradient:	8%
Position on slope:	middle
Meso- and micro-relief:	nil
Erosion:	severe sheet erosion, moderate rill erosion
Rockoutcrops:	very few
Surface stoniness:	very few stones
Drainage class:	well drained
Flooding:	nil
Groundwater level:	always very deep
Presence of salts and alkali:	nil
Soil fauna influence:	large influence by termites, more than one fungus comb per square meter
Expected root deptn:	very deep
Particles:	all soil horizons are slightly gravelly this gravel consists of Quartz particles and has a diameter of 2-4 mm.

Shrub site (Transect 3):

Ah	0 - 30 cm	Dark red (2.5YR 3/6) when moist, slightly gravelly sandy clay loam; fine crumb structure and strong fine granular structure; very friable when moist, slightly sticky and slightly plastic when wet; pH 6; common very fine, fine, medium and coarse, mostly discontinuous, random and vertical, exped, vesicular and tubular simple pores; very frequent fine, medium and coarse roots; quartz particles; clear and wavy transition to:
Bt1	30-100 cm	Red (2.5YR 4/8) when moist; slightly gravelly sandy clay; fine crumb structure and moderate very fine to fine angular blocky structure; very hard when dry, firm when moist, sticky and slightly plastic when wet; abundant thin clayskins; many fine, medium and coarse, mostly discontinuous, exped, tubular and simple pores; common fine, medium and coarse roots; quartz and some micas primary minerals; abrupt and wavy transition to:
Bt2	100-125 cm	Red (2.5YR 4/8) when moist; very gravelly sandy clay; fine crumb structure and moderate very fine and fine angular blocky structure; hard when dry, firm when moist, sticky and slightly plastic when wet; few fine and medium roots; quartz particles; abrupt and wavy transition to:
Bt3	125-160 cm	Red (2.5YR 4/8) when moist; gravelly sandy clay fine crumb structure and moderate fine angular blocky structure; hard when dry, firm when moist, sticky and slightly plastic when wet; abundant thin clay skins; few to common very fine, discontinuous random, exped, tubular and simple pores; few to common fine and medium roots quartz particles with a diameter of 5-50 mm; clear and wavy transition to:
BC	160-200 cm	Red (2.5YR 4/6) when moist, gravelly sandy clay; fine crumb structure and moderate fine angular blocky structure; hard when dry, firm when moist, sticky and slightly plastic when wet; abundant thin clay skins; few to common, very fine discontinuous, random, exped, tubular and simple pores; very few fine roots; clear and wavy transition to:
R	200-220+ cm	Rock: Biotite gneiss.

Sealed soil site (Transect 3):

Bt1	0 - 75 cm	Red (2.5YR 4/6) when moist; slightly gravelly sandy clay; fine crumb structure; hard when dry, friable when moist, sticky and slightly plastic when wet; abundant thin clay skins many to common, fine, discontinuous, random, exped, tubular and simple pores; common fine and medium roots; abrupt and wavy transition to:
Bt2	75-85 cm	Red (2.5YR 4/8) when moist; very gravelly sandy clay; common to few, fine and medium roots; quartz particles; abrupt and wavy transition to:
Bt3	85-125 cm	Red (2.5 YR 4/8) when moist; gravelly sandy clay; fine crumb structure and moderate fine angular blocky structure; very hard when dry, friable when moist, sticky and slightly plastic when wet; abundant fine clay skins; strong effervescense with HCl, pH 6; common fine, discontinuous, random, exped, tubular and simple pores; few to common, fine and medium roots; quartz particles with a diameter of 5-50 mm; clear and wavy transition to:
BC	125-170 cm	Red (2.5YR 4/6) when moist; gravelly sandy clay; fine crumb structure and moderate fine angular blocky structure; very hard when dry, friable when moist, sticky and slightly plastic when wet; abundant thin clay skins; common fine, discontinuous, random, exped, tubular and simple pores; few fine roots; biotite gneiss particles; clear and wavy transition to:
R	170-200+cm	Rock, Biotite gneiss with very few fine roots.

Vegetation isle (transect 3):

Ah 0 -20 cm	Dark red (2.5 YR 3/6) when moist; slightly gravelly sandy clay loam; fine crumb and moderate to strong subangular blocky structure; hard when dry, friable when moist, slightly sticky and slightly plastic when wet; few thin clay skins; few coarse (over 20 mm!), continuous, random, exped, vesicular and tubular, open pores; very frequent to frequent fine roots; clear and irregular transition to:
ABt 20-50 cm	Red (2.5 YR 4/6) when moist; gravelly sandy clay; fine crumb and moderate to strong fine subangulaar blocky structure; friable when moist, slightly sticky and slightly plastic when wet; common thin clay skins; few coarse (over 20 mm!), continuous, random, exped, vesicular,tubular and open pores; common fine roots; abrupt and wavy transition to:
Bt1 50-55 cm	Red (2.5 YR 4/6) when moist; very gravelly sandy clay; common thin clay skins; common fine roots; abrupt and wavy transition to:
Bt2 55-75 cm	Red (2.5 YR 4/6) when moist; gravelly sandy clay loam; fine crumb structure and moderate fine angular blocky structure; friable when moist, slightly sticky and slightly plastic when wet; common very fine discontinuous, random, exped, tubular and simple pores; common to few fine roots; gradual and irregular transition to:
BC 75-85+ cm	Transition to Biotite rock.

