# TRAINING PROJECT IN PEDOLOGY
# KISII KENYA

# Erosion in the Kisii - West area

PRELIMINARY REPORT NO 8

AGRICULTURAL UNIVERSITY
WAGENINGEN - THE NETHERLANDS

# EROSION IN THE WESTERN PART OF THE KISII DISTRICT

by

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Preliminary Report no. 8
December 1975

Training Project in Pedology, Kisii - Kenya.
Agricultural University, Wageningen - the Netherlands

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## Preface

This report of the Training Project in Pedology at Kisii, Kenya of the section on Tropical Soil Science of the Agricultural University at Wageningen, the Netherlands is the eighth one of a series to be presented to Kenyan officials.

The Project started in November 1973 after assent had been granted by the Office of the President of Kenya. It is meant for training of post graduate students at the Agricultural University at Wagenignen and for furnishing research opportunities to the staff. The activities of staff and students are directed to obtaining a better knowledge of the soil and the agricultural condition of the project area to provide a basis for the further agricultural development of the area.

The Project in Kisii is conducted by:
Ir. W.G. Wielemaker, teaching and research
Ing. H.W. Boxem, management.
Visiting specialists from the Agricultural University at Wageningen help to resolve special problems.

This report is a result of special study of structure stability surface sealing and erosion of soils in the western part of the Kisii district. Preceding this research a related study has been carried out in the same area on the decline of organic matter (Preliminary Report no.4). These investigation should be taken together as a first step in the assesment study of soil degradation due to permanent cultivation.
This report has been written by Messrs G.R. Hennemann and J.H. Kauffman. Mr. H.W. Boxem edited and recompiled it to this presentation.

We hope to pay back with these reports a small part of the great dept we owe to Kenya in general and many Kenyans in particular for their valuable contributions to the good functioning of the project.

The supervisor of the project
J. Bennema, Professor of Tropical Soil Science

## 1. INTRODUCTION

In areas where people have destroyed natural vegetation in order to have new arable land, soil degradation on slopes is a major problem in agriculture.

Bare slopes, deprived from their protective cover, are becoming unstable when exposed to the unhampered impact of rainfall and soil erosion will spread fast. The humus-rich topsoil will be washed away, which usually results in a strong decline of soil fertility and crop yields as organic matter, particularly in red tropical soils, plays a vital role in the plant nutrient cycle.

In the last two decades land scarcity has become a serious problem due to an exponentially increasing population.
One of the results is a strong increase of the permanent landuse without fallow periods.

During the surveys some indications of the present of soil degradation have been noticed.
Hence research and measures directed on maintainance of a good soil condition is of vital importance for future farming in the area.

### The process of topsoil degradation under influence of cultivation.

The vegetation is protecting the topsoil against the destructive power of the rainfall.
However cultivation the soil lies unprotected during a part of the year, after the harvest and specially in the period after the land has been ploughed. In thi situation the soil is lying bare until the growing crop (and weeds) has covered the surface.

Particularly during the period after ploughing the organic matter content of the topsoil is declining.
This is caused by three changed conditions:

- less organic matter returns to the soil

  By harvesting, burning and grazing less organic matter is returning to the soil as compared with the organic input under natural vegetation.

- Absence of a protective cover

  The strongly increased solar radiation is resulting in a higher mineralization rate of the organic matter.

- Soil tillage
  the top-soil tillage is giving a better aeration of the soil, which also enhances the mineralization of the organic matter.

Mineralization is causing tremedous losses of nutrients.
Van Wissen (1975) calculated losses of 20 tons organic C/ha in the upper 37.5 cm of the soil after only two years of cultivation, assuming a C/N quotient of 10 this means a loss of 2 tons of nitrogen.
The organic matter content influences the structure stability and hence the susceptibility to sealing erosion.
Due to the decrease of the organic matter content and due to soil tillage less stable and smaller soil aggregates are formed, which are carried away during rainshowers by run-off.
Thus it is evident that susceptibility to sealing and erosion will increase during cultivation.

The following aspects of topsoil degradation have been investigated in the Kisii west area:

- the decline of the organic matter content during cultivation (van Wissen 1975)
- Structure Stability and surface sealing (Kauffman, chapter 3 of this report)
- Erosion phenomena and soil erodibility (Hennemann, chapter 4 and 5 of this report)

Topsoil behaviour during rainshowers

The actual force in the proces of topsoil degradation is the impact of the rainshower (erosiveness) and therefore close field observations of the surface soil during and after the rainfall are very usefull.

On basis of many observations the change of the soil surface during rainshowers can be represented schematically.

Lowering of clod stability

by drop impact and rapid wetting

Destruction of clods

detachment of aggregates and filling up of depressions

Decrease of infiltration capacity

through small micro-channels and
sedimentation of soil on terraces

Run-off and soil-wash (aggregates)
through small micro-channels and
sedimentation of soil on terraces

Widening of micro-channels into rill x)
uprooting of crops and complete removal of ploughlayer

---

x) At the end of the dry season there rills and micro-channels are cleared away by ploughing.

## 2. THE ENVIRONMENT

The research area has been restricted to Kisii West.
A few months before this erosion study a soil survey had been completed of the same area, so for general environmental characteristics we refer to the Kisii West semi-detailed soil survey (T.P.I.P - Kenya, report no. 5), to be published in 1978.

As stated in the introduction erosion by water is largely determined by the following factors:

1- Precipitation
2- Soil type
3- Topography
4- Vegetation
5- Soil tillage and conservation measures

### 2.1. Precipitation

From the point of view of erosion the main aspects of the rainfall are:

- the intensity of the downpours
- the total amount of the downpours
- the distribution of the rainfall during the year
- the total annual rainfall

The mean annual precipitation ranges from about 1500 mm in the west to 2000 mm in the east of the research area.
This annual precipitation fluctuates considerably from year to year
There are two periods of rainfall and two intervening dry periods.
( reference is made to the chapter climate in P.R. 5)
Few data about rain-intensities and storm frequences are available.
The rain intensities in Kisii town during several years has been studied. Reference is made to the chapter about climate in the report about the soils of the Mapsheet 130 (IN Preparation)

Mean intensities are ranging from 0.01 - 0.86 mm/min and maximum intensities are reaching 1.6 mm/min.

N.Hudson in "soil conservation" established "although there is some variation from one storm to another most rain falling at intensities of less than 0.25 mm/min are not erosive".
So attention for the erosion problem is necessary, particularly because high intensities occur at the start of the wet season, when maize and millet plants are small and the fields are practically bare.

## 2.2. Soils

During the detailed and semi-detailed surveys of the Marongo and Kisii West areas it was difficult to classify the soils according to the erosion classes of the Soil Survey Manual.
Yet it was clear that soil erosion was present because of the occurrence of semi-natural terraces. The semi-natural terraces is the object of study in chapter 4.

The susceptibility to erosion of the soil types is different due to differences in structure stability and the related susceptibility for surface sealing.

The majority of the Kisii West soils comprises deep, well drained, dark red clay soils of different lithological origin.

The topsoils are usually thick and rich in organic matter (3 - 7%).

They have been classified as Tropo- and Palehumults provisionally because sufficient physioal and chemical data could not be obtained at the moment.

Three groups can be distinguished:
- soils developed on basalt
- soils developed on quartsites
- soils developed on Wanjare granite

### Soils developed on basalt

Mostly deep, moderate to strong subangular blocky, dark red clay soils with a textural B-horizon. A-horizons are dark brown to dark reddish brown with a crumby or subangular blocky structure, thickness is ranging from 10 to about 60 cm.
The porosity is well developed and the internal drainage is usually very high.
These soils are of high agricultural value.

### Soils developed on quartsites

Shallow to moderately deep and locally deep dark reddish brown to dark red weak subangular blocky clay soils with weakly developed textural B-horizon. The A-horizon is less developed and lighter in colour than in the basaltic soils, while textures are more sandy.

### Soils developed on Wanjare granite (coarse grained)

With textures of slightly to very gravelly clay, these soils are rather conspicuous in the field.
The high content of gravel could be a result of residual enrichment. They are mainly deep dark red weak subangular soils, with weakly developed textural B-horizon. A-horizons are well developed but do not reach the thickness of the soils developed on basalt.
Porosity is high and internal drainage is good.

## 2.3. Topography

The major part of the Kisii West area consists of rolling, slightly convex hills.
Slope gradients range from 5 - 30% with steeper gradients along valley-sides. (Gucha landscape; see Kisii West semi-detailed survey)
In the southern, undulating part of the area near Riokindo and Nyabitunwa slope gradients are between 5 - 15% (Riokindo landscape).
In the west quartsite ridges occur, giving rise to large table mountains as Venjo and the Marongo ridge. (Marongo landscape).
These ridges have steep to very steep (up to 70%) strainght slopes, covered with rocky and shallow soils, during rains much run-off occurs with a rapid discharge.
Here more than anywhere else, natural erosion has impeded or even prevented the development of deep soils with a dark top-soil.
On basaltic scarps, which are usually covered by a thick colluvial layers slope gradients are less steep (25-45%), though soils are shallow, permeability is high compared with soils on quartsite scarps, due to the colluvial layers in the subsoil.

## 2.4 Vegetation, landuse and soil-conservation

### 2.4.1. Developments in the past

Vegetation, agriculture and particularly soil-conservation practices should be considered against the background of agricultural developments and changes in the past.

Originally the Kisii West area was covered by a dense vegetation of moist intermediate and montane forest species (1600-2000m).
In the drier zone West of Marongo and Venjo massives a broad-leave-tree savanne occurred (Combretum-type).
Due to this vegetation, protected and fixed humus-rich topsoils were developed.

By the end of the 19th century the Abagussii tribe i.e. Kisii, moved into the area after being driven out of their settlements in the Kericho Highlands (Belgut area).
They practised shifting cultivation with locally some pastoralism, as natural grazing land hardly occurred (Ochieng 1972).

When population started to grow and land-pressure became noticeable in the 30s and 40s, the system of shifting cultivation, which until then had been common practice had to be changed into more or less permanent cultivation.

Accelerated erosion became a problem but farmers could not cope with it as they had little or no experience in techniques of soil-conservation. The bulk of the erosion in those days must have been caused by a too intensive cultivation of crops in steep areas.
(L.H. Brown - private communications)

Also in the rest of Kenya farmers had already got erosion problems, particularly in areas as Machakos, Kikuyu and around Lake Baringo.
At the end of the 1930s the Kenyan Soil Conservation Service was founded.
Erosion surveys were made in order to investigate the distribution, magnitude and causes of erosion in the different areas.
In the early 40s conservation works were started in the Kisii area.

The conservation measures comprised among others the construction of the so called trashlines.
These trashlines were build up from old maize stalks, weeds and sometimes stones or soil-material; they were laid down along the contours of the slope in order to prevent or hamper runn-off and to enhance sedimentation of transported soil.
Usually these lines should be raised up each year with new material
In this way a sort of semi-natural terraces or taluds could develop.
In the Annual Report of the P.A.O. Nyanza Province 1950 the following statement is made:
"In the Highland division of South Nyanza nearly all land is controlled by trashlines. Banks resulting from old trashlines can be seen. New trashlines are put in as established custom when new land comes into cultivation.

The trashlines are beginning to cause a market benching effect and the whole countryside is going to have a sort of laterally combed out appearance.
..... as result of spread of soil-erosion contour-ploughing and contour-cultivation is commoner .....".

The easy construction and maintainance of the trashlines were clear advantages, wheras narrow or broad-base terraces could only be achieved by communal labour, which was not very popular.

Disadvantages were: a) Restricted utilization as it is unsuitable for every steep areas.
b) Vulnerability just after construction, as the maize-stalks are washed away by runn-off.

Other conservation measures were put in at the same time:
- Improved rotation systems with resting fallows or grass-leys
- Use of farmyard manure or compost (if available)

The main problem by these introductions originated from the discrepancy between the old tribal system and the new agricultural situation.

a) Landtenure: Land did not secure anchorage as it was in fact communal property. The key to a succesfull conservation strategy was seen in private landtenure: farmers should have tittle to the lands they used.
In the 1950s a program of landconsolidation was started: plots were enclosed by hedges (Mauricias and fences, which could serve at the same as breaks for runn-off and soil wash.

b) Intensification of the cultivation: The introduction of new promising crops as hybrid maize, coffee, tea and pyrethrum was leading to a more permanent used of the land; fallow periods became less frequent, which was an unfortunate development.

In the 60s the zeal for soil conservation seemed to weaken: farmers started to plough up the taluds, where in due course much humus- rich topsoil had been sedimentated.
This picture became wide-spread after 1968; from that moment onwards the situation is steadily deterioting.

### 2.4.2. Present situation

The original moist montane and intermediate forest is now vanished completely and has been replaced by arable and grazing land.
On the steep scarps and outcrops, where shallow soils occur, a semi-natural vegetation is present: tall grassland with locally dense shrubs; cattle grazing is common in these places
In the poorly drained valley-bottoms in the south of the area (Riokindo landscape) a sort of grouped tree grassland occurs. These valleys are used as communal grazing land.

The main subsistence crop is maize, followed by bananas, wimbi, sweet potatoes and cassave.
Main cash crops are coffee, tea, sugarcane and pyrethrum. Population density is high (300-400 inhabitants/km$^2$); the population growth is 3.8% / year, which means a doubling within 18 years.
The average size of the holding is now 4-5 acres.

As far as conservation is concerned the proper measures have been neglected, but on steeper valley-slopes the terraces have been well-maintained with grass-covered taluds.

Most parcels are enclosed by hedges (Mauricias spp.) or fences (Euphorbia spp. or sisal).

These plantings are considered as "live wash stops", but field observations reveal that runn-off with soil wash is often streaming through these fences.
Where taluds have been well maintained, the benching appearance of slopes is clearly visible.

# 3 Structure Stability and Surface Sealing.

## 3.1. Introduction

The structure stability of a soil is the resistence of a soil against deformation caused by mechanical or physical/chemical influences.

The Structure Stability of a soil has been determined by the cohesive powers in (intra) and between (intra) the soil aggregates.
The water content of a soil is a factor which strongly influences those cohesive powers.

The intra-aggregate cohesive is the result of the swelling power (which want to separate the elementary particles of the aggregates) and the powers which keep those particles together as caused by side-sheet attraction, Madelung attraction and the cohesion caused by the humus.

The inter-aggregate cohesion is high at a low water content and a high water content.

The inter-aggregate cohesion is mainly the result of the cohesive power caused by cappilary water.
The inter-aggregate cohesion exist in a narrow moisture content range of the soil.
Another inter-aggregate cohesion is caused by the input of fresh organic matter, which induces a temporarily strong resistence of the soil against erosion.
The micro-biological conversion of this fresh organic matter gives gluey materials which makes the aggregates stronger and connects them with each other.

From the point of view of erodability the intra-aggregate cohesion is much more important than the inter-aggregate cohesion, for that reason the determination of the aggregate stability of a soil is a good indication for the Structure Stability of a soil.
In principle every description of the behaviour of the soil which is subjected to a destructive power gives information about the Structure Stability.
In the literature one finds a lot of well standardized methods, many of them requiring standard equipment like e.g. sieve machines.
For lack of such equipment it seemed the best to use several simple methods to get information about the structure-stability of the soil (section 3.2.1.).

Soil properties determining the cohesive powers of the soil aggregates are:

- organic matter content of the soil
- kind of organic matter
- micro biological activity
- texture
- kind of clay mineral
- C.E.C., base-saturation and pH
- quantity of Fe and Al oxides

Some of those factors are not studied at all, others are only partly studied.

Surface sealing is all the processes in the topsoil caused by the precipitation, which deteriorate the permeability of the topsoil for water and air.

Factors determining the surface sealing processes are:

- rainfall
- soiltype
- vegetation
- slope
- soil
- soil management

The rainfall is the cause of the detachment of the soil in small particles by:

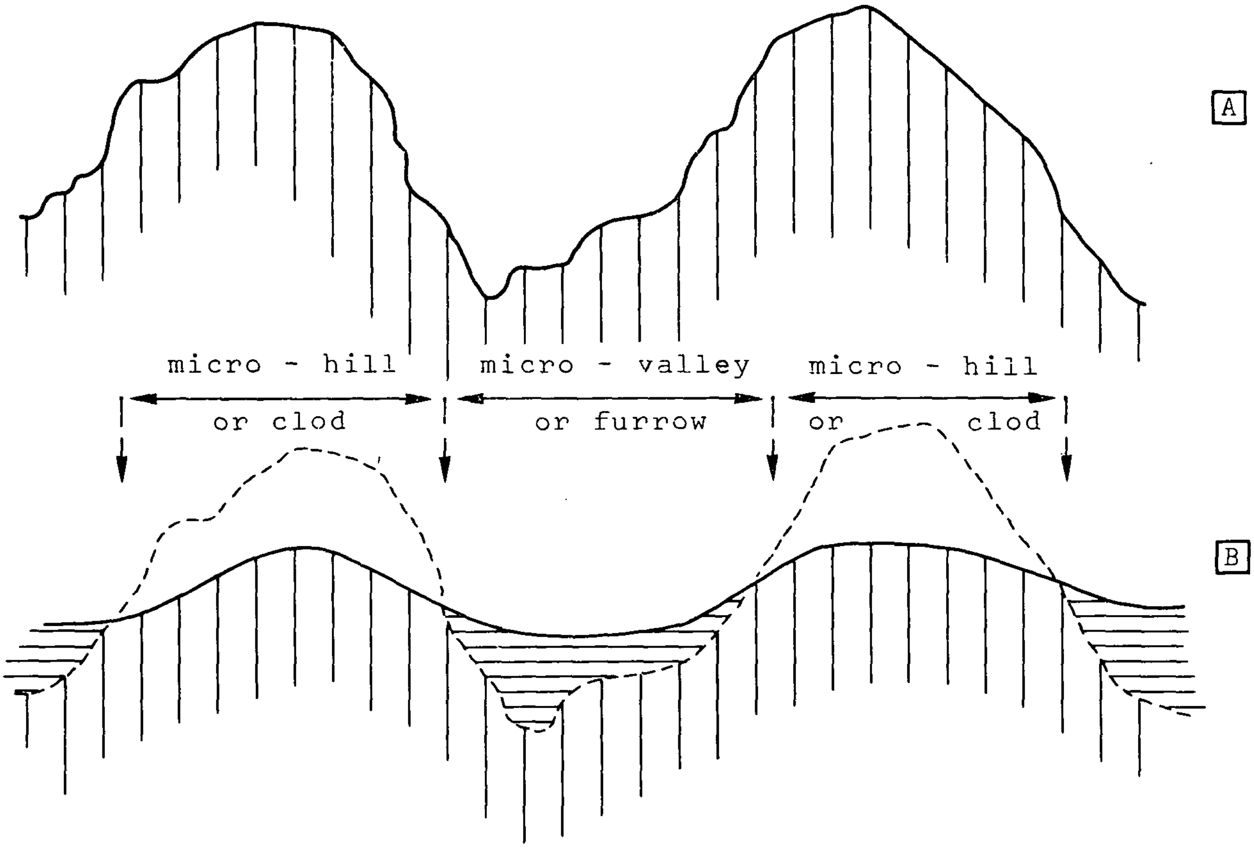
- the kinetic energy of the falling rainrops
- the swelling power and air explosion due to suddenly wetting of dry aggregates.

The soil can have a strong or a weak resistence against those detachment forces.

The vegetation absorbs the kinetic energy of the falling rain, thus protecting the soil.

Man has often a negative influence on the vegetation cover by keeping too many heads of cattle on a certain area or by reclaiming land for agriculture.

As mentioned before there exists at least one period in Kisii of complete bare soil and this situation takes place just during rainy seasons.



A = just after tillage
B = after a few weeks

Fig. 1 Diagram of the planation proces in cultivated land

The slope gradient of the field is in the first phase of the surface sealing process of minor influence, but the micro-slopes of the plough-ridges or clods, caused by the cultivation of the land are very important.

The implements of soil cultivation at the moment in the Kisii district are hoe (jembe) and the plough (tractive power by oxen ); the latter becomes more and more important.

The soil surface after cultivation with the hoe gives an irregular view, mico-hills (clods) and micro-valleys (depressions) in different forms and sizes.
The result of the cultivation by the ox-plough is also irregular although sometimes a pattern of plow ridges and furrows exist.
The uthor does not want to discuss the advantages or disadvantages of the plough used at the moment in Kisii. The only point of interest the relief caused by tilling, from that point of view you may conclude that there are only slight differences in micro-relief comparing the hoe with the plough.

Jongerius (1970) gives a grouping of all kind of slaking phenomena in the Ap ( in this study the terms of slaking and surface sealing are synonymous).
The regrouping phenomena in the topsoil caused by human influence (removal of the vegetation and cultivation of the land) are called by Jongerius agriconcentration or anthropogenic concentrations.

These agriconcentrations are divided in four types:

1. diruconcentrations: crust formation caused by the fact that structure elements at the surface are destroyed by the mechanical force of the precipitation and by the explosion of enclosed air.
2. satuconcentrations: regrouping phenomena in the whole Ap by water saturation.
3. abruconcentration: regrouping phenomena by micro-erosion of the clods.
4. lamiconcentration: regrouping phenomena by tillage under very wet conditions.

work hypothesis for the surface sealing proces.
The micro-relief of the soil surface after cultivation consists of very sharp micro-hills (clods or plough ridges) and micro-valleys (depressions or furrows).
This micro-relief has very deep slopes, slope percentages of 100 % are not exceptionable.

In principle in very soil which has been cultivated takes action a micro-planation proces which consists of micro-erosion of the clods and sedimentation of material in the depressions.
The name micro-erosion is also used by Sekera (1951) although for erosion on a still smaller scale.

From the point of view of macro-erosion it is important to know with what velocity and in what form the micro-erosion and sedimentation takes action.

See the diagram of the planation proces in cultivated land (figure 3)

The possible results of the planation proces, caused mainly by the precipitation are:

1. considerable decrease of the roughness of the soil surface, so decrease of the rain absorbing surface and a decrease of the resistence of the surface against run-off.
2. A division of the soil surface in Micro-Hills on which erosion is acting upon (sealing phenomena could happen in the upper millimeters of the soil surface) and Micro-Valleys in which sedimentations takes place (sealing phenomena could happen in the sedimentation layer)

The object of this study is the topsoil structure and the susceptibility to surface sealing of some soils in the Kisii West area.
The aims are:

- the determination of the structure stability
- a description of the surface sealing proces
- a calculation of the permeability (K-factor) of a sealed soil
- influence of some soil properties causing surface sealing.

## 3.2. STRUCTURE STABILITY

### 3.2.1. Methods

The study of the structure stability of the soil is partly fieldwork and partly laboratory work.

FIELDWORK A - profile descriptions
B - sampling
LABORATORY WORK C - repetition of some field determinations
D - behaviour of soil aggregates on submersion
E - determination of the aggregate stability
F - determination of the structure stability

Selection of the plots.
The selection criterions of the plots for studying the topsoil structure as well as the surface sealing are:

- wide range of structure stability
- different climatic conditions
- different organic matter contents
- a part of the plots must be identical to the plots selected by two other participants of the Training Project in Pedology, who were studying other facets of the erosion problem. (G.R. Hennemann and H.L.M. van Wissen).

#### A - Profile descriptions

The descriptions of the soil profile took place up to a depth of at least half a meter, in general up to 1 meter.
Description of the profiles according to the Soil Survey Manual and the FAO guidelinees for soil description.

#### B - Sampling

The samples were taken generally on 3 depths in the soil profile, in the Ap, the A1 and the B horizon.
In the Ap (about 0-15 cm), the upper part of the soilprofile, which is ploughed every season.
In the A1 (about 15-25 cm depth), this is the unploughed so the undisturbed part of the A horizon (dark topsoil due to organic matter).
In the B-horizon (about 50-65 cm depth), the horizon in which the colour becomes dark red (2.5 YR 3/6)
For the numbering of the soil pits and samples see Appendix I.

## C - Repetition of some field determinations in the laboratory.

The determinations are :

- the structure according to the Soil Survey Manual
- the consistency according to the Soil Survey Manual

The aim is mainly to check the possible variations in the field determinations of the structure of different locations.

The most variable condition in the field is the moisture of the soil

In the laboratory the moisture content of the soil such as air dry, field capacity and wet are easy to create.

In the field, especially the first two moistire contents are very variable.

## D - Behaviour of soil aggregates on submersion.

The aim of this method of investigation is to gain an insight into the behaviour of a specific soil towards water on complete wetting and to classify it accordingly.

Some air aggregates or fragments are wetted completely and suddenly.

Alteration of the aggregates during and after immersion are noted.

The soil is classified with the aid of the determination table and the observations.

For the complete descriptions of the method is referred to "behaviour of soils on submersion" of Janse and Koenigs.

## E - Determination of the Aggregate Stability by comparing the aggregate size distribution before and after wetting.

A soil consists of aggregated and non- or less aggregated components.

The amount and size of the aggregates is a measure for the aggregate formation.

The change in the aggregate size distribution is measure for the aggregate stability.

The aggregate size distribution on a certain moment is determined by dry sieving, because the intra-aggregate cohesion is high at a low moisture content.

Four sieves are used with apertures of 2000, 500, 250 and 125 mu.

The aggregate size distribution is given in weight percentages. For lack of a motor driven sieving apparatus the determination is done by hand, The exactness of such a determination is less than with a machine, but standardizing a manual determination is possible. The experience learns that after 40 movements of shaking a sufficient accurancy has been reached. (10 times shaking in horizontal plane than turning 90° and again 10 times, this repeated to two times more gives 40 times shaking).

The determination of the Aggregate Stability in short:

The material consists of some natural air dry fragments of about 1 to 2 cm in diameter of every sample and some dishes to put the fragments in.

- first wetting by suddenly immersion of the fragments
- 12 hours in a drying oven
- first aggregate size distribution determination by dry sieving and weighing the fractions.
- second wetting by suddenly immersion of the fractions together
- 12 hours in the drying oven
- second aggregate size distribution

## F - The determination of the structure stability in semi-natural conditions.

The best method or the determination of the structure stability is the comparison of the behaviour of the soil in the field.

However, such a comparison needs equal conditions. This means comparing two locations that the weather influences on those spots ought to be exactly the same during the study period, this is therefore impossible.

A solution for this problem is the collection of undisturbed samples and studying them on one spot.

For this determination clods are taken from every sample site with clods size of about 5-25 cm diameter and air dried.

These clods are subjected to the weather during 20 days on the same spot.

The clods are put on a plastic sheet on ashort grassland. The erosion of the clods is followed by description, estimation of the clod destruction velocity and by the taking photos on several times.

After 20 days the samples have been air-dry sieved and the two fractions weighed (apperture of the sieve is 2 mm).

From these two fractions an clod destruction percentage have been calculated which could be used as an objective check for the clod destruction estimations during the period of 20 days

### 3.2.2. Results

#### A - Profile descriptions

From eleven spots complete profile descriptions are available, three spots are located outside the Kisii West area in the drier area in the neighbourhood of Bondo (total annual rainfall about 1300 mm).
See Appendix II: Location map of the research plots.( page 87)
Two tables have been derived from the profile descriptions to give a view on the enviromental and soil structure data.
For complete profile descriptions see Appendix VII.( page 99)

Table I - Environmental characteristics

| Location | Number | Parent Material | Climate | Cultivation period | Slope % |
|---|---|---|---|---|---|
| Masai 0 | 1007 | basalt | Kisii | 0 | 8 |
| boundary 10 | 1008 | basalt | Kisii | 10 | 3 |
| " 30 | 1004 | basalt | Kisii | 30 | 10 |
| Nyamasege | 1009A | basalt | Kisii | | 10 |
| Nyamasege | 1015 | basalt | Kisii | | 30 |
| Ndiru | 1003 | basalt | Bondo | 50 | 2 |
| Wanjare | 1000 | granite | Kisii | | 10 |
| Riosiri | 1014 | granite | Kisii | | 2 |
| Nyabondo | 1001 | granite | Bondo | | 5 |
| Nyabondo | 1002 | granite | Bondo | | 4 |
| Mageche | 1005 | quartzite | Kisii | | 6 |
| Itumbi | 1016 | quartzite | Kisii | | 8 |

Table II shows the structure data from the profile descriptions of 3 horizons, the Ap, A1 and B.
In general the Ap horizon (=ploughed topsoil) is difficult to describe in terms of peds as in the Soil Survey Manual.
"Peds are formed by natural genesis and are bounded by natural voids. The fragments in an Ap horizon are formed by applying shear forces to the soil during tillage" Bouma (1969).

Structure grade, size and type are described according to the Soil Survey Manual.

Table II Abbreviations of structure determinations.

| Structure grade | Structure size | Structure type |
|---|---|---|
| VW = very weak | VF = very fine | CR = crumb |
| W = weak | F = fine | SAB = subangular blocky |
| M = moderate | | AB = angular blocky |
| S = strong | | G = granular |

Table III - Field data about the Structure of topsoil and subsoil.

1007 Ap: W - VF - Cr/G
Al: M - VF - SAB
B : M - VF - AB

1004: Ap: W - VF - Cr/G
Al: W - VF - CR/SAB
B : M - VF/F - AB

1015: Ap: W - VF/F - SAB/G
Al:M/W - VF/F - AB

1000: Ap: W - VF/F - Cr/G
Al: W - VF/F - SAB
B : W - VF/F - AB

1001: Ap: single grain
Al:

1005: Ap: W - VF - SAB
Al: W/M- VF/F - SAB
B : W/M- VF - AB

1008: W - VF/F - Cr/G
M - VF/F - SAB
M/S- VF - AB

1009: W - F - Cr/G
M/W- VF/F - SAB
S - VF/F - AB

1003: W - VF - SAB/G
W - VF - SAB/AB
W - VF - AB

1014: W - VF - SAB
W - VF - SAB

1002 B: massive

1016 W - VF - SAB/AB
W - VF - AB
M/W- VF/F - AB

conclusions:

- the topsoil has a weak structure grade and the subsoil a moderate one (compare this with the laboratory check on page 23).
- the size of the structure elements is similar in nearly all the profiles
- the structure type is granular in the Ap horizon and/or crumby and/or subangular blocky, in the Al subangular blocky and in the subsoil angular blocky
- exceptions are the profiles located outside the Kisii West area.

## C. Repetition of some field determinations in the laboratory.

Structure and consistency classes according to the Soil Survey Mannual.

**STRUCTURE:** grade:
class 4 = very strong
class 3 = strong
class 2 = moderately strong
class 1 = weak

size :
VF = very fine
F = fine

type :
AB = angular blocky
SAB = subangular blocky

**CONSISTENCY:** when dry :
class 4 = very hard
class 3 = hard
class 2 = slightly hard
class 1 = soft

when moist:
class 3 = firm
class 2 = friable
class 1 = very friable
class 0 = loose

when wet : stickiness:
class 1 = slightly sticky
class 0 = non-sticky

: plasticity:
class 2 = plastic
class 1 = slightly plastic
class 0 = non-plastic

See table IV on page 24.

Conclusions:

- in general the field determinations agree with the determinations in the laboratory. There is only one remarkable difference: the structure grade estimated in the field is often inverse to the one estimated in the laboratory. The moisture content ifference is probable the cause of this difference (the soil profiles were described just after the rainy season).
- Comparison of the consistency determinations when wet (plasticity and stickiness) within and between the profiles shows a uniform picture: anon-sticky and a non- to slightly plastic topsoil with a slightly sticky and slightly plastic subsoil. (small deviations for the soils located outside the Kisii West area
- the consistency determinations when dry and moist show a more variable view: soils developed on basalt are hard or slightly hard and friable or very friable or loose.
- The cultivation sequence shows a tendency of a decrease in consistency class with increasing cultivation period.

Table IV - structure and consistency determinations

| | | STRUCTURE | | | CONSISTENCY | | | |
|---|---|---|---|---|---|---|---|---|
| Number<br>Location | Depth | Grade | Size | Type | Dry | Moist | Wet<br>Stickiness | Plasticity |
| 1007 | 2-10 | 3½ | VF-F | (S)AB | 4 | 3 | 0 | ½ |
| Masai-0 | 15-24 | 3½ | VF-F | (S)AB | 4 | 2 | 0 | ½ |
| | 50-56 | 2 | VF-F | AB | 3 | 1 | 1 | 1 |
| 1008 | 2-10 | 2 | VF-F | SAB | 3 | 1 | 0 | ½ |
| Masai-10 | 15-25 | 2 | VF-F | (S)AB | 3 | 1½ | 0 | ½ |
| | 50-57 | 2-1½ | VF-(F) | AB | 2½ | 1 | ½ | 1 |
| 1004 | 2-10 | 1½ | VF-(F) | SAB | 2 | 1 | 0 | ½ |
| Masai-30 | 15-25 | 2 | VF-F | (S)AB | 4 | 1½-2 | 0 | ½ |
| | 50-57 | 2 | VF-F | AB | 3 | 1 | 1 | 1 |
| 1009A | 2-10 | 1½ | VF-F | (S)AB | 2 | 2 | 0 | ½ |
| Nyamasege | 15-25 | 1½ | VF-F | (S)AB | 3 | 1 | 0 | ½ |
| | 50-57 | 2-1½ | VF-(F) | AB | 2 | 3 | 1-½ | 1 |
| 1015 | 5-15 | 1 | VF-(F) | SAB | 2 | 2 | 0 | 0-½ |
| | 25-32 | 1½ | VF-(F) | AB | 2 | 1½ | 1 | 1 |
| 1003 | 0-15 | 1 | VF | (S)AB | 2½ | 2 | 1 | 1-1½ |
| Ndiru | 15-30 | 1½ | VF | (S)AB | 2 | 1½ | 1 | 1½ |
| | 35-40 | 1½ | VF | AB | 2 | 1 | 1 | 1½ |
| 1000 | 0-15 | 1 | VF | (S)AB | 2-1½ | 1 | 0 | 0 |
| Wanjare | 20-35 | 1½ | VF | (S)AB | 2-1½ | 1 | 0 | 0 |
| | 55-65 | 1 | VF | AB | 2-1½ | 0 | 0 | 0 |
| 1014 | 5-15 | 1 | VF | (S)AB | 1½ | 1 | 0 | ½ |
| Riosiri | 40-50 | 1 | VF | AB | 1½ | 1 | 0 | ½ |
| 1001 | 0-5 | single grain | | | 1 | 2 | 0 | 0 |
| Nyabondo | 10-20 | | | | 1½ | 1 | 0 | 0 |
| 1002 | 15-30 | massive | | | 23/4 | 2 | 1½ | 2 |
| 1005 | 5-15 | 1½ | VF | (S)AB | 1½ | 1 | 0 | 1-½ |
| Magenche | 20-30 | 2 | VF-(F) | AB | 2 | 3 | 0 | ½ |
| | 60-70 | 1½ | VF-(F) | AB | 2 | 2 | 0 | ½ |
| 1016 | 5-15 | 1 | VF | (S)AB | 1½ | 1 | 0 | ½ |
| Itumbi | 50-55 | 1 | VF-F | AB | 3 | 3 | 0 | ½ |

## D. The behaviour of soil aggregates on submersion.

In the classification table of Jansw and Koenigs the following types are distinguished:

Type 1 - STABLE NOT WORKING SOILS: the aggregates do not fall apart and are not easily dispersed on stroking with a brush.

Type 2 - STABLE WORKING SOILS: the aggregates fall apart in fragments which are not easily dispersed on stroking with a brush.

Type 3 - UNSTABLE WORKING SOILS: the aggregates fall apart in fragments which are easily dispersed in stroking with a brush.

Type 4 - SOILS MODERATELY SUSCEPTIBLE TO AIR EXPLOSION.

Type 5 - SOILS VERY SUSCEPTIBLE TO AIR EXPLOSION

Type 6 - AUTOMATICALLY DISPERSING SOILS (slaking soils)

Type 7 - Na-CLAYS, dispersion and a noticeable swelling

These types express a range from soils not-susceptible to surface sealing to soils very susceptible to surface sealing.

Table V consists of rows and columns, the columns (vertically) give the submersion types within a profile on three depths, the rows (horizontally) give the submersion types of the profile at a certain depth.

TABLE V - Submersion types

| | 1007 | 1008 | 1004 | 1009A | 1015 | 1003 | 1000 | 1014 | 1001 | 1002 | 1005 | 1016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ap | 1 | 1 | 3-5 | 1-4 | 4-5 | 5-6 | 5-6 | 4-5 | 6 | | 5 | 4 |
| A1 | 1 | 1 | 3 | 1 | | 5 | 5 | | 4-5 | | 4 | |
| B | 2 | 5 | 5 | 4-5 | 5 | 5-6 | 5-6 | 5 | | 6-7 | 5 | 5 |

Conclusions:

- the unploughed topsoil (A1 or A3) is less susceptible to surface sealing than the subsoil (B).
- the ploughed topsoil (Ap) is often more susceptible to slaking than the second layer (unploughed topsoil, A1 or A3).
- the soils developed on basalt of Kisii West are clearly less susceptible to surface sealing than the other soils.
- the negative influence of the length of the cultivation period on the susceptibility to surface sealing could be observed in the cultivation sequence of soils 1007 - 1008 - 1004 (respectively 0 - 10 - 30 years cultivation on the same soil type and with the same environmental conditions.

## E. Determination of the Aggregate Stability by comparing the aggregate size distribution before and after wetting.

The aggregate size distribution - expressed in weight percentages after the first and second wetting are given in Appendix III.

From the data in Appendix III 2 fractions are taken for further evaluation:

- the fraction>2mm, this fraction indicates the resistence of the original material against forces (the higher the percentages bigger than 2 mm, the higher the aggregate stability).
- The fraction<0.125 mm (=125 mm),
  in agriculture we are interested in the smallest aggregates because: the permeability of soil for water is proportionally with the diameter of the pores and therefore in a sedimentation situation proportionally with the aggregate size.
  Secondly fine aggregates are easily carried away by wind and water thus giving rise to wind and water erosion.
  The fraction 0.125 mm could be an indicator for sealing phenomena in the topsoil.

In general a soil with a strong aggregate stability is not or slightly susceptible to surface sealing, but the revers is not so clear.
A soil with a low aggregate stability (=here defined as a soil with less aggregates bigger than 2 mm) could have more or less aggregates smaller than 0.125 mm and could be so more or less susceptible to surface sealing .

These two criteria - the fractions>2 mm and<0.125 - are combined in a classification, which is rather arbitrarely, but constructed for case of handling the data in Appendix III.

| CLASS | %>2 mm | %<0.125mm | |
|---|---|---|---|
| I | 70 | 5 | |
| II | 30-70 | 5 | - decreasing aggregate stability |
| III | 10-30 | 5 | |
| | 10-50 | 5- 10 | |
| IV | 10 | 5- 10 | |
| V | 10 | 10- 15 | - increasing sealing danger |
| VI | 10 | 15- 20 | |
| VII | 10 | 20 | |

The data in Appendix III are now classified and tabulated.

TABLE VI - Aggregate stability class

| | 1007 | -1008 | -1004 | -1009A | -1015 | -1003 | -1000 | -1014 | -1001 | -1002 | -1005 | -1016 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ap | I | II | III | III | III | VII | III | V | VII | | IV | V |
| A1 | I | I | II | II | | V | II | | IV | | IV | |
| B | IV | IV | IV | III | III | VI | II | V | | VI | IV | IV |

Conclusions:

- the topsoil (A) has a better aggregate stability than the subsoil (B)
- the ploughed topsoil (p) is more susceptible to aggregate defredation than the unploughed second topsoil layer (A1 or A3).
- the soils developed on basalt of Kisii West have a better aggregate stability than the other soils.
- the negative influence of the cultivation period on the aggregate stability could be observed in the cultivation sequence (1007 -1008 -1004) after 30 years the influence of the cultivation is also visible in the undisturbed deeper parts of the A-horizon.

## F. The determination of the structure stability in semi-natural conditions

The air dry clods were subjected to the weather on 25-6-74.
In the afternoon the clods weere attacked by a hailstorm, so on 26-6-1974. the first observations about the resistence of the clods against natural destructions forces were made.
The observation were repeated on 1-7-1974 and on 19-7-1974 the experiment was finished.
In Appendix V all the clod destruction percentages (estimated and measured) and other observations are shown.
As already stated the measured clod destruction percentage is the weight percentage of all the destructed clod material.

Conclusions from Appendix V:

- the estimated clod destruction percentages show a fair correlation with the measured data.
- the presence of a crust or a weak crust is clearly correlated with the presence of fine particles in the destructed clod material.
  Fine particles induce always a weak crust.
  Medium to fine particles sometimes induce a weak crust.
  Large to medium particles induce only in one case a weak crust.
- The spherical voids are a noticable phenomenon.
  their presence is bound to the presence of crusts or weak crust and are known in heavy sealed soils.

More attention will be paid in the section about surface sealing.

- Clod destruction evaluation of an Ap-horizon only based on the destruction percentage is contestable, but combining the clod destruction percentage with other observations - size of the aggregates and degree of cementation of the eroded material - evaluation is quite possible.

For ease of comparing the results of the several structure stability determinations (table V and VI) a classification has been constructed. The clod destruction percentage and the velocity of clod degradation are the criteria.

| Clod Destruction Class | Percentage at 19 July | |
|---|---|---|
| A | 10 | strong inter-aggregate cohesion |
| B | 10-30 | |
| C | 30-50 | |
| D | 50-75 | |
| E | 75-100 | weak inter-aggregate cohesion |
| F | 100- at 1 July | |

The data in Appendix V are now classified and tabulated in Table VII.

TABLE VII - Clod destruction class

| 1007 | -1008 | -1004 | -1009A | -1015 | -1003 | -1000 | -1014 | -1001 | -1002 | -1005 | -1016 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| A | E | B | $E^x_o$ | C | $E^x_o$ | D | E | $F^x_o$ | | $D^x$ | D |
| A | A | B | D | | C | B | | $E^x_o$ | | B | |
| D | D | E | F | E | F | F | F | | $F^x_o$ | $F^x$ | F |

In some cases the class smybol has a suffix:

x = a weak crust was formed in the eroded clod material

o = spherical voids were observed in the crust

The combination of a high clod destruction % (=weak inter-aggregate cohesion) and the presence of a weak crust (= weak intra-aggregate cohesion) indicates a soil very susceptible to surface sealing.

## 3.3. SURFACE SEALING

### 3.3.1. Methods

As stated in section 2 a micro-planation proces occurs in every soil which has been tilled, this results into micro-erosion of the clods and filling of the depressions with the eroded clod material.

From the point of view of macro-erosion it is important to know the the velocity and the form of micro-erosion and sedimentation.

The study of the sealing proces comprises out of field work and laboratory work:

| | |
|---|---|
| FIELDWORK | A - Surface descriptions (and the talking of undisturbed samples) |
| | B - Observations during rainshowers |
| LABORATORY WORK | C - Study of undisturbed top soil samples |
| | D - Determination of thehydraulic conductivity of sand and aggregate fractions. |

#### A. Surface descriptions

The factors influencing the micro-planation proces are similar to those of the macro-erosion:

- precipitation
- soil
- vegetation cover
- relief
- land tillage

Describing a soil surface one had to pay attention to these factors. The following form was hereby used:

Number, location and date

1. Soil
   - if present the soil pit number
   - classification
   - parent material
   - horizons, thickness and colour
   - texture
2. Vegetation
   - crop name (and important weeds)
   - estimation of crop covering percentage and growth phase
   - date of sowing
   - crop rotation

3. Land tillage - data of ploughing and weeding
   - implements used (plough or hoe )
   - cultivation period
4. Micro-relief - visibility of clods and micro-valleys (sharp or gradual transition from clod to micro-valley and the height difference between them)
   - estimation of coverings % of clods and micro-valleys
   - roughness of the clod and micro-valley surfaces.
5. Erosion and sedimentation image:
   - the micro-relief part describes the components of the surface, in this part the arrangment and cohesion of the soil components are described in a trasverse section of the upper centimeters of the soil.
   - erosion image of the clods (micro-hills or plough ridges): pay attention to the often very thin smooth cemented surface layer.
   - sedimentation image of the micro-valleys: observe the presence of stratification, diameter aggregates and other particles, thickness of the sedimentation layers and also the presence of spherical voids.