monolith number: EAK71 country: KENYA soil description ISRIC

CLASSIFICATION FAO/UNESCO,1974: chromic luvisol
USDA,1975: rhodustalf udic, clayey, isohyperthermic
Diagnostic horizons: ochric, argillic
(other) Diagn. criteria:
Local classification:

LOCATION : Marimanti research station, EMIproject, Meru District, E. Province
: Latitude: 37 58 20 E Longitude: 0 09 08 S Altitude: 600 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 2.86

GENERAL LANDFORM : plain Topography: undulating
PHYSIOGRAPHIC UNIT : upper slope in uplands
SLOPE Gradient/aspect/form: 2 % convex
POSITION OF SITE : upper slope
MICRO RELIEF Kind: Pattern: nil
SURFACE CHAR. Rockoutcrops: nil Stoniness: nil
Cracking: nil Sealing: capped Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: slight sheet and moderate rill Aggradation: nil

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PARENT MATERIAL I : residual material Derived from: gneiss Texture:
Weathering degree: partial/moderate Resistence: high
Remarks: basement system

EFFECTIVE SOIL DEPTH(cm) : 130

WATER TABLE Depth(cm): Kind: no watertable observed
DRAINAGE : well
PERMEABILITY : slow Slow permeable layer from (cm): 0 to: 5
FLOODING frequency: nil Run off: rapid
MOISTURE CONDITIONS PROFILE : 0 - 50 cm dry

LAND USE :
VEGETATION Structure: deciduous woodland Status: degraded
Landuse/vegetation remarks: also millet/fallow

CLIMATE koppen: Aw Soil Moisture Regime: ustic

Station: MARIMANTI ----- 00 09 S/ 037 59 E; 587 m.a.s.l; 1 km N from site. Relevance: very good

	Period	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T min (C)	10	20.0	18.4	19.8	20.9	21.4	20.8	19.2	19.4	19.5	20.0	21.1	20.3	18.9
T max (C)	10	32.3	31.9	33.8	34.6	33.1	32.2	31.7	31.0	31.3	33.2	34.2	30.0	30.9
Prec (cm)	12	87.9	1.9	3.3	7.9	26.8	9.7	1.0	0.2	0.1	0.3	8.8	22.5	5.4
EA class A pan (cm)	10	228.7	15.9	17.7	22.5	18.1	16.6	16.8	18.0	20.8	24.2	25.4	17.3	15.4
tot.global rad. J/m2	10	452.0	462.0	481.0	487.0	498.0	479.0	409.0	365.0	393.0	450.0	477.0	469.0	455.0
No of Raindays	10	57.0	4.0	3.0	4.0	12.0	6.0	2.0	2.0	1.0	1.0	4.0	12.0	6.0

PROFILE DESCRIPTION

Ah 0- 10cm 2.5YR 3.0/4.0 moist; loamy sand; single grain and fine moderate subangular blocky; sticky non plastic friable hard; few very fine/fine random discontinuous exped tubular pores and few very fine/fine random discontinuous exped vesiculair pores; slightly porous; few fine /very fine roots; clear smooth boundary to

AB 10- 20cm 2.5YR 3.0/4.0 moist; sandy clay loam; fine crumb and fine moderate angular blocky; sticky slightly plastic friable hard; thin thin clay cutans ; common very fine/medium random discontinuous exped vesiculair pores; common/few very fine /fine roots; clear smooth boundary to

Bt 20- 50cm 2.5YR 4.0/6.0 moist; sandy clay; fine moderate crumb and fine moderate angular blocky; sticky slightly plastic friable hard; broken thin clay cutans ; common very fine/medium random discontinuous exped vesiculair pores; common/few very fine /fine roots;

REMARKS:

Monolith 71 is sampled near EAK 53 and 54. The profile surface is partly covered by grass and partly bare soil. The slides demonstrate clearly the difference in infiltration rate.
The covered and bare soil profiles differ mainly from eachother in the epipedon (A and AB horizon) mainly:

Profile characteristics	grass covered	bare soil
Surface	no sealing small "catchment" of sandwash	5 cm, capped some sandwash
Stucture	more crumby and subangular blocky	more angular blocky
Consistency dry	slightly hard	hard
moist	very friable	friable
Pores	more pores and more continuous pores	
Roots	more roots	

Slides: 10.155 - 10.157 and 10.142 - 10.155.