A small piece of millimeter paper and a magnifying glass is a good aid in the estimation of the particle diameter.

The cohesion of the eroded and sedimentated material has been described by using three classes: loose (not cemented), a weak crust (weakly cemented) and a crust (stronger cemented).

Studying a loose topsoil or a weak crust is often difficult without disturbing the transverse section, carefully wetting of the upper centimeters gives the possibility of talking small stronger clods.

For the micro study of the sealed topsoil a binoculair (100 times magnifying) was used.

Small soils peels have been made on several spots (dimensions about 10 x 20 cm).

Dry loose topsoils were carefully wetted before putting glue on it.

## B. Observation during rainshowers.

One of the possibilities to study the sealing process are field observations.

Infiltration velocity versus pricipitation intensity.

Run-off occurs if the infiltration velocity is lower than the rain intensity.

In the field local conditions may be of importance for the origin of stagnant water.

A factor influencing the local precipitation intensity is the presence of crop cover. Leaves intercept the rain and so run-off and concretion of water towards the leaf ends (=leaf wash) one start.

On relative small spots just below broad leaves leaf wash increases the precipitation intensity.

Factors influencing local infiltration velocity:

- compaction of the topsoil by cultivation, tracks, footprints....
- sealing (redistribution of topsoil material caused by the procipitation resulting in lower hydraulic conductivity).

Maize is the main crop in Kisii, the maize plant has broad leaves with interception and leaf wash possibilities.

Appendix IV shows a simple field method for the ddtermination of differences in the precipiation caused by maize leaves.

The same Appendix shows a calculation method for the determination of local precipitation difference caused by the maize plant;also a calculation method of the crop cover percentage is given.

## D. Hydraulic conductivity

One of the possible sealing phenomena is the presence of mostly very thin layers (consisting of very fine particles) which are located in the filled up micro-valleys (see figures 7A and 7B).

The hydraulic conductivity of the soil is determined by the sizes of the pores and not by the total air-filled pore volume (=porosity).

For example, a soil consisting of spherical sand grains with a diameter of 2 mm has the same porosity as a soil of spherical sand grains of 0.01 mm, but the pore size differs enormous, resulting in a large hydraulic conductivity differences

Fig. 2 Vertical photograph of plough ridges with a micro-valley in between

In an undisturbed sedimentation profile (no bio-activity) the pore size and so the hydraulic conductivity is determined by the particle size distribution.
In a stratified sedimentation profile, the hydraulic conductivity is determined by the particle or aggregate diameter of the layers containing the finest particles.

The determination of the hydraulic conductivity of the sedimentation profile in a micro-valley is difficult bacause of disturbance of the often very thin waterstagnant layers.
An attempt has been made to determined the hydraulic conductivity indirectly.
In the laboratory the k-values are measured of fractions with a certain diameter. Now the correlation between the k-value and the particle diameter is known.
With the measured diameter of the particles in the often thin sedimentation layers (with the smallest particles) the hydraulic conductivity can be calculated.

Material for the k-value test:
- glass percolation tubes (0 2.6 cm)
- cotton to close the tubes at one side
- measuring glasses and stopwatch
- sieve sand and aggregate fractions

Calculation method:
The hydraulic conductivity or k-value of the column was calculated with the law of Darcy:

$$Q = K \cdot \frac{H}{L} \cdot F$$

$$v = K \cdot \frac{H}{L}$$

Q = output water ($cm^3$/min)
K = hydraulic conductivity (cm/min)
H = hydraulic head (cm)
L = length of soil profile in column (cm)
F = transverse surface of the tube ($cm^2$)
v = velocity (cm/min)

For a stratified soil profile yields in a stationary saturated situation $= v = kl \cdot \frac{H1}{Li} = k2 \cdot \frac{H2}{L2}$

1 = layer 1
2 = layer 2

The hydraulic conductivity of a fraction have been determined in a layer of 1 cm thickness.
This 1 cm thick layer is protected against disturbance by putting some coarse sand at the lower and upper boundary.
With measuring glass and stopwatch Q could be obtained.

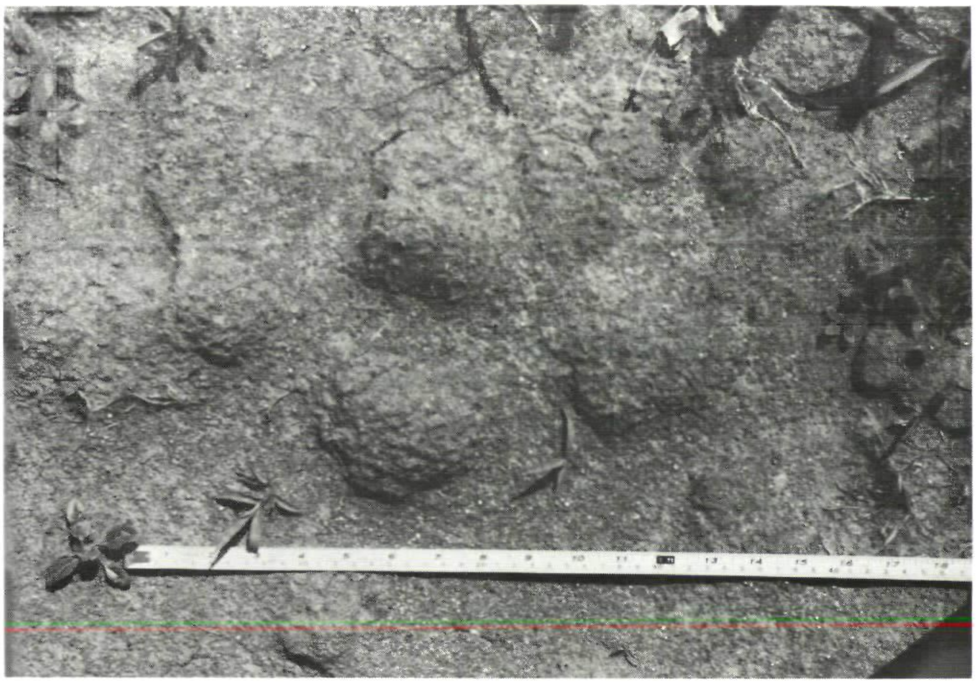


Fig. 3 Sealed surface, description no. 2

Fig. 4 Sealed surface, description no. 4

## 3.3.2. Results

### A. Surface descriptions

For complete surface descriptions see Appendix VIII and the figures 3 and 4.

In general:

- The soils located outside the Kisii West area (near Ndiru and Bondo) are very susceptible to surface sealing.
  The micro-planation proces in the ploughed fields is fully developed, resulting in large, flat sheetwash planes with scattered smooth eroded clods (see figure 3 and 4, page 32).
  In the sedimentation layer abundant spherical voids are present.
- The soils of the Kisii West area are not or moderate susceptible to surface sealing.
  Although the micro-planation proces occurs in every soil which has been ploughed, a strong decrease in infiltration capacity resulting in runn-off and erosion is probably only of importance on soils developed on quartsite and granite.
  The soils developed on basalt are not or less susceptible to surface sealing.

Evaluation of the susceptibility to sealing of soils with only surface descriptions is unreliable because of uncertainity about the weather and cultivation differences.
Yet it gives an impression of the possible susceptibility to sealing and about the forms of sealing.
Studying the sealing proces the field descriptions are indispensable. The results of structure stability determinations in the laboratory gives us the right sequence of aggregate stability and susceptibility to sealing (3.2. structure stability).

Remarkable is the presence of the spherical voids in some sealed soils. In the sedimentation profile of alternating layers with coarse and fine particles spherical voids occur with a diameter of about 1 to 3 mm.
These voids are no bio-pores, they are complete spherical and not connected with each other (see also discussion).

## B. Observations during rainshowers.

The observations are fully described in Appendix IV and could be summarized:

- erosion of clods and sedimentation in depressions has been observed
- The presence of (maize) plants and local compactions of the topsoil influences the occurrence of runn-off spots.
- Precipitation, intercepted by maize leaves and running to leaf ends (= "leaf wash") makes the rain intensity on spots just below the leaf ends maximum 3 or 4 times higher than the'free precipitation".
- A theoritical approach of the influence of this "Leaf wash" on the precipitation intensity on small sports just below the maize leaves shows agreement with local intensity measurements in the field.
- One observation shows on a soil (parent material basalt) with well developed maize plants the rain intensity must be 0.5-1.0 mm/min before some runn-off starts.

## C. Undisturbed topsoil samples.

Several small topsoil peels of soil developed on basalt, quartzite and granite have been made and studied with a binoculair (maximum magnification 100x).
See picture 5 and 6.

In general:

- soils on basalt show a weakly developed sedimentation layer, which consists of coarse to medium sized aggregates.
- soils developed on quartzite and granite show a clearly developed sedimentation layer in which very thin, very fine grained layers occur.

  These layers present probably the bottleneck in the water infiltration proces.

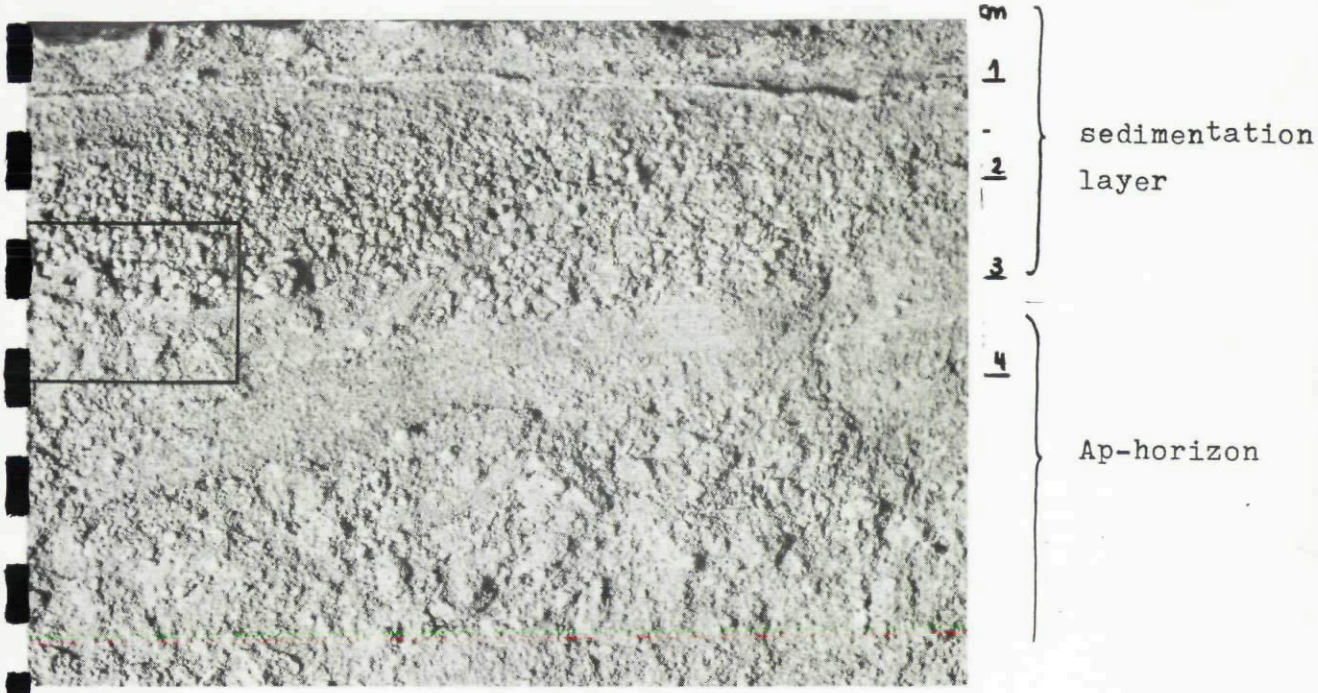


Fig. 5 Micro soil peel, parent material Kitere granite, near Riosiri (surface description no. 13)

Fig. 6 Detail of Fig. 5, see inset

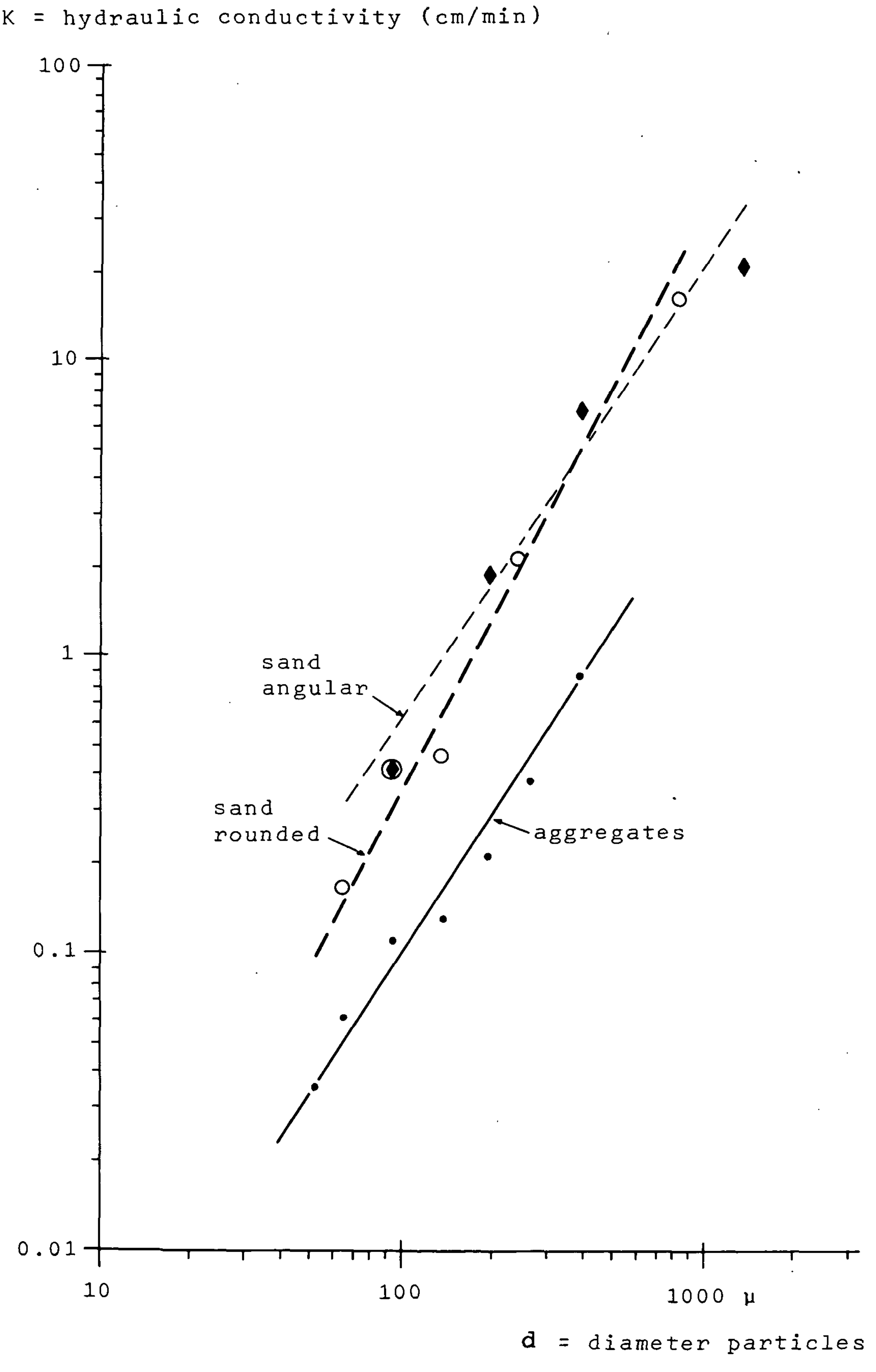


Fig. 7 Hydraulic conductivity versus particle size.

## D. Hyraulic conductivity (K-factor).

Two types of sand (angular and rounded) and aggregates of a soil developed on basalt are used for the hydraulic conductivities of the sieves fractions.

For the results of the K-factor determinations of the fractions see table IX.

Table IX: K-factors of sand aggregate fractions.

| diameter of particles. | K-factor cm/min. |
|---|---|
| SAND - angular | |
| 500 - 2000 mu | 20.8 |
| 250 - 500 mmu | 6.9 |
| 125 - 250 mu | 1.8 |
| 60 - 125 mu | 0.42 |
| SAND - rounded | |
| 500 - 1000 mu | 16.0 |
| 150 - 300 mu | 2.1 |
| 105 - 150 mu | 0.46 |
| 75 - 105 mu | 0.41 |
| 50 - 75 mu | 0.17 |
| AGGREGATES | |
| 300 - 420 mu | 0.86 |
| 210 - 300 mu | 0.38 |
| 150 - 210 mu | 0.21 |
| 105 - 150 mu | 0.13 |
| 75 - 105 mu | 0.11 |
| 50 - 75 mu | 0.06 |
| 50 | 0.035 |

The data from table IX are graphically presented in figure 7. (page 36) Figure 7 shows that the hydraulic conductivity as a function of the particle diameter is probably a straight line (on double log paper). The mathmetical function which expresses this straight lines is:

$\log K = \log a + b.\ \log d$

K = hydraulic conductivity
d = diameter midway of the particle fraction

or $K = a.d^{b}$

a and b = parameters

From data out of table IX the K - d functions for the different materials was calculated.

angular SAND: $K = 600.d^{1.49}$
rounded SAND: $K = 1850.d^{1.83}$
AGGREGATES: $K = 94.d^{1.47}$

Theoretically the hydraulic conductivity is a square power function of the pore size (Poiseuille, Darcy) and thus a square power function of the particle size.

Other investigators show experimentically that the K-factor is a function of the specific surface.
The K- d function of rounded sand agrees the best with the theory of $K = f(d^2)$
The deviation of the angular and aggregates function $K = f(d^{1.5})$ is probably due to the difference in shape between these particles and spheres of the same diameter and the falling apart of the aggregation.

The graph and functions can be used to predict the order of magnitude of the K-factor in fine grained sedimentation layers.
A rain intensity of 1.0 mm/min is not extremely high in the Kisii West area (see chapter environment).
According to figure 7 a K-factor of 1.0 mm/min belongs to an aggregate diameter of 100 mu (0.1 mm).

Although on the existing hydraulic gradients during the shower one may conclude that a thin layer with a particle size of bout 100 mu or less in the topsoil could stagnant water

Only the soil peel taken from a granite soil (Kitere granite) shows a sedimentation profile with unbroken thin layers consisting of particles of 100 mu or smaller.
With the naked eye a sedimentation profile in a micro-valley is clearly build up of alternating coarse and fine grained layers.
Microscopic study of the fine grained layers shows that the upper particle size boundary is rather sharp and measurable but the lower boundary is diffuse, so the defining of a diameter midway is rather difficult.

## 3.4. DISCUSSION

There are few theories describing the sealing processes in detail. The general theory is: "uncovered soils seals as the result of the power by which the raindrops are beating the soil. The soil falls apart into fine particles and these particles block the pores which are important for infiltration".

This is of cause true but their are several possibilities to get the result of blocked pores.
In this study the importance of sedimentation layers in depressions between clods and plough ridges has been studied.
It is obvious that the hydraulic conductivity in a sedimentation profile is determined by the layer with the finest particles.
Such a layer could be located at the surface but also some centimeters deeper in the sedimentation profile.

An explanation for the sealing proces in the micro-valleys is only one part of the story, left are the possible sealing processes on the clods and plough ridges. The sealing occurs here in the upper millimeters of the topsoil.
A clear thin crust on clods was only found in the soils very susceptible to surface sealing.
On nearly all the plots studied the clods were rounded by erosion having a more or less smooth surface. This decrease in roughness of the clod surface is already an indication for lowered infiltration capacity.

Although the sealing proces of the clods is not known at the moment the filling of micro-valleys or furrows with sometimes clear sedimentation profiles are a proof for (temporarily?) bad infiltration capacity of the clods.

The spherical spaces are a known phenomenon is soils suscptible to sealing. Jongerius (1957) calls this a "gas bubble" structure. His (is the field) prove explanation is that on sealed spots with a saturated topsoil algae are responsible for these gas bubbles.
After fininshing the determination of the clod stability in semi-natural conditions (see page 20 and 31) these spherical voids were also observed in the eroded clod material of some soils which showed this phenomenon also in the field.
Although the samples have been observed often, algae growth was not noticed(but at the moment the author was not familiar with theory of Jongerius).

Required circumstances for the presence of the gas bubble structure
- saturated topsoil during a certain time
- fine grained matrix.

Another possible explanation for the origin of the gas bubble structure could be a big rise of the topsoil temperature. This temperature rise in the saturated sealed topsoil causes the free making of dissolved air and expansion of the enclosed air will cause spherical voids (topsoil temperature rise due to insolation). This hypothese was cheked with a saturated puddled soil in a petri-scale in the windo-sill on a clear day, although not aboundant spherical voids of about 1mm Ø had been developed.

The presence of spherical voids indicates undoubtly a soil strongly susceptible to sealing, the reverse conclusion however must be handed carefully.
The absence, does not mean always that the soil is less susceptible to sealing, the conditions for the developing of the voids during a stagnant water period were not good (less insolation or no algae growth).

# 4. THE INFILTRATION CAPACITY

## 4.1. Introduction

The infiltration capacity of the soil is the ability of the surface soil to soak up water (mm/min)
Infiltration rates of different soiltypes in the Kisii West area have been determine, as they usually provide information of the amount of runn-off and erosion, that might occur.
However, considering the runn-off simply as the difference between precipitation and the measured infiltration capacity is a risky simplification.
Infiltration capacity itself can be considered as a useful soil-characteristics determined according to a standard-method.

## 4.2 Materials and methods

### 4.2.1. The floater + ring infitrometer (fluctuating hydraulic head)

The principle of this method is a plastic floater connected with a measuring-tape, which indicates the fall of the water-level in the ring during the infiltration (see fig. 8).

The method has been tested before use in the field.
Recorded infiltration rates appeared to be very high and fluctuating due to the rapid changes of the hydraulic head.
A full ring was emptied often within 20 minuts, which made frequent fillings necessary with the help of a jerrycan.

Only on soils with low or medium infiltration rates this method could be applied succesfully.
Readings had to be done with at least a 15 minutes time-interval in order to level out the strongest fluctuations of the infiltration.

### 4.2.2 The nozzle + ring infiltrometer (constant head, Fig. 9)

A new and more adapted infiltration-method has been developmant in order to meet two requirements:

I) Higher water-supply capacity
II) Constant hydraulic head with only minor fluctuations.

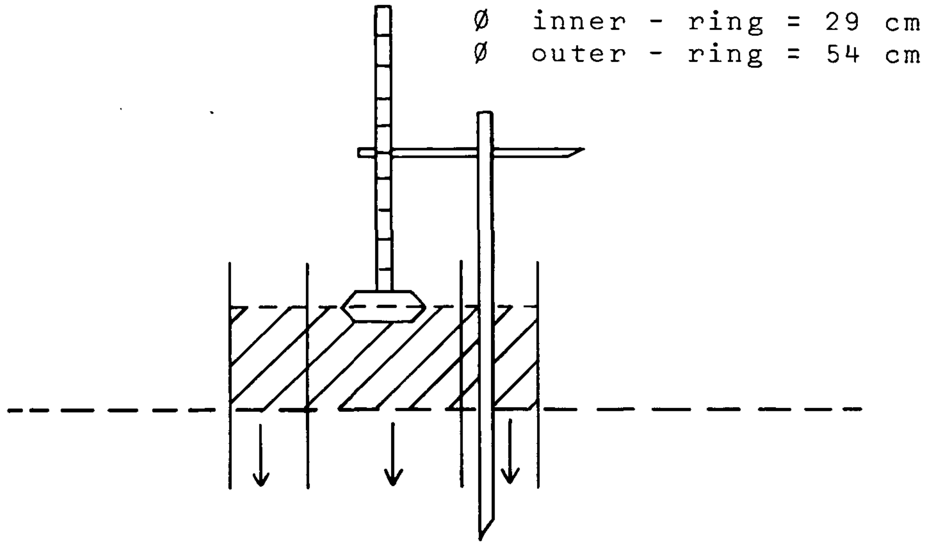


Fig. 8 Sketch of floater + ring infiltrometer

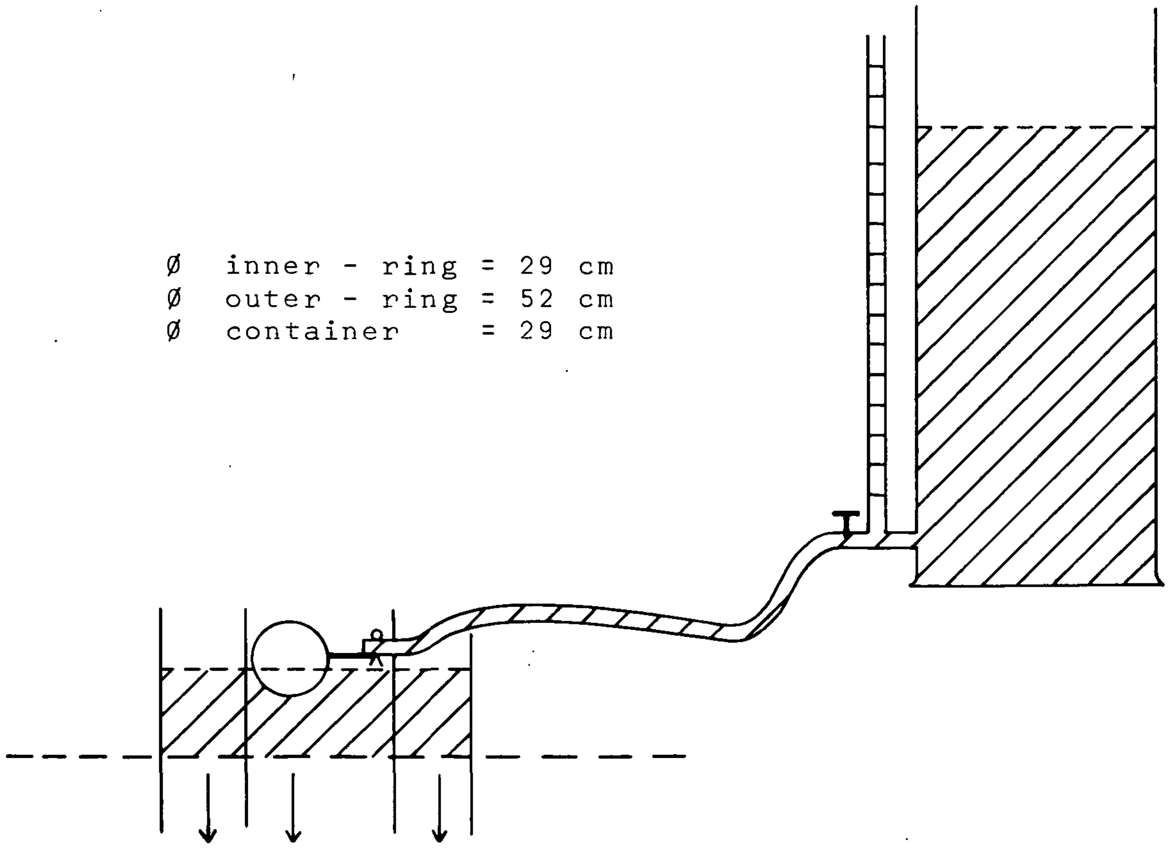


Fig. 9 Sketch of nozzle + ring infiltrometer

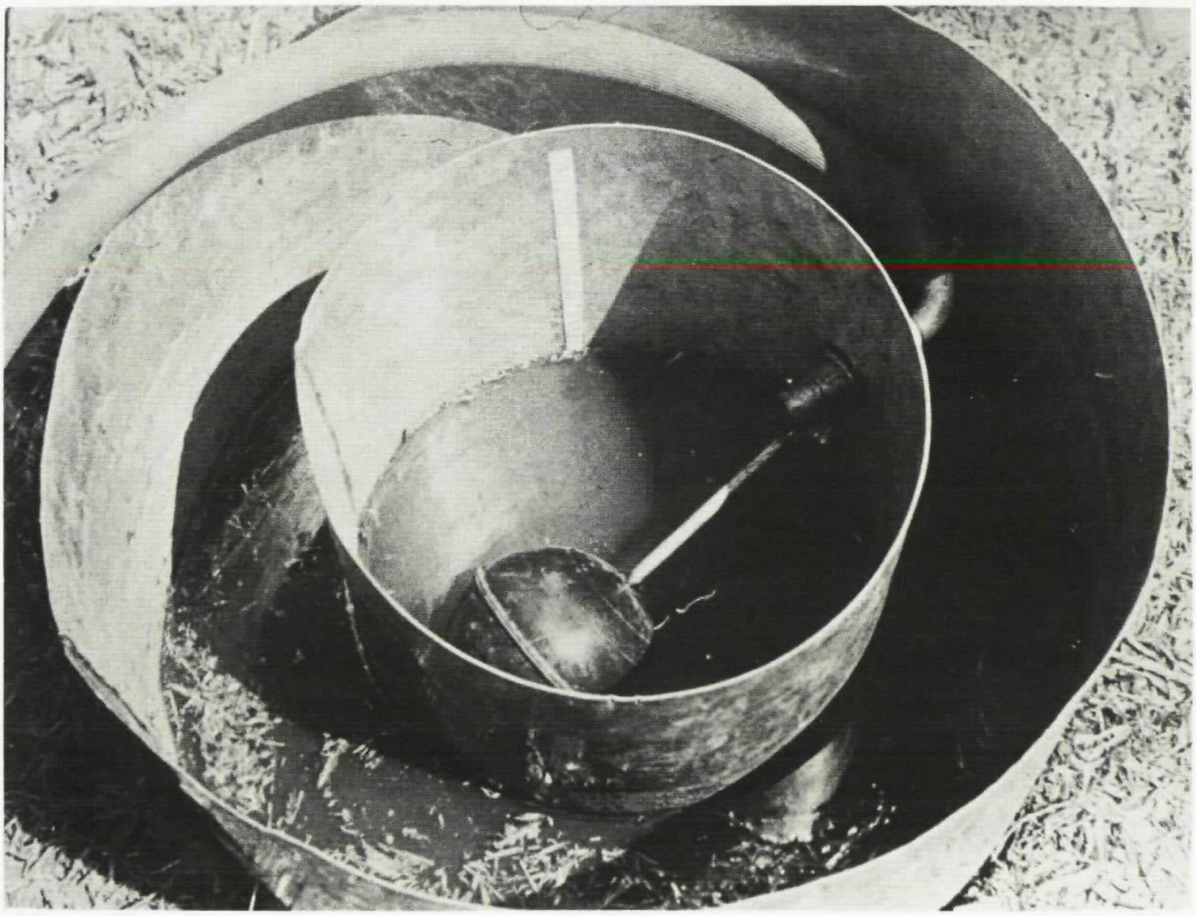


Fig. 10 The floater consisting of a plastic ball is connected with a nozzle (nozzle + ring - infiltrometer)

The "cistern" principle, containing a floating ball + arm connected to a regulation nozzle, has proven to be very suitable for this purpose (see fig. 1).
The changes of the waterlevel inside the inner-ring could be controlled with this self-regulating mechenism: only small fluctuations did occur (1-2 cm).
A water container (60 litres) with a calibrated gauge-glass was connected for a permanent water supply (see fig. 9).
When during the infiltration-tests large quantities of water were needed a big reservoir (400 litres) was used.
The outering was filled directly with the help of jerrycans and maintained on the same level as the water inside the inner fing.

Advantages of this method are:

1) slow water-movement during the filling of the ring, by which the soil-surface remains relatively undisturbed during the test.
2) Constant hydraulic head, by which the flactuations of the infiltration are considerbly less.

Disadvatages of the method are:

1) Low maximum waterflow through the nozzle (55-60 litres/ hr.)
   Due to this, the initial infiltration rates of the most permeable soils could not be recorded.
2) Plugging of the nozzle by small floating particles like grass-roots , sediment etc., which resulted in a slowing down of the water-flow.
   In that case container had to be cleaned completely before continuing the test.

A general problem was the inaccessibility or absence of water in the field. Some fieldplots could not be tested as water was absent. Roads were often impassable, which restricted the use of a large water-reservior.

### 4.3.3. The selection of fieldplots.

Ten fieldplots have been selected on the basis of their soil-characteristics.

TABLE X - Environmental characteristics

| Location | Pitnumber | Parentmaterial | Soildepth | Infiltration method |
|---|---|---|---|---|
| Masai 0 | 1007 | basalt | deep | I[x] |
| Masai 10 | 1008 | " | " | I+II |
| Masai 30 | 1004 | " | " | I+II |
| Magenche A | 1005 | quartzite | shallow | I |
| Magenche B | 1006 | " | deep | I"II |
| Magenche C | 1005 | " | " | I+II |
| Wanjare | 1000 | granite | mod. deep | I |
| Ndiru | 1003 | basalt | mod. deep | I+II |
| Bondo A | 1001 | granite | mod. deep | I+II |
| Bondo B | 1002 | granite | deep (planosol) | I+II |

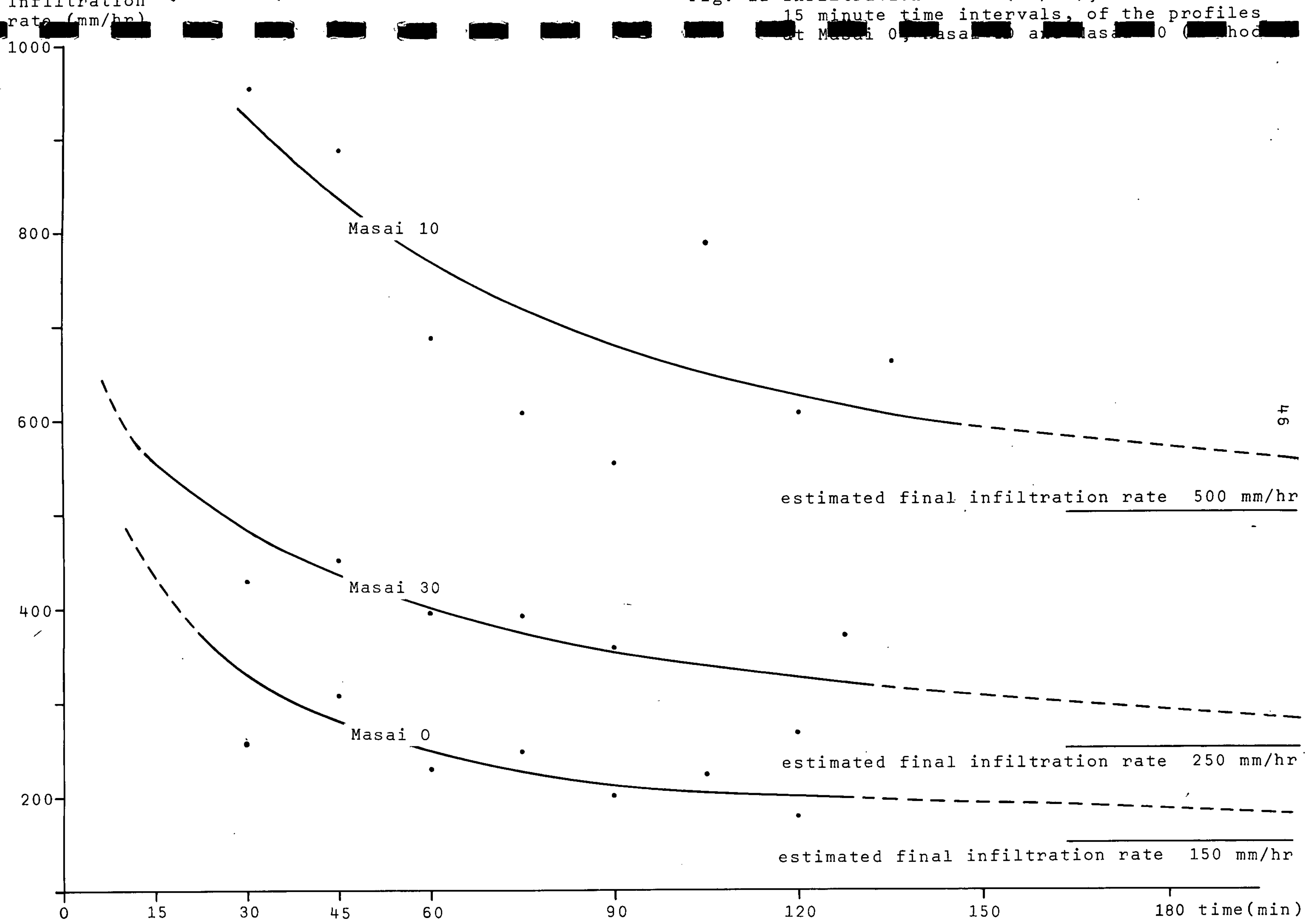
[x]) to the nozzle+ring infiltration method and the floater+ring infiltration methods referred as method I and method II, respectively.

The Masai and Wanjare profiles have already been investigated in previous study on organic matter by van Wissen (1975 P.R. 4).
The other profiles are selected in consulting with Kauffman.
The tested soils include most of the common soiltypes of the Kisii West area and also 3 soils, which are developed under drier climatic conditions in East Nyokal-South Nyanza (Ndiru-Bondo A -Bondo B)

Before starting the infiltration, the soil surface was studied in order to get an "average" plot for the test without large depressions, clods or plough ridges.
Infiltration has been determined each 15 minutes with the aid of a stopwatch; this has been done mostly during 2-3 hours.

Soilpits were dug near the infiltration plots, described and classified according to the FAO "Guideliness for soil descriptions" and the Munsell Soil Colour Charts. The detailed profile descriptions are present in Appendix VII. Soil samples were taken from each horizon for further analysis in the laboratory.

15 minute time intervals, of the profiles
at Masai 0, [redacted] and [redacted]0 ([redacted]hod



## 4.3. RESULTS

### 1) MASAI 0 - MASAI 10 - MASAI 30 (prof. 1004/1007/1008 - App. VII)

The three soilprofiles are located in the southern part of the Kisii West area at the Kisii-Masai boundary near Nyabitunwa.

The mean average rainfall is about 1500 mm.
Originally, the area has been covered by a montane Acacia vegetation, which has been reduced to an open savannah grassland due to continuous grazing by cattle.

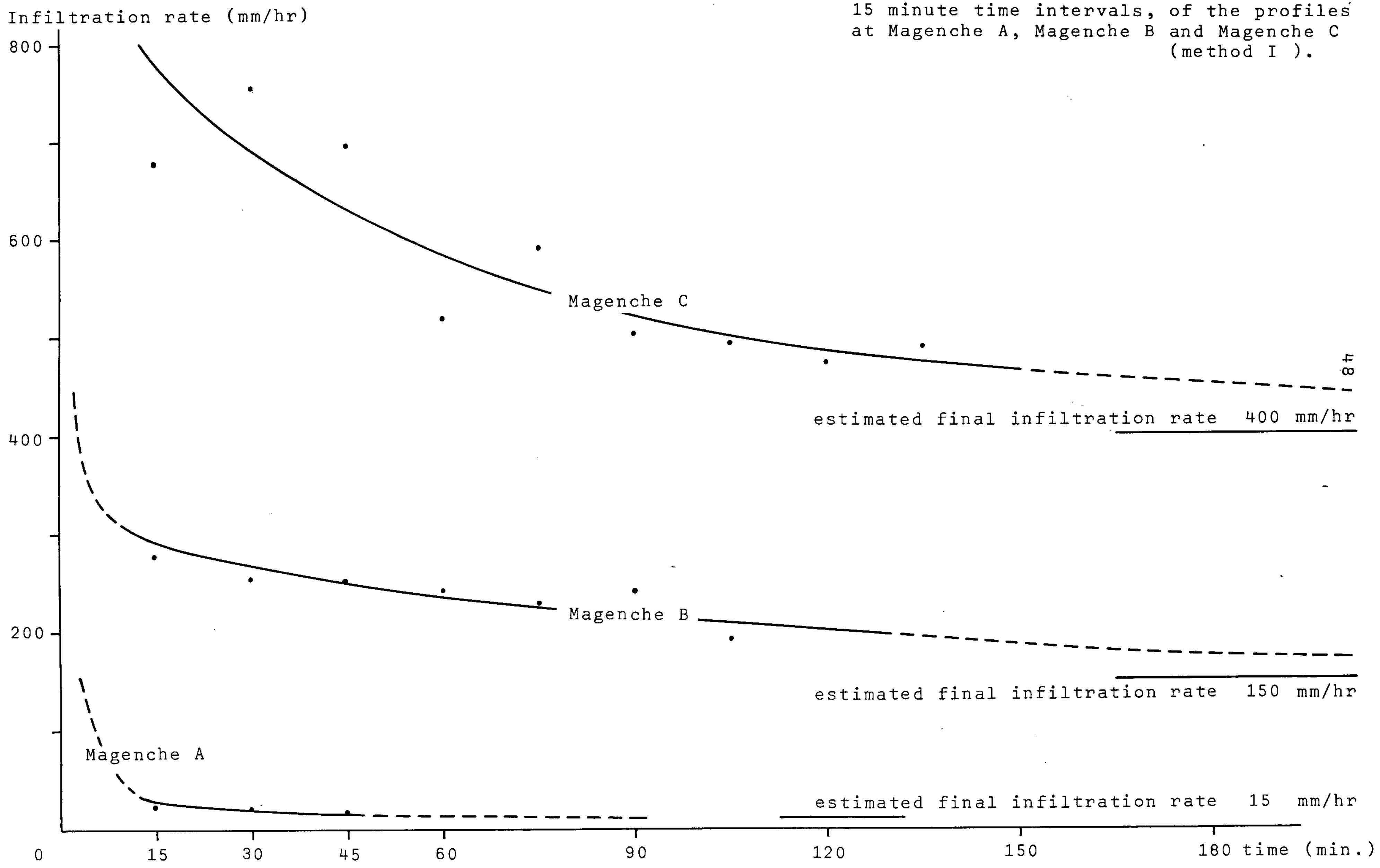
The three soils have been development on basaltic rock (Bukoban - system). They consist of deep, well-drained and dark red, very fine clay soils with thick dark humus- rich A-horizons.
The Masai 0-profile belongs to the Nyaborumbasi series and the Masai 10- and Masai 30- profiles to the Chang'aa series (Marongo detailed P.R. 3).

The soils have been cultivated for different periods: the Masai 0-profile is still under semi-natural grass-vegetation; the soils of Masai 10 and Masai 30 have been cultivated for resp. 10 and 30 years. This range in cultivation period has resulted in varying characteristic of the topsoil (van Wissen 1975).