CLASSIFICATION FAO/UNESCO,1974: chromic luvisol
USDA,1975: rhodustalf udic, clayey, isohyperthermic
Diagnostic horizons: ochric, argillic
(other) Diagn. criteria:
Local classification:

LOCATION : Marimanti agricultural research station, Meru district.
: Latitude: 00 09 08 S Longitude: 037 58 20 E Altitude: 600 (m.a.s.l.)
AUTHOR(S) - DATE (mm.yy) : Kuyper - 0.00

GENERAL LANDFORM : plain Topography: undulating
PHYSIOGRAPHIC UNIT : uplands
SLOPE Gradient/aspect/form: 2 % convex
POSITION OF SITE : upper slope
MICRO RELIEF Kind: Pattern: nil
SURFACE CHAR. Rockoutcrops: nil Stoniness: nil
Cracking: nil Sealing: capped Salt: nil Alkali: nil
SLOPE PROCESSES Soil erosion: severe sheet and moderate rill Aggradation: nil

PARENT MATERIAL I : residual material Derived from: gneiss Texture:
Weathering degree: partial/moderate Resistence: high
Remarks: basement system

EFFECTIVE SOIL DEPTH(cm) : 150

WATER TABLE Depth(cm): Kind: no watertable observed
DRAINAGE : well
PERMEABILITY : slow Slow permeable layer from (cm): 0 to: 2
FLOODING frequency: nil Run off: rapid
MOISTURE CONDITIONS PROFILE : 0 - 150 cm dry

LAND USE :
VEGETATION Structure: deciduous woodland Status: degraded
Landuse/vegetation remarks: also millet/fallow

CLIMATE koppen: Aw Soil Moisture Regime: ustic

Station: MARIMANTI ----- 00 09 S/ 037 59 E; 587 m.a.s.l; 1 km N from site. Relevance: very good

	Period	Annual	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T min (C)	10	20.0	18.4	19.8	20.9	21.4	20.8	19.2	19.4	19.5	20.0	21.1	20.3	18.9
T max (C)	10	32.3	31.9	33.8	34.6	33.1	32.2	31.7	31.0	31.3	33.2	34.2	30.0	30.9
Prec (cm)	12	87.9	1.9	3.3	7.9	26.8	9.7	1.0	0.2	0.1	0.3	8.8	22.5	5.4
EA class A pan (cm)	10	228.7	15.9	17.7	22.5	18.1	16.6	16.8	18.0	20.8	24.2	25.4	17.3	15.4
tot.global rad. J/m2	10	452.0	462.0	481.0	487.0	498.0	479.0	409.0	365.0	393.0	450.0	477.0	469.0	455.0
No of Raindays	10	57.0	4.0	3.0	4.0	12.0	6.0	2.0	2.0	1.0	1.0	4.0	12.0	6.0

PROFILE DESCRIPTION

A 0- 12cm 2.5YR 3.0/6.0 moist; sandy loam,slightly gravelly; fine moderate granular and fine moderate crumb; slightly sticky non plastic friable slightly hard; thin thin clay cutans ; many very fine pores and few fine/medium random exped tubular pores;

AB 12- 20cm 2.5YR 4.0/6.0 moist; sandy clay loam,slightly gravelly; fine moderate crumb and fine moderate subangular blocky; slightly sticky slightly plastic friable hard; broken thin clay cutans ; common very fine pores and/few fine/medium random exped tubular pores;

B 20- 50cm 2.5YR 4.0/8.0 moist; sandy clay,slightly gravelly; fine moderate to strong angular blocky and fine moderate to strong subangular blocky; slightly sticky slightly plastic firm hard; continuous thin clay cutans ; common very fine pores and few fine/medium random discontinuous exped tubular pores;

REMARKS:

Trial area for regrowth of degraded overgrazed land.
This profile is an example of a vegetation mound of erosional origin. The roots of the shrub and the termite activity in the mound make the mound more erosion resistent. The local termite activity is induced by the organic material produced by the shrub (roots, leaves).

Slides: 10,150 and 10,142 - 10,157.

APPENDIX 2: FERTILITY ANALYSE DATA

SITUATION	BARE SOIL		ANNUAL		PERENNIAL		SHRUB		TREE	
MEAN DEPTH (cm)	10	50	10	50	10	50	10	50	10	50
pH	7.2	6.9	7.2	7.2	6.7	6.8	7.2	6.6	6.5	6.8
C%	.35		.40		.31		.38		.65	
N%	.09		.11		.09		.10		.16x	
Na m.e. %	.11	.13	.57	.27	.17	.13	.13	.17	.13	.13
K m.e. %	.35	.15	.47	.43	.61	.15	.61	.21	.57	.15
Ca m.e. %	2.9	2.1	4.3	2.5	3.6	1.7	3.3	2.5	3.6	2.1
Mg m.e.%	2.0	2.8	1.3	2.7	2.4	3.1	1.5	2.1	1.8	1.9
Mn m.e.%	.77	.65	.70	.59	.66	.68	.43	.59	.54	.45