TABLE XI. Infitration rates (mm/hour), recorded at 15 minutes time: intervals. (Fig. 11).

| | MASAI 0 | MASAI 10 | | MASAI 30 | |
|---|---|---|---|---|---|
| | method I | method I | method II | method I | method II |
| 15 min. | 724 | 1296 | 804 | 768 | 360 |
| 30 | 254 | 952 | 612 | 428 | 241 |
| 45 | 306 | 888 | 712 | 448 | 184 |
| 60 | 230 | 688 | 488 | 396 | 168 |
| 75 | 248 | 608 | 588 | 392 | 204 |
| 90 | 202 | 556 | 488 | 360 | 180 |
| 105 | 226 | 788 | 572 | 338 | 144 |
| 120 | 179 | 608 | 620 | 268 | 112 |
| 135 | | 664 | 418 | 373 | |

Fig. 12 Infiltration rates (mm/hr), recorded at 15 minute time intervals, of the profiles at Magenche A, Magenche B and Magenche C (method I ).



### 2) MAGENCHE A - MAGENCHE B - MAGENCHE C (profile 1005 - App. VII)

The three soilprofile are located 1.5 km east of Magenche (South Mugirango) on a long concave slope with outcropping quartzitic rock at the upperpart.
Climate and original vegetation are comparable with Masai area. The Magenche profiles are part of a soil catena, developed on resistant quartzitic rock (Bukoban system, see Fig. 14).

Magenche A: the profile consists of a shallow, dark soil with only an A-horizon, directly overlying impermeable, slightly weathered quartzite. It belongs to the Marongo series.

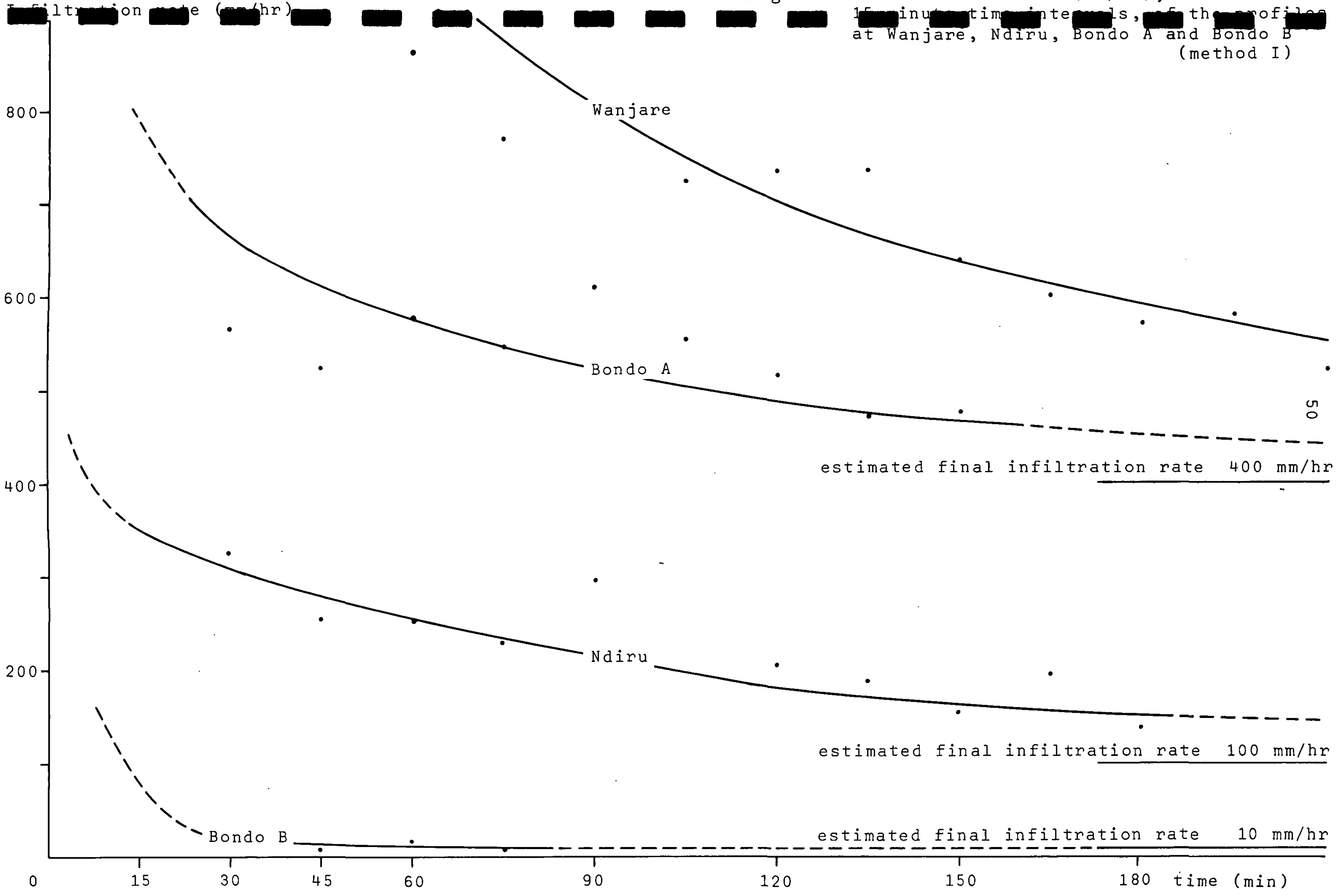
Magenche B: the profile has a thin, dark reddish brown A-horizon with a dark red clayey subsoil.
Textures are fine clayey, but more sandy than the Masai soils, due to the quartzitic parent material (Nyangori series, PR 3 Marongo detailed survey).

Magenche C: the profile is comparable to the previous soil, except for the A-horizon, which is better developed and darker in colour (Nyangori series).

TABLE XII Infiltration rates in mm/hr, recorded at 15 minutes time-intervals. (Fig. 12)

| | MAGENCHE A | | MAGENCHE B | | MAGENCHE C | |
|---|---|---|---|---|---|---|
| | method I | method II | method I | method II | method I | method II |
| 15 min. | 24 | | 280 | 592 | 680 | 788 |
| 30 | 20 | | 256 | 564 | 758 | 856 |
| 45 | 18 | | 252 | 360 | 699 | 780 |
| 60 | | | 244 | 500 | 522 | 605 |
| 75 | | | 232 | 384 | 592 | 458 |
| 90 | | | 244 | 476 | 505 | 441 |
| 105 | | | 192 | 376 | 496 | 452 |
| 120 | | | | | 477 | |
| 135 | | | | | 490 | |

Fig. 13 Infiltration rates (mm/hr), recorded at 15-minute time intervals, of the profiles at Wanjare, Ndiru, Bondo A and Bondo B (method I)



### 3) WANJARE (profiles 1000 - Appendix VII)

The profile located near the Kebuye Range in the Irigonga sub-location (Wanjare)
The precipitation in the area is about 1600 mm/year; the vegetation type can be described as Western intermediate forest. The area has been cultivated with maize and wimbi (mainly) for about 6 to 8 years.

The soil is gravelly (30%) and moderately deep. developed on coarse grained Wanjare granite (Otula series - Irigonga soil survey, PR 2)
Due to the short cultivation period the A-horizon is still well-developed and dark.
Rotten rock (porous) is present at a depth of 1 meter.

TABLE XIII Infiltration rates in mm/hr, recorded at 15 minute time-intervals (Fig. 13)

| | WANJARE METHOD I (recorded in duplo) | |
|---|---|---|
| 0 min. | - | |
| 15 | - | (infiltration exceeds maximum water-supply though nozzle) |
| 30 | - | |
| 45 | - | |
| 60 | 864 | |
| 75 | 770 | |
| 90 | 893 | |
| 105 | 725 | |
| 120 | 734 | |
| 135 | 736 | |
| 150 | 638 | |
| 165 | 602 | |
| 180 | 572 | |
| 195 | 582 | |
| 210 | 526 | |
| 225 | 512 | |

### 4) NDIRU (profile 1003 - Appendix VII)

The profile is located 2 km south of Ndiru village in the sub-district of North Nyokal (South Nyanza), westly of the Kisii West area.

The mean annual precipitation is about 1300 mm, while the original vegetation (Western Combretum savannah) has almost disappeared.

The soil is a moderately deep, reddish brown clay loam with a well-developed A- horizon, developed on basalt (Nyanzian system).
Manganese and iron concretions are present in the subsoil and soft rotten rock occurs at 80 cm.

Cultivated crops are maize, wimbi and groundnuts.
The area has been under cultivation for a long time (probably more than 30 years).

TABLE XIV Infiltration rates in mm/hr, recorded at 15 minutes time-intervals (Fig. 13, page 50).

| | NDIRU | |
|---|---|---|
| | method I (recorded in duplo) | method II |
| 0 min. | - | - |
| 15 | - | 176 |
| 30 | 326 | 136 |
| 45 | 258 | 120 |
| 60 | 254 | 108 |
| 75 | 230 | 96 |
| 90 | 294 | 80 |
| 105 | 198 | 72 |
| 120 | 205 | 62 |
| 135 | 188 | 66 |
| 150 | 154 | 60 |
| 165 | 195 | 58 |
| 180 | 140 | 52 |

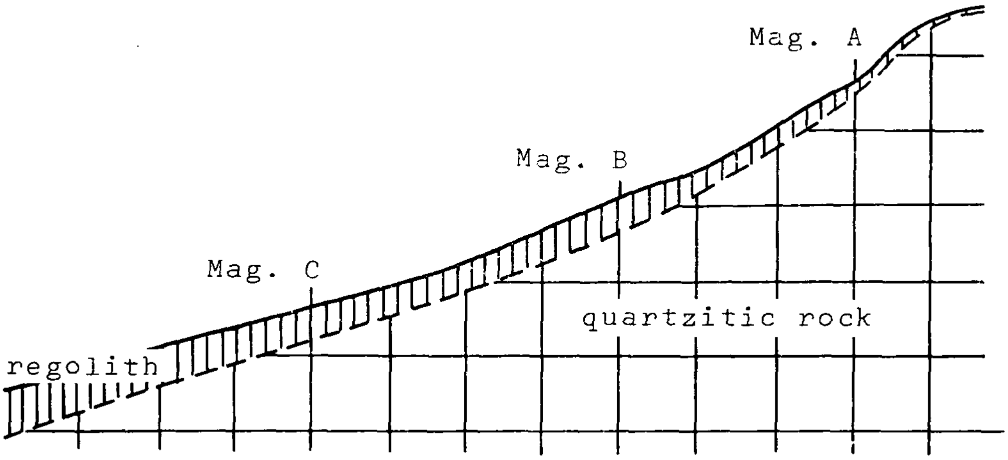


Fig. 14 Location of the three profiles at Magenche

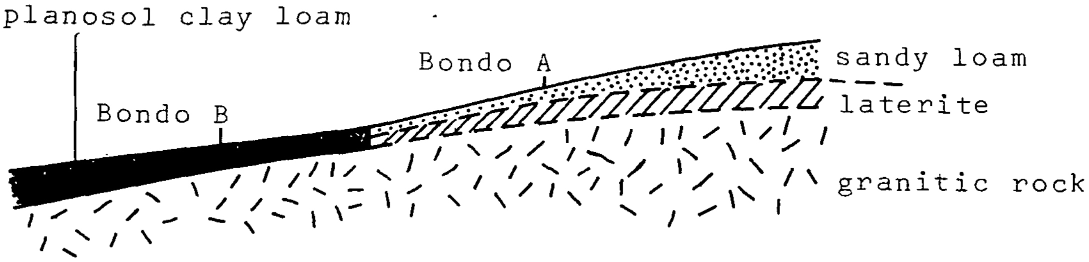


Fig. 15 Location of the two profiles at Bondo

## 5) BONDO A - BONDO B (profiles 1001 + 1002 → App. I)

The Bondo profiles are located some kilometers westly of Bondo village in the North Nyokal subdistrict (South Nyanza).

The mean annual precipitation is about 1200 mm; the original vegetation belongs to the Western Combretum savannah type, but has been replaced by cultivated land almost everywhere.
The profile of Bondo A consists of a rather shallow, sandy loam developed on fine-grained granite (Kitere type).
The profile has a grey, sandy subsoil with cemented iron-manganese concretions; at a depth of 60 cm a laterite pan occurs with some stagnating water (Fig.15)
The fieldplot has been cultivated with maize.

The soil of Bondo is a strongly eroded planosol (Fig. 16)
It is a moderately deep or deep, very dark grey clay loam with a thin, coarse sandy topsoil, while the subsoil has a dense and massive structure with a low porosity.
The site is suffering from severe gully erosion due to overgrazing.

TABLE : XV Infiltration rates in mm/hr, recorded at 15 minute time intervals (Fig. 13, page 50).

| | BONDO A | | BONDO B | |
|---|---|---|---|---|
| | method I | method II | method I | method II |
| 0 | - | - | - | - |
| 15 | - | - | - | - |
| 30 | 567 | 424 | 20 | 156 |
| 45 | 524 | 348 | 8 | 100 |
| 60 | 576 | 343 | 16 | 84 |
| 75 | 548 | 312 | 8 | 60 |
| 90 | 612 | 348 | 2 | 56 |
| 105 | 556 | 280 | | 48 |
| 120 | 516 | | | 44 |
| 135 | 471 | | | |
| 150 | 474 | | | |

The cumulative amounts of water, infiltrated during the first 60 minutes of the infiltration (I cum. 60) have been computed and listed together with the estimated final infiltration rates (I fin.) (Fig. 11, 12, 13).
As a comparison the maximum precipitation, recorded in 60 minutes (April '74 - Cassela rainrecorder at Kisii town) has been added to the table ( Table XVI)

TABLE XVI Cumulative infiltration during the first hour of the test and final infiltration rates (estimated)

| Soilprofile | Icum. 60 in mm. | Ifin. in mm/hr (estimated) | Pmaximum in mm. (60 min.) |
|---|---|---|---|
| MASAI 10 | 878 | 500 | 22.1 |
| WANJARE | 827 | 400 | |
| MAGENCHE C | 667 | 400 | |
| BONDO A | 557 | 400 | |
| MASAI 30 | 449 | 250 | |
| NDIRU | 303 | 100 | |
| MAGENCHE B | 306 | 150 | |
| MASAI O | 275 | 150 | |
| MAGENCHE A | - | 15 | |
| BONDO B | 21 | 10 | |

## 4.4. SOIL ERODIBILITY

For the determination of the soil erodibility, beside the final infiltration rate (=permeability of the soil profile), other soil properties need to be known.

Wischmeyer and others (1969) succeeded in providing a good correlation between soil erodibility and an index of 15 soil properties. So a quantitative estimate could be made of the erosion, which will occur, when the soil is subjected to rainfall of known erosive power.

Simplified this correlation provided the soil erodibility nomograph method, using only five soil properties (Wischmeyer, Johnson and Cross 1971)

These properties are as below:

a) % silt and very fine sand (2 - 100 mu)
b) % sand (100 - 2000 mu)
c) % organic matter
d) structure type and structure size
e) permeability

With these soil properties known, the so-called erodibility factor or K-value can be derived with the aid of the erodibility nomograph. However, when using this method, one has to consider its validity.

I) The method is essentially constructed for medium-textured soils. When clay percentages become high as in the soils of the Kisii West area (50-75%), the effect of the organic matter become reversed: with higher organic matter percentages the aggregation of the soil with usually increase, which results in a higher detachibility and also erodibility of the soils.

II) The method is tested on soils of the east and mid-west of the United States (temperate regions).

In red tropical soils a considerable amount of free iron oxides is present, which has a luting effect on the clay particles.

Hence the percentage of dispersable clay is higher than the percentage of the natural clay, which is defining the erodibility.

So the computed K-value can only be rough approximation of the soil erodibility.

K-values have been computed for the soils which also the infiltration capacity has been determined.

These values have been compared with the structure stability of the soils as determined by Kaufmman (see table XVII)

Determination of the relevent soil properties

a + b) The silt + very fine sand fraction (2-100 mu) are determining the particle size parameter in the nomograph.

Textures have been investigated in the laboratory by sieving and suspension titration ( = determination of dispersable clay)

c) The organic matter percentage have been determined with the Walkley-Black method.
For the calculation of the organic matter percentage a multiplication factor of 1.72 has been used.

d) Structure type and structure size:

Four classes have been distinguished:

1) very fine crumby of subangular
2) fine subangular or angular
3) medium coarse angular
4) blocky, platy or massive

Structure types and sizes have been determined in the field.

e) Permeability
The relative permeability classes as coded below refer to the soil as a whole.
They can be deduced from the infiltration data of section 4.3

According to the modified formula of Kostiakov: $I = b.t^{-\frac{1}{2}} + a$ the infiltration rate is reaching a constant level after some time. This value a corresponds with the estimated final infiltration rate (I fin.) (see table XVI) and also with the permeability of the soil profile as a whole.

Six classes are distinguished:

| | |
|---|---|
| 1) rapid infiltration | over 125 mm/hour |
| 2) moderately rapid | 62.5 - 125 mm/hour |
| 3) moderate | 20 - 62.5 mm/hour |
| 4) moderately slow | 5 - 20 mm/hour |
| 5) slow | 1.25 - 5 mm/hour |
| 6) very slow | less than 1.25 mm/hour |

## 4.5. DISCUSSION

### 4.5.1 Infiltration capacity (see tables XI/XII/XIII/XIV/XV/XVI and fig. 11-12-13

High infiltration capacities with high final infiltration rates (estimated) of the deep soils in the Kisii West area.
Ifin. of the deep soils is always more than 150mm/hr.

The high infiltration capacities can be explained from the high porosity and the strong rootdevelopment of the soils, which continue to a considerable depth (Verwey 1975)
The well developed humusrich topsoil too, contributes to a rapid infiltration.

The presence of krontovinas should be mentioned; they have been created by fieldmice making extensive corridor systems filled up from above with loose topsoil aggregates.
Also other animals as termites, beetles and small ants are creating holes and cirrodrs, thus increasing the infiltration capacity of the soil.
Although no detailed information about these krontovinas is available, their effect on infiltration should not be underrated.

The very gradual decrease of the infiltration rates of most of the soils.
Especially soils with higher infiltration rates need a longer time for reaching a constant final rate (more than 3.5 hour for the Wanjare profile - Fig. 13)

The consequence is that Ifin. has to be estimated as the infiltration tests have lasted for 3 hours maximumly

The gradual decrease of the infiltration rate might be explained from the great profile depth of most of the soils.
Also the high porosity of the soil and of the underlying rotten rock is playing a role (e.g. Wanjare profile).
By means of the factors much infiltration water is needed for reaching a stage of saturated waterflow moving with a constant velocity, which corresponds with the final infiltration rate.

Method II gives lower infiltration records usually than method I does. (see tables XI/XII/XIV/XV)

The lower records obtained from method II can be explained from the "puddling" effect of the water flow on the soil surface, when the ring is filled again with the help of a jerrycan.
When using method I, the surface is hardly disturbed (gentle nozzle flow).
Especially at soils with a considerable silt fraction the records from method I and II are strongly diverging (see table XI/XIV/XV)

Infiltration classes.

The investigated soils can be divided into three infiltration classes based on the Icum. 60-value and on the Ifin.-value (see table XVI)

class I: Icum.60 of over 400 mm- Ifin, of over 250 mm/hour
soil with a very high infiltration capacity (at Masai 10, Masai 30 Wanjare, Magenche C and Bondo A).

Although developed on different parentmaterial the soils have some common properties:

a) Soildepth over 100 cm without impermeable or stagnating layers in the subsoil.
b) A high porosity throughout the soil profile
c) A well developed, humusrich topsoil.

However the soil profile at Bondo A has different properties: it has a soil depth of 60 cm and lacks a humusrich topsoil.
The high infiltration rate can be ascribed to the sandy texture (sandy loam) and to the minor effect of the laterite pan, which is discontinuous and rather porous.

Conspicuous are the lower infiltration rates of the Masai 30 profiles when compared to the Masai 10 profile.
Here the effect of the longer cultivation period, resulting in an increase of the sealing , is evident.

A different aspect is the increasing "gap" between the infiltration rates when recorded with method I or with method II.
At the Masai 10 profile infiltration rates are recorded with method II, which are some 25% lower than the rates recorded with methods I.

At the Masai 30 profile this difference has been increased to 50% (see table XI). This can be explained by a decrease of the aggregation and a higher susceptibility to sealing of the Masai 30 profile (see also table XVII - Structure Stability).
The structure loss due to the continuing surface tillage and the decrease of organic matter content (see table XVII) are responsible for this higher susceptibility.

class II Icum.60 between 250 and 400 mm - Ifin. between 100 - 250 mm

Soils with a high infiltration capacity, (at Magenche B, Masai and Ndiru).
The Ndiru profile has a low infiltration capacity,when compared to the soils of Masai, which are also developed on basalt.

Four soil characteristics are conspicuous:

a) moderate soil depth
b) low to medium porosity
c) low content of organic matter (1.4%)
d) relatively high content of silt and very fine sand (35%)

These factors result in a relatively low infiltration rate and also a easily slaking of the soil surface during the infiltration test.
The Magenche B profile has a lower infiltration rates than the Magenche C profile (303 mm against 667 mm), as it forms an eroded phase of the latter. With a good, dark humusrich and porous A-horizon missing, the infiltration rate is lower.
The truncation of the topsoil has benn caused by the stronger erosion at the position of the Magenche B profile: just below a quartzite scarp which provides large amounts of runn-off during heavy showers.
The Masai 0 profile has a rather low infiltration capacity when compared to the Masai 10 and Masai 30 profiles.
This can be ascribed to 2 factors:
d) The effect of soil tillage, which opens the surface soil and raises the soil porosity; however, soil tillage has never occured at the Masai 0 fieldplot.

The presence of a dense grass-sod may be a factor, which hampers the infiltration.
Also the effect of trampling by cattle should be taken into consideration.

class III: Icum.60 below 25 mm - Ifin. below 25 mm/hr.
Soils with a medium to low infiltration capacity (at Magenche A, Bondo B).
The Magenche A profile is very shallow (20 cm) at the upperslope of the Magenche catena (quartzite outcrops- see fig. 14).
The underlying quartzites are only slightly weathered, so the permeability of the rock is almost zero.
During heavy showers large amounts of run -off occur, which causes considerable erosion downslope (Magenche B)

The Bondo B profile is truncated planosol with a dense and massive structure and a low porosity.

### 4.5.2. Soil erodibility

Low erodibility of the soils of the Kisii West area.
Table XVIII shows, that the calculated K-values of the Kisii West soils are very low (less than 0.05).
No significant differences between these values could be determined as they are low.

Taking the restrictions of the soil erodibility nomograph method into account, one may consider the soils of the Kisii West as less erodible.
This supposition is supported by the medium and high values for the structure stability (submersiontype 1- 5, stability class I-V, clod-destruction A- E) as determined by Kauffman (see table XVIII)
Remarkable is the influence of the parentmaterial on the structure stability.
The profiles at Masai (basalt), Magenche (quartzite) and Wanjare (granite) show a range of decreasing structure stabilities.
This decrease is also correlated with organic matter content, which decreases from 7.6% (Masai O) to 2.6% (Wanjare)

The higher erodibility of the soils at Ndiru and Bondo.

The soils at Ndiru and Bondo A+B have a soil erodibility, which is higher than the erodibility of the Kisii West soils. The K-values are ranging from 0.08 to 0.22.

In all three profiles the relatively low percentage of organic matter and the relatively high percentage silt + very fine sand (2 - 100 mu) are conspicuous, which can be ascribed to the different climatic conditions: these are much drier (± 1200 - 1300 mm) than the conditions in the Kisii West area and typical for a savannah climate with 2 pronouced dry seasons.

The lower structure stability of the Ndiru and Bondo profiles
The structure stability of the soils is very low in comparison with the structure stability of the Kisii West soils. Especially the combination of a high clod destruction percentage and the presence of a weak crust indicates a high susceptibility to surface sealing. (see table XVII)

TABLE XVII. Soil erodibility (K-value) and structure stability

| Parent material | Location + Pitnumber | Texture % clay | % silt | % sand | % Org. matter | Structure | Permeability | K-value (erodibility) | Structure stability subm. typ | stability class | clod destr. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BASALT | MASAI 0(1007) | +70 | +25 | +5 | 7.6 | 1 | 1-2 | 0.05 | 1 | I | A |
| | MASAI 10(1008) | +70 | +25 | +5 | 6.6 | 1-2 | 1 | 0.05 | 1 | II | E |
| | MASAI 30(1004) | +70 | +25 | +5 | 5.4 | 1 | 1 | 0.05 | 3 | III | B |
| QUARTZITE | MAGENCHE B (1006) | 50 | 17 | 33 | 3.3 | 1-2 | 1 | 0.05 | | | |
| | MAGENCHE C (1005) | 50 | 17 | 34 | 4.1 | 1 | 1 | 0.05 | 5 | IV | $D^+$ |
| GRANITE | WANJARE (1000) | 47 | 16 | 37 | 2.6 | 1 | 1 | 0.05 | 4-5 | V | E |
| BASALT | NDIRU (1003) | 35 | 35 | 30 | 1.4 | 1 | 2 | 0.08-0.10 | 5-6 | VII | $E_o^+$ |
| GRANITE | BONDO A (1001) | 16 | 27 | 57 | 0.9 | 1-2 | 1 | 0.10-0.12 | 6 | VII | $F_o^+$ |
| | BONDO B (1002) | 41 | 22 | 37 | 0.7 | 4 | 4-5 | 0.20-0.22 | 6-7 | VI | $F_o^+$ |

## CLASSES OF STRUCTURE STABILITY

### Submersion type

type 1 - STABLE NOT WORKING SOILS: the aggregates don't fall apart and are not easily dispersed on stroking with a brush,

type 2 - STABLE WORKING SOILS: the aggregates fall apart in fragments which are not easily dispersed on stroking with a brush.

type 3 - UNSTABLE WORKING SOILS: the aggregates fall apart in graments which are easily dispersed with a brush.

type 4 - SOILS MODERATELY SUSCEPTIBLE TO AIR EXPLOSION!

type 5 - SOILS VERY SUSCEPTIBLE TO AIR EXPLOSION.

type 6 - AUTOMATICALLY DISPERSING SOILS (= slaking soils)

type 7 - Na-clays, dispersion and noticeable welling.

### Stability class (see for method page 23 - chapter 2)

| CLASS | % aggregates over 2 mm | % aggregates below 0.125mm |
|---|---|---|
| I | over 70 | below 5 |
| II | 30 - 70 | " |
| III | 10 - 30 | " |
| IV | below 10 | 5 - 10 |
| V | " | 10- 15 |
| VI | " | 15- 20 |
| VII | " | over 20 |

### Clod destruction class

| CLASS | % non-destructed clods after a 4 week exposure to natural rainfall. |
|---|---|
| A | less than 10% |
| B | 10 -30% |
| C | 30 -50% |
| D | 50 -75% |
| E | 75-100% |
| F | 100% after 2 weeks of exposure |

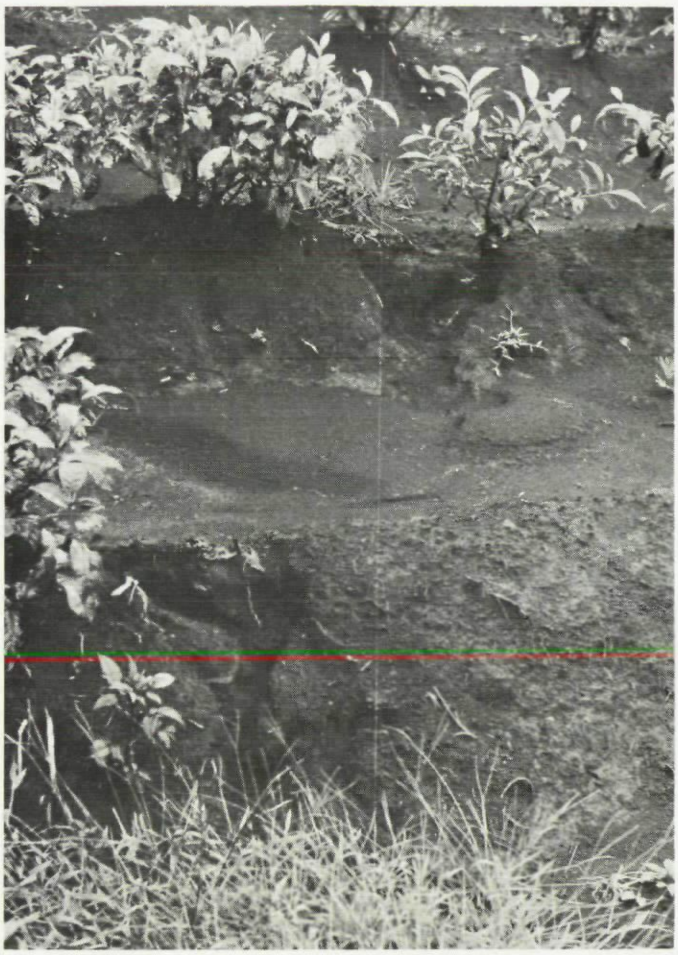


Fig. 16 Destruction of the ridges and filling up of the depressions by small detached soil aggregates (stage 1)

Fig. 17 Accumulation of soil at the lowerside of the terrace Runoff has cut the grassed terrace wall, thus causing erosion at the lower bench terrace (stage 2)

# 5. A STUDY OF SOME SEMI-NATURAL TERRACES

## 5.1. aim of the study

In the Kisii West area the study of the already mentioned semi-natural terraces (see page 8 of the introduction) can provide a valuable contribution to erosion research in general.
The terraces have been developed by steady accumulation of eroded soil along so-called " trashlines", built up of maize stalks and weed.
Particularly on old and well maintained terraces the benching effect on the original slope profile has become clearly visible.

An effort has been made to estimate soil accretion and erosion on the basis of heights of the grassed check-walls of the terraces and of differences in topsoils on the terraces.

## 5.2. the formation of the terraces

Two stages of erosion on the terraces can be distinguished.
They are described below:
Stage 1: Micro-or puddle- erosion is predominant.
The term "puddle-erosion" is used by Hudson (1971); it means washing of aggregates into depressions, structure loss and decrease of infiltration capacity, followed by sealing.
The micro-relief of the surface is planated by the destruction of clods and in an advanced stage plough contours and cultivation ridges if present become partly burried by detached soil aggregates (see fig. 1 and fig. 17).
However, no net soil loss occurs.

Stage 2: Rill erosion is predominant
In this more advanced stage plough-contours have been broken through and a downward movement of soil aggregates through small channels and rills has started (channels are winding between the maize plants reaching a length of about 2 - 3 meters.

As erosion becomes more serious, rills become interconnected, deeper and longer.
Finally broad rills develop (widths up to 1.5 mtr) locally with a complete removal of the ploughlayer.
Sometimes the run -off is crossing the grasses check-walls, thus causing erosion at the terrace below.

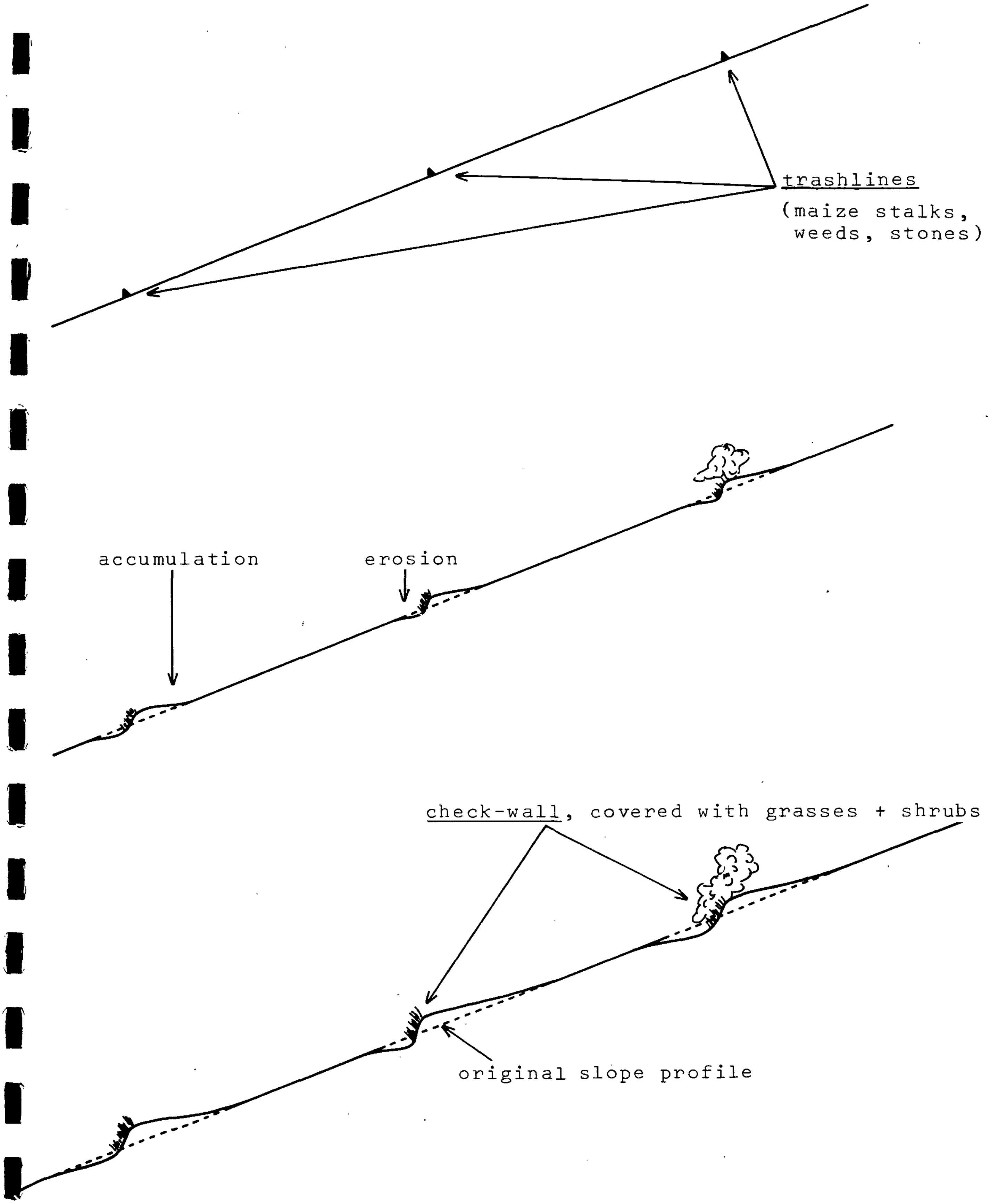


Fig. 18 Development of semi-natural terraces

The run-off in the rills, charged with small topsoil aggregates (0.5 - 1 mm) is hampered at the end of the terrace by the trashline or grassed check-wall (in a later stage) and will loose its load.
The aggregates are sedimented in fine layers of varying thickness and texture. Soon a kind of sedimentation sheet develops at the lower side of the terrace, causing a clear concave break of the slope (Fig. 18)

The unloaded water breaks through the grassed check-wall (Fig. 18) and accelerated by the steeper gradient of that wall, starts to erode the upperside of the terrace below.
Hence this part of the terrace is suffering strong erosion, which explains the often visible convexity at the upperslope of the terrace.

Both factors, sedimentation at the lowerside of the terrace and erosion at the upperside are creating a typical convex-straight-concave terrace slope as is visualized in figure 18.
The straight midslope of the terrace, which is a part of the original slope is yielding to the expansion of the concave lower slope and the convex upper slope and will finally be replaced by them.
This will result in agentle convex-concave slope profile of the terrace.
Each year the trashlines are raised up with maize stalks and weed, so after some years grassed check-walls develop (Fig. 18)

The effect of erosion and accumulation on the soil profile is conspicuous, as at lowersides of the terraces soils tend to have thick, dark A-horizons, whereas soils at uppersides have usually thin topsoils.

## 5.3. METHODS

The selected fieldplots are located in the Kisii West area (see App. I and II)
Criteria for selection have been:

a) The presence of well maintained terraces
b) Variability of soiltype and slope
c) The presence of maize as a cultivated crop

TABLE XVIII Environmental characteristics of the fieldplots

| LOCATION | PIT NO. | SOILTYPE | SLOPE |
|---|---|---|---|
| MASAI | 1004 | deep well-drained soils developed on basalt (Nyabondo+Chang'aa series) | 1 - 15% |
| MAGENCHE | 1005<br>1006 | deep well-drained soils developed on quartzite (Nyagori+Marongo 3 series) | 5 - 15% |
| IKOBA/ RIOSIRI | - | deep well-drained soils developed on basalt+ quartzite. (Nyagori + - Chang'aa series) | 12- 17% |
| IKOBA II/III | 1010<br>1011<br>1012 | deep well-drained soils developed on basalt (Nyaborumbasi+Chang'aa ser.) | 13- 22% |
| IKOBA I | - | " " | 13- 19% |
| ITUMBI II | - | shallow+mod.deep soils developed on basalt (Gucha series) | 16- 29% |
| OGEMBO | 1015 | deep well-drained soils developed on basalt (Chang'aa series) | 18- 36% |
| ITUMBI I | - | shallow, gravelly soils developed in colluvium of quartzites and basalts (Marongo I series) | 25- 36% |

At each location the following general characteristics have bee ivestigated:

a) The age of the terraces
b) The causes and the degree of erosion in the past
c) The frequency of fallow periods
d) Tillage practices.

Of each terrace the following factors have been determined:

a) The length (L) and slope gradient (S) of the terrace; the length of the terrace has been determined by spacing, while gradients have been measured with a Haga inclinometer.

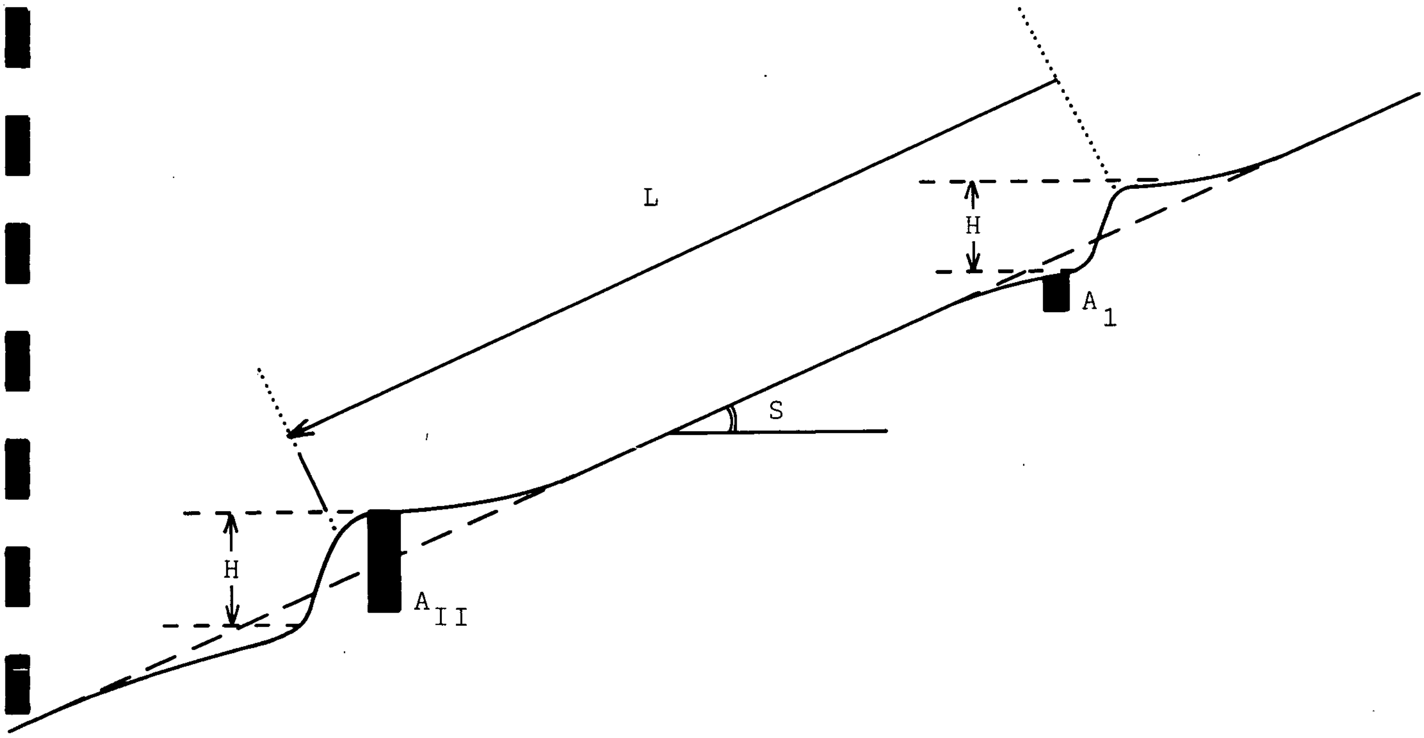


Fig. 19 Cross-profile of terrace

The length L and the slope gradient have been transformed into a so -called topographic or LS-factor (Soil Loss Equation - Wischmeyer & Smith 1965).

The values of the LS-factor have derived from the slope-effect chart or computed with the formula:

$$\text{LS-factor} = L\,(0.0076 + 0.0053S + 0.0076S^2)$$

L = length in meters

S = gradient in % (for gradient over 20%)

b) The <u>height of the grassed cheek-walls (H)</u> (Fig. 19)

c) The soil profile at upper-and lowerside of the terrace

This has been done with the help of an Edelman auger; for close observations pits have been dug, described and sampled (see for detailed descriptions Appendix VII)

S Special attention has been paid to the depth of the A-horizon at the upperside (AI) and at the lowerside (AII) of the terrace (Structure: very fine subangular blocky or crumbs; colours: darker than 5 YR 3/3 and 2.5 YR 3/3)

The difference in depth of A-horizons at both sides of the terrace (AII-AI) is a measure of the soil transport, that has occurred since the construction.

AII-AI can be considered as the sum of the erosion at the upperside and the accumulation at the lowerside of the terrace.

## 5.4. Results

### 5.4.1. General

a) The age of the terrace.

For all terrace in the area an age 16 years was found.

Soil conservation is said to have been enforced by the former colonial government in 1958.

This has been done in the whole Kisii District at the same time.

b) Causes and degree of erosion in the past.

Some erosion has occurred in the past along tracks due to the presence of cattle.

Rill erosion has been the result of the frequent trampling of the soil by this cattle.

However, serious erosion never seems to have been wide spread due to the good vegetative cover or the presence of frequent fallow periods.

c) The frequency of fallow periods.

There exists much uncertainty about the number of fallow years since the construction of the trashlines.

There is general trend to cultivate the land more permently due to the population density, which is rapidly increasing. The lack of information about this subject is caused by the non-willingness of the farmers to talk about this project

d) The tillage practices

The tillage practice are the same for the whole area.

Ploughing is done twice a year at the end of the dry season.

It is usually done in circles, working from the centre towards the edges; in this way the soil transport occurs in the same direction.

Weeding is done with a hoe or jembe four times in a year (twice in each cropping period).

The soil surface is loosed and moved over a small distance usually in a upslope direction.

### 5.4.2. VALUES OF H AND AII -AI (see Appendix VI)

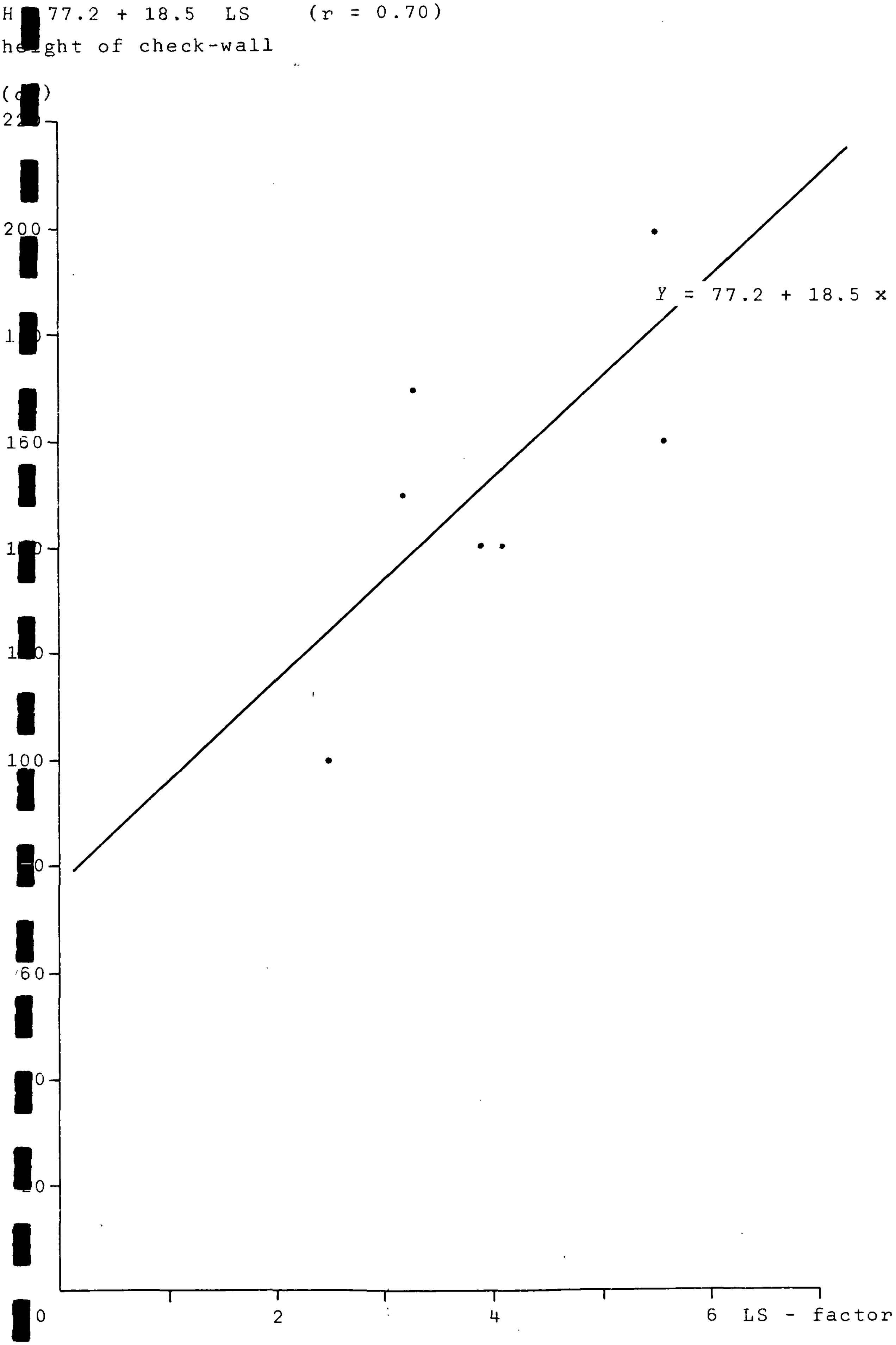


Fig. 20 Increasing heights (H) of check-walls at terraces with longer or steeper slopes (higher LS - factor).

### 5.4.3 Correlation between H or AII-AI and the LS-factor

Correlation coefficients (r) have been computed between H (height of check-wall) or AII-AI (difference in depth of A-horizons) and the LS-factor.

They have listed in Table XXVII together with critical r-values indicating a 95% confidence limit.

TABLE XXVII Correlation coefficients between H and LS and between AII-AI and LS.

| LOCATION | H and LS | AII-AI and LS | Critical r-value | |
|---|---|---|---|---|
| MASAI | r=0.20 | r=0.12 | r=0.67 | (n=7 ) |
| MAGENCHE | r=0.09 | r=0.17 | r=0.67 | (n=7 ) |
| IKOBE/RIOSIRI | r=0.37 | r=0.18 | r=0.62 | (n=8 ) |
| IKOBA II/III | r=0.50 | r=0.55 | r=0.81 | (n=5 ) |
| IKOBA I | r=0.58 | r=0.30 | r=0.99 | (n=3 ) |
| ITUMBI II | r=0.54 | r=0.40 | r=0.90 | (n=4 ) |
| OGEMBO | r=0.70 | r=0.61 | r=0.67 | (n=7 ) |
| ITUMBI I | r=0.22 | r=0.16 | r=0.55 | (n=10) |

Assuming a confidence limit of 95% only the H-values of the Ogembo fieldplot show any significance with a correlation coefficient of 0.70 (critical r-value = 0.67 for n=7)

The derived equation is as below:

$$\underline{H} = \underline{77.2} + \underline{18.5}\ \underline{LS} \qquad \text{(see fig. 20)}$$

### 5.4.4 Values of D. Hav (mean annual increase of height of the check-wall) and of D. (AII-AI) av (mean annual increase of difference in depths of A-horizons)

The age of the terraces is the same for all fieldplots. Therefore, for each fieldplot the mean annual increase of both H and AII-AI can easily be calculated.

Of each fieldplot the average value for H and for AII-AI have been computed, which subsequently has been divided by the age of the terraces (=16 years).

In this way, two new factors are created:

D.Hav = mean annual increase of the height of the check-wall.

D. (AII-AI) av = mean annual increase of the difference in depths of A-horizon at the upperside and the lowerside of the terrace.

The values of D.Hav and D.(AII-AI) av are listed in table XXVII

TABLE XXVIII Values of D.Hav and D. (AII-AI) av with average values of each LS-factor at each fieldplot.

| LOCATION | LS-factor (average) | D.Hav | D.(AII-AI) av |
|---|---|---|---|
| MASAI | 1.1 | 3.1 | 0.6 |
| MAGENCHE | 1.1 | 3.5 | 1.0 |
| IKOBA/RIOSIRI | 2.0 | 5.0 | 1.5 |
| IKOBA II/III | 2.6 | 6.0 | 2.8 |
| IKOBA I | 2.8 | 5.2 | 3.1 |
| ITUMBI II | 3.2 | 6.7 | 2.2 |
| OGEMBO | 4.3 | 9.0 | 2.2 |
| ITUMBI I | 4.5 | 6.2 | 1.9 |

Correlation coeficients between D.Hav or D. (AII-AI) av and the LS-factor do not appear to pass the confidence limit of 95%

r = 0.52 (D.Hav) (critical r-value = 0.62
r = 0.58 (D.AII-AI) av) for n = 8)

After the separation of the D.Hav-values of Itumbi I and Itumbi II and the D. (AII-AI) av-values of Itumbi I, Itumbi II and Ogembo on the basis of different soil properties (see section 5.5), the following correlation coeficients are obtained.

$\Delta$ Hav = 1.35 + 1.71 LS (r=0.97)

$\Delta$ ($A_{II}$ - $A_{I}$) av = -0.73 + 1.32 LS (r=0.97)

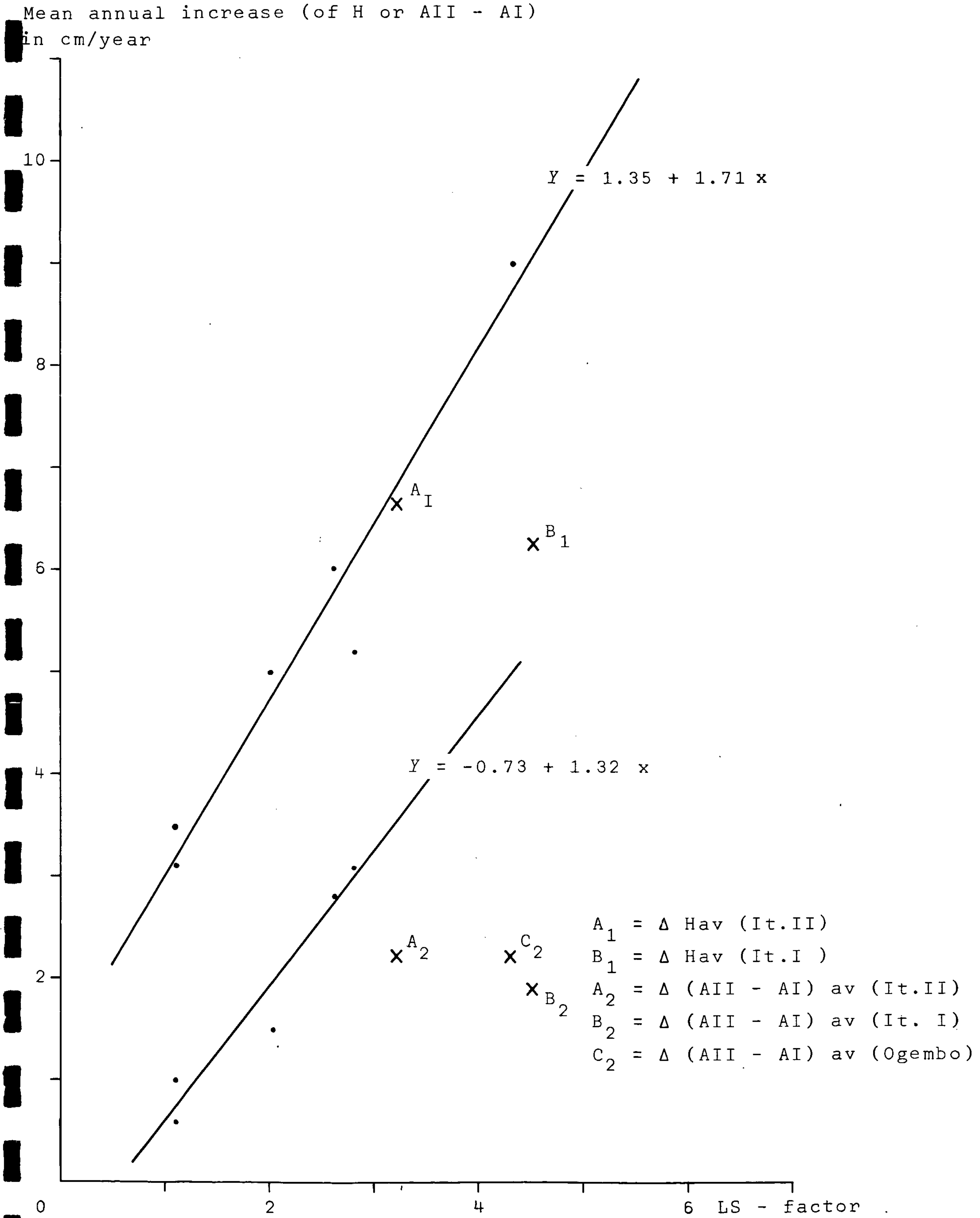


Fig. 21 Mean annual increase of height with higher LS factor

$r = 0.97$ (D.Hav) critical r-value = 0.73; n=6
$r = 0.97$ (D. (AII-AI)av) critical r-value = 0.81; n=5

The derived equations are as below:

a) D.Hav = 1.35 + 1.71 LS ( Fig. 21)
b) D.(AII-AI)av = 0.73 + 1.32 LS (Fig. 21)

## 5.5 DISCUSSION

Before drawing any conclusion one should consider the validity of the field data obtained.
This validity is restricted by lack of information about the following;

A) The age of the terraces: Field information is often uncertain or lacking due to the reserve of most of the farmers towards this matter.
Building of the trashlines is said to have been started in 1958, but this does not correspond with agricultural reports of the Kisii District.
According to these records all the land has been controlled by trashlines since before 1950.
Mr. L. Brown, District Commisioner of South Nyanza from 1953-1956, confirmed this (private communication)

So.perhaps conservation works are of older date than 1958, but probably they are more or less of the same age, as the construction of trashlines has been obligatory and effectuated for the whole Kisii area at the same time (Mr. L.Borwn - private communications).

B) The condition of the check-walls: At many places check-walls have been cultivated (maize) and weeded, which results in a decrease of their height.
Locally they have beem ploughed up and rebuilt at other places.
Hence these walls are considerably lower and less developed as they would have been under "normal" conditions.
Detailed field information about the maintainance of the check -walls could not be obtained.

C) The increase of the landoccupation: Little is known about the rotation schemes used during the land occupation in the first years. When land was not as scarse as it is now, fallows and grass-leys were used more frequently.
At present a fallow season is used mostly on stony and shallow soils during the short rains.

## Values of H and AII-AI.

The height of the investigated check-walls (H) is ranging from 0 to 200 cm (Ogembo-terrace VII); the average height is about 90 cm. The height of the check-walls at some terraces of the Masai plot is 0, as the slope gradient and hence the LS-factor is very low (see table XIX).

The differences in depth of A-horizons (AII-AI) are considerably lower than the corresponding values for H.
This "gap" will be discussed later in this chapter.
The values of AII-AI are ranging from 0 up to 65 cm (Ikoba II/III terrace III).
The average value of AII-AI is about 40 cm.
Values of AII-AI are 0 or very low on some terraces of the Magenche and Ikoba/Riosiri plot, where on the upperslope a clear A-horizon is absent.
Both plots have soils, developed on quartzitic parentmaterial.

Correlation of H and AII-AI with the LS-factor.
The computed correlation coefficients of H with the LS-factor are low Magenche, Ikoba I/, Riosiri and Itumbi I) or even negative at Ikoba I/III, Itumbi II) (see table XXVIII).
Only the correlation coefficient of H at the Ogembo plot (r=0.70) is crossing the confidence limit of 95% (r=0.67 for n=7).
The computed correlation coefficients of AII-AI with LS are comparable to those of the H with LS, although values tend to be somewhat lower: they never reach the confidence limit of 95%.

A low correlation of H and AII-AI with the LS-factor does not neccessarily mean, that soil transport occurs independently from slope length and slope gradient.

The reason should be found probably in a locally lower effectiveness of the check-walls, where they are in a bad condition: on those places the run-off, carrying topsoil aggregates, is crossing the check-walls and will loose its load at trashlines or check- walls which are better maintained and more effective.
This supposition is supported by field evidence. (Fig. 17)

Only the H-values at the Ogembo plot show a significant correlation with the LS-factor, which would mean that here soil transport has been controlled effectively by the check-walls on all parts of the slope. Well-maintained walls are present indeed, except at terrace VIII, where the check-wall is seriously eroded.
The H-values of this terrace had to be ommitted in order to reach a sufficient significance level.

The computed equation is:

$$H = 18.5\ LS + 77.2 \qquad \text{(see fig. 20)}$$
$$(r = 0.70;\ n = 7)$$

Values of D.Hav and D(AII-AI)av

The mean annual increase of H and AII-AI, expressed as D.Hav and D.(AII-AI)av respectively, show a better, though not significant correlation with the LS-factor.

| | | |
|---|---|---|
| D.Hav: | $r=0.52$ | ($r_{critical} = 0.62$ for $n=8$) |
| D.(AII-AI)av | $r=0.58$ | ( " " ) |

Subsequently, values of D.Hav of the fieldplots of Itumbi I and Itumbi II and the values of D.(AII-AI)av of the fieldplots of Itumbi I, Itumbi II and Ogembo have been omitted, as they are all more or less deviating (see fig. 21)

Correlation coefficients appear to be high after correction :

| | | |
|---|---|---|
| D.Hav: | $r=0.97$ | ($r_{critical} = 0.73$ for $n=6$) |
| D.(AII-AI)av | $r=0.97$ | ($r_{critical} = 0.81$ for $n=5$) |

The higher correlation can be explained by the occurrence of different soiltypes on the fieldplots of Itumbi I, Itumbi II and Ogembo.

Soils of the Itumbi I and Itumbi II fieldplot consist mainly of shallow, gravelly red clays, developed on colluvium of quartzitic and basaltic gravels and stones.
The rotten rock (mostly basalt) occurs at some depth.
They are described as Ruptic lithic Oxic humitropeptic troporthent, belonging to the Marongo I series (Detailed soil survey of the Marongo area - Appendix I, PR. 3).

Due to their shallow depth the supply of soil material is hampered after some times when the gravelly, less erodeble subsoil comes at the surface.
Hence that rate of the accumulation is slowed down, which results in lower values of H and AII-AI (see points A1, B1, A2 and B2 - Fig. 21)

The soils of the Ogembo field plot consists of deep, red friable clays belonging to the Chang'aa series, which lacks a thick, humus rich topsoil.
As they are often considerably eroded without a clear A-horizon, the determination AII-AI values becomes rather speculative.
The colours and structure of the topsoil correspond more to the image of a A3- or B1-horizon.
Hence the determined D (AII-AI)av- values might be considered as rather low and not corresponding with the real change of the topsoil on the terrace (point C2 - Fig. 21).
This view is supported by the high values of D.Hav at Ogembo,which fully corresponds with the expected value of D.Hav (point C1 Fig.21)

The derived equations for mean annual accumulation and erosion are below:

$$D.Hav = 1.71\ LS + 1.35 \qquad (r = 0.97)$$

$$D\ (AII-AI)\ av = 1.32\ LS - 0.73 \qquad (r = 0.97)$$

It aapears that both for D.Hav and D. (AII-AI) av alinear correlation exists with the LS-factor.
The mean annual increase of H is ranging from 3.1 up to 9.9 cm (1 LS-factor 5).
The mean annual increase of AII-AI is ranging from 0.7 to 5.9 cm (1 LS-factor 5).

### The difference between values of D.Hav and D. (AII-AI) av

As D.Hav and D.(AII-AI)av represent the same, i.e. the mean annual increase of the height between two terraces, reflected in the height of the check-walls (D.Hav) or reflected in the difference of soil profiles (D(AII-AI) av), they should have the same values.
However, this not the case, as there is a gap between the values of D.Hav and D.(AII-AI)av, ranging from 2.3 up to 4 cm (1 LS-factor 5)

One can explain this gap, which occurs at all fieldplots, by assuming, that the original soil profile had been partly removed. (A-horizon with or without the upperpart of the B-horizon) in the first years, when erosion was more serious.
In later years some accumulation of topsoil has ocurred due to the declining effectiveness of the check-walls, which has resulted in the formation of a new A-horizon on the old truncated B-horizon.
As AII-AI-values are not including that of the B-horizon, which has eroded from original soil profile, AII-AI-Values tend to be lower than the H-values.

Comparison with present-day rates of accumulation (field observation)

The determination of present- day rates of accumulation is locally easy, as the recently deppsited soil consists of horizontally stratified layers of loose soil aggregates ($A_{sedim.}$ - profile 1011 and 1012)

Ikoba II/III - terrace I $A_{sedim.}$ = 8 cm (prof. 1011-App.VII)
" - terrace IV $A_{sedim.}$ = 16cm (prof. 1012-App.VII)

These values are much higher than the computed values for the fieldplot of Ikoba II/III (D.Hav = 6 cm; D (AII-AI)av = 2.8 cm).
Moreover, the present-day rates include only the accumulation and not the erosion on one terrace.

These higher values cannot be explained by a higher preciptitation or alate sowing date, by which the land without a vegetative cover has been exposed to the early rains.
In fact, the precipitation during april and may 1974 was definitely below the average (the record precipitation in Kisii was 244 mm in April '74 whereas the average is about 320 mm).
The wet season has started time (last week of march), so one may assume, that farmers have not been surprised by the rains and consequently have not sown too late.

The explanation could be the intensifying of the cultivation and the gradual decline of the fallow period.
This has been indiced by the introduction of cash crops in early years and by the increasing population density.
By that, the surface soil has been exposed more frequently to the rainfall, which results in more erosion and accumulation.
Moreover, the susceptibility to sealing increases due to the deterioration of the soil structure (see structure stability at Masai 0-10-30- Table XVII), so higher rates of erosion can be expected.

## 5.6 Conclusions:

- The accumulation and erosion of soil (H and AII-AI) on the terraces is not correlated with slope length of gradient (LS-factor) at each separated terrace, except for the terraces of the Ogembo fieldplot.

- This could be an indication for a rather low effectiveness of the check-walls of most of the terraces.

- A good correlation (r=0.97) is present between mean annual accumulation and erosion (D. Hav-and D(AII-AI)av) and the LS-factor for deep, non-eroded soils.

- The range of soil properties of the deep soil profiles, developed pn basalt or quartzite do not disturb this good correlation, which is an indication, that the erodibility of the soils is not very variable (see also the low, unfform K-values - table XVII)

- There are indications, that the rate of accumulation and erosion (D.Hav and D (AII-AI)av) has increased in recent years. This is probably caused by the more intensive cultivation and the absence or decline of the fallow period. Also the increase of the susceptibility to sealing during continuing cultivation (Masai profiles - table XVII) plays a role.

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# Appendicies I - VI

## APPENDIX I - List of soil pits and samples

| Profile Number | Samples Number | Depth | Horizon |
|---|---|---|---|
| | 1 | 2 -10 | A1 |
| 1007 | 2 | 15-24 | A3 |
| | 3 | 50-56 | B1 |
| | 4 | 2 -10 | Ap |
| 1008 | 5 | 15-25 | A1 |
| | 6 | 50-57 | B1 |
| | 7 | 2 -10 | Ap |
| 1004 | 8 | 15-25 | A3 |
| | 9 | 50-57 | B1 |
| 1009A | 10 | 2 -10 | A1 |
| | 11 | 15-25 | A3 |
| | 12 | 50-57 | B2 |
| 1015 | 13 | 5 -15 | Ap |
| | 14 | 25-32 | B1 |
| | 15 | 0 -15 | Ap |
| 1003 | 16 | 15-30 | B1 |
| | 17 | 35-40 | B2cn |
| | 18 | 0 -15 | Ap |
| 1000 | 19 | 20-35 | A1 |
| | 20 | 55-65 | B1 |
| 1014 | 21 | 5 -15 | A1 |
| | 22 | 40-50 | B2 |
| 1001 | 23 | 0 - 5 | Ap |
| | 24 | 10-20 | A1 |
| 1002 | 25 | 15-30 | B |
| | 26 | 5 -15 | A1 |
| 1005 | 27 | 20-30 | B1 |
| | 28 | 60-70 | B2 |
| 1016 | 29 | 5 -15 | Ap |
| | 30 | 50-55 | B2 |

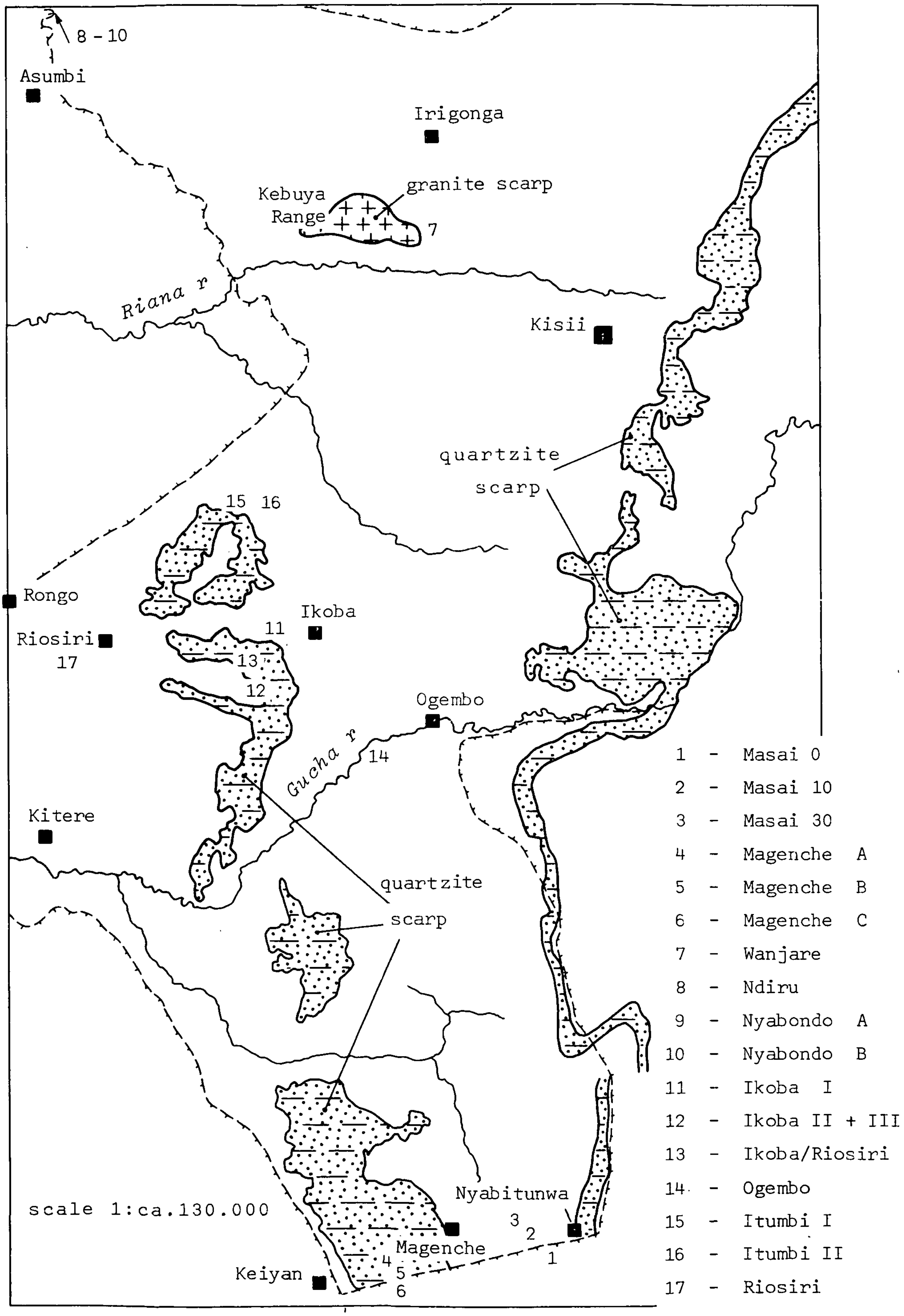


Fig. 22 Location map of studied field points.

-·-·-·- = Kisii West boundary

## Appendix III - Aggregate Fractions in weight Percentages

| Sample NR | first or second | 2 | 2-½ | ½ | ½-¼ | ¼-1/8 | 1/8 (mm) |
|---|---|---|---|---|---|---|---|
| 1 | AF - 2 | 90,48 | 2,13 | 1.39 | | | |
| | AF - 2 | 92,49 | 4,40 | 3.11 | 2,18 | 0.82 | 0.27 |
| 2 | AF - 1 | 95,80 | 2,04 | 1.55 | | | |
| | AF - 2 | 90,72 | 5,89 | 3,39 | 2,17 | 0.93 | 0.37 |
| 3 | AF - 1 | 19,33 | 48,91 | 31,75 | | | |
| | AF - 2 | 4,18 | 43,17 | 52,65 | 31,48 | 13,66 | 7,55 |
| 4 | AF - 1 | 58,59 | 24,37 | 17,04 | | | |
| | AF - 2 | 41,95 | 29,28 | 28,76 | 16,35 | 8,05 | 4,47 |
| 5 | AF - 1 | 92,93 | 4,48 | 2,58 | | | |
| | AF - 2 | 85,00 | 9,59 | 5,41 | 3,35 | 1,33 | 0,59 |
| 6 | AF - 1 | 20.03 | 47,82 | 32,15 | | | |
| | AF - 2 | 3,90 | 42,55 | 53,49 | 32,09 | 14,02 | 7,38 |
| 7 | AF - 1 | 42,6- | 31,50 | 25,90 | | | |
| | AF - 2 | 29,17 | 36,13 | 43,71 | 24,29 | 11,59 | 7,41 |
| 8 | AF - 1 | 60,07 | 29,39 | 10,54 | | | |
| | AF - 2 | 47,38 | 38,27 | 14,35 | 10,28 | 3,03 | 1,16 |
| 9 | AF - 1 | 9,34 | 50,82 | 39,84 | | | |
| | AF - 2 | 0,47 | 39,77 | 59,76 | 39,23 | 13,93 | 6,46 |
| 10 | AF - 1 | 49,99 | 29,05 | 20,97 | | | |
| | AF - 2 | 31,39 | 29,54 | 39,06 | 22,67 | 10,89 | 5,25 |
| 11 | AF - 1 | 74,50 | 14,75 | 10,75 | | | |
| | AF - 2 | 67,38 | 16,86 | 15,76 | 10,35 | 4,01 | 1,70 |
| 12 | AF - 1 | 22,14 | 40,50 | 37,36 | | | |
| | AF - 2 | 14,52 | 35,30 | 50,18 | 26,85 | 15,14 | 8,30 |
| 13 | AF - 1 | 51,38 | 26,85 | 21,77 | | | |
| | AF - 2 | 31,26 | 30,69 | 38,05 | 21,53 | 10,28 | 5,67 |
| 14 | AF - 1 | 35,33 | 36,99 | 27,69 | | | |
| | AF - 2 | 25,04 | 39,04 | 35,92 | 22,50 | 9,30 | 4,35 |
| 15 | AF - 1 | 16,68 | 23,66 | 59,66 | | | |
| | AF - 2 | 6,11 | 16,84 | 77,05 | 20,29 | 27,45 | 28,09 |

| NR | DESTR TYPE | 2 | 2-½ | ¼ | ½-¼ | ¼-1/8 | 1/8 |
|---|---|---|---|---|---|---|---|
| 16 | AF - 1 | 16,04 | 42,79 | 41,17 | | | |
| | AF - 2 | 3,91 | 26,90 | 69,19 | 32,71 | 22,93 | 13,13 |
| 17 | AF - 1 | 7,40 | 35,51 | 57,09 | | | |
| | AF - 2 | 3,67 | 15,71 | 80,62 | 33,42 | 28,65 | 18,21 |
| 18 | AF - 1 | 34,90 | 31,27 | 33,77 | | | |
| | AF - 2 | 35,31 | 30,21 | 36,48 | 12,26 | 16,43 | 7,97 |
| 19 | AF - 1 | 42,41 | 47,31 | 10,28 | | | |
| | AF - 2 | 38,33 | 49,19 | 12,47 | 9,12 | 2,57 | 0,87 |
| 20 | AF - 1 | 41,08 | 35,66 | 23,26 | | | |
| | AF - 2 | 39,09 | 32,10 | 28,81 | 19,47 | 6,16 | 3,30 |
| 21 | AF - 1 | 3,51 | 31,49 | 65,01 | | | |
| | AF - 2 | 1,29 | 24,74 | 73,97 | 37,25 | 22,65 | 13,67 |
| 22 | AF - 1 | 2,03 | 34,02 | 63,94 | | | |
| | AF - 2 | 1,47 | 31,36 | 67,15 | 36,98 | 19,34 | 10,39 |
| 23 | AF - 1 | 8,40 | 21,99 | 69,91 | | | |
| | AF - 2 | 1,05 | 12,76 | 86,19 | 31,65 | 30,38 | 23,33 |
| 24 | AF - 1 | 6,23 | 30,35 | 63,24 | | | |
| | AF - 2 | 1,11 | 15,79 | 83,09 | 37,06 | 27,70 | 17,28 |
| 25 | AF - 1 | 27,68 | 23,18 | 49,15 | | | |
| | AF - 2 | 1,17 | 21,82 | 77,02 | 37,74 | 22,39 | 16,37 |
| 26 | AF - 1 | 26,54 | 27,89 | 45,57 | | | |
| | AF - 2 | 6,87 | 28,25 | 64,88 | 37,97 | 18,35 | 8,39 |
| 27 | AF - 1 | 55,73 | 26,54 | 17,73 | | | |
| | AF - 2 | 16,11 | 47,19 | 36,70 | 26,86 | 7,74 | 2,14 |
| 28 | AF - 1 | 8,68 | 38,65 | 52,67 | | | |
| | AF - 2 | 1,12 | 24,69 | 74,19 | 46,09 | 19,23 | 8,62 |
| 29 | AF - 1 | 15,56 | 27,76 | 56,68 | | | |
| | AF - 2 | 6,61 | 26,97 | 66,42 | 30,99 | 19,09 | 13,80 |
| 30 | AF - 1 | 17,62 | 45,49 | 36,89 | | | |
| | AF - 2 | 0,12 | 42,39 | 57,49 | 36,52 | 13,17 | 7,90 |

## APPENDIX IV

### 1. Field observations during raing showers.

Location: Getutu hill, 14-6-1974

Slope: 23%
Soil : dark red, very fine clay soil developed on basalt; clods and micro-valleys visible, micro-valleys covered with coarse aggregates; soil is moist only the upper centimeter is dry.

Precipitation intensity is estimated between 0.5 and 1 mm/min.
Duration of the shower about 15 min.
Vegetation: maize with a crop cover of 20%.

I. Raindrops have a strong impact in the loose aggregates in the micro-valleys and on the clod-surfaces. A rain drop makes an little hole of 3-5 mm depth and 2-3 mm width.
Less material splashes away, the soil mass is for the main part pushed aside. Aggregates are worked loose from the clods and roll-down from the often very steep slopes of the clods. The micro-valleys is filled with those aggregates, the destruction of aggregates in the micro-valleys in smaller fragments is less, the surface is covered with coarse (stronger) aggregates.

II. stagnant water and run-off starts that first on places where local conditions influencing the precipitation or infiltration.
Spots just below maize leaf ends, foot prints, the outer side of the leaf canopy of trees are the first spots which becomes saturated.
Run-off starts from these spots and is visible over some decimeters to some meters.
The water is brownish-reddish due to transported clay and aggregates.
The relative narrow run-off paths stops easily at less steeper, more porous parts.

### 2. Local precipitation measurement

Location: between Ikoba and Marongo

The maize leaf collects the precipitation water and let it run down partly to the stem and partly to the leaf end, the last one is important. With not to many wind during the rain the total precipitation on a spot of about 1 $dm^2$ will be more than "free" precipitation.

Material: some plastic boxes (8.4 x 8.4 x 6 cm) and a measuring glass of 100 ml.

The boxes are put just below the leaf ends (correction in the beginning of the shower is necessary) gives us an impression about the differences in the local precipitation.

The precipitation collected in the box consists of:

- "free precipitation water, this will be about the half of the total free precipitation outside the influence of plants because the leaf sreens partly the box.
- the intercepted water, this amount depends on the surface of the maize leaf.

4 boxes are placed outside the influence of plants

5 boxes are placed below the leaf ends, z = the distance between the soil and leaf which end, c= width of the leaf and be the horizontal length of the leaf which intercepts the water, (see figure) z/c-b is the hotation for the box below a leaf end.

- Free precipitation: 22.26,25,25 ml
  average precipitation is 24.5 ml
  surface of the box = 70 $cm^2$

precipitation = 3.5 mm

length of the shower = 45 min

average intensity = 0.15 mm/min

- precipitation below the maize leaves:

25/10-13 = 70.5 ml

22/12-20 = 104.0

75/10-10 = 76.0

12/9-18 = 48.0

55/8-14 = 93.5

- Average free precipitation = 24.5 ml
  lowest total leaf " = 48.0 (about 2 times the free precip.)
  highest " " " = 104.0 (about 4 times " " "

Other observations during the shower:

Soil is a deep, dark red. very fine clay soil.

Slope is 12% - maize.

Clods are clearvisible, micro-valleys are weakly developed.

The soil does'nt have any difficulty with the absorbting of the rain.

Only below leaf ends, foot prints.. for a while shiny surface of water saturation occurred. Impact of rain drops is not or slightly visible.

### 3. Calculation of the intercepted rain by a maize leaf and the calculation of the crop cover percentage. (Fig. 23)

Line X-X = the boundary on the maize leaf where the water starts
running to the leaf end
Line Y-Y = the boundary where the perpendicular hits the curved maize leaf
a = length of the leaf, projected on a horizontal plane
b = that part of the leaf, projected on a horizontal plane
c = the width of the leaf at the line X-X
d = " " " " " " " Y-Y
e = maximum width of the total surface that screens the soil
f = width of the total leaf base
p = plant distance
R = row distance
S = soil surface
SP = soil surface covered by maize plants
C = covering percentage

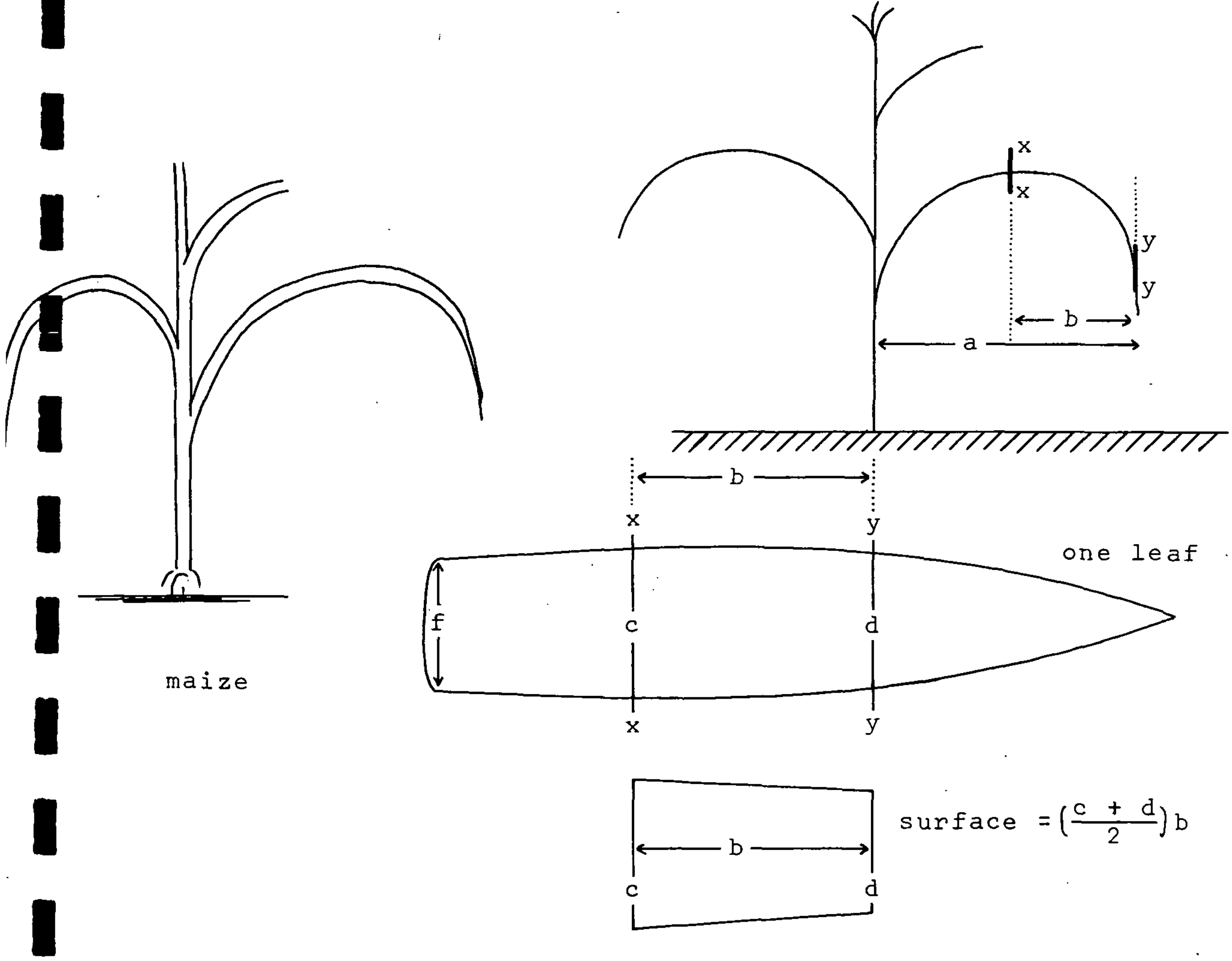


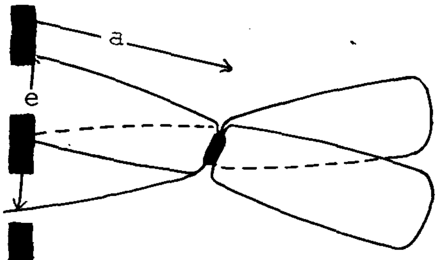
Fig. 23 Sketch demonstrating the calculation of the intercepted rain.

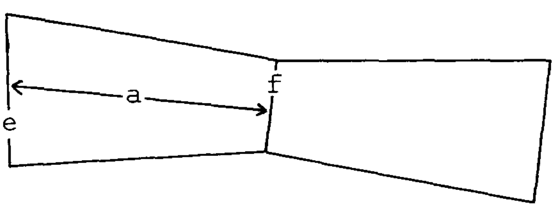
## Appendix V Clod Destruction Percentage

| Soil Pit Number | Sample Number | Estimated 26 June | Estimated 1 July | Measured 19 July | Measured 19 July | Other observations |
|---|---|---|---|---|---|---|
| | 1 | 0-1 | 1-5 | 1-5 | 6.4 | large A, loose |
| 1007 | 2 | 0-1 | 1-5 | 1-5 | 9.2 | large A, loose |
| | 3 | 30 | 40-50 | 75 | 72.3 | large to medium A, loose. |
| | 4 | 10 | 65 | 90 | 100.0 | large A, loose |
| 1008 | 5 | 1 | 2 | 5 | 10.0 | large A, loose |
| | 6 | 30 | 50 | 60 | 64.3 | large to medium A, loose. |
| | 7 | 5 | 35 | 20 | 27.8 | large A, loose |
| 1004 | 8 | 2 | 25 | 30 | 40.3 | large A, loose |
| | 9 | 50 | 85 | 100 | 100.0 | medium A, loose |
| | 10 | 30 | 75 | 100 | 100.0 | medium to fine A, WC (speric voids) |
| 1009A | 11 | 5 | 45 | 60 | 48.8 | large A, loose |
| | 12 | 60 | 95 | 100 | 100.0 | large A, WC |
| | 13 | 8 | 25 | 20 | 51.0 | large A, loose |
| 1015 | 14 | 70 | 85 | 100 | 100.0 | large A, loose |
| | 15 | 12 | 75 | 100 | 82.9 | medium to fine A, WC (spheric) |
| 1003 | 16 | 2 | 25 | 40 | 51.0 | large A, loose |
| | 17 | 90 | 100 | 100 | 100.0 | large A, loose |
| | 18 | 5 | 35 | 60 | 32.0 | medium to fine A, loose (+gra |
| 1000 | 19 | 5 | 15 | 30 | 35.0 | medium to fine A, loose. |
| | 20 | 90 | 100 | 100n | 100.0 | medium to fine A, loose. |
| 1014 | 21 | 50 | 75 | 75 | 100.0 | fine A, WC |
| | 22 | 80 | 100 | 100 | 100.0 | fine A, WC |
| 1001 | 23 | 50 | 100 | 100 | 100.0 | fine A, WC (spheric-al voids) |
| | 24 | 12 | 25 | 100 | 45.6 | fine A, WC ( " " voids |
| 1002 | 25 | 50 | 95 | 100 | 100.0 | fine A, (abundant " |
| | 26 | 10 | 65 | 75 | 46.0 | medium to fine A, WC |
| 1005 | 27 | 10 | 15 | 30 | 22.8 | large to medium A, loose. |
| | 28 | 10 | 100 | 100 | 100.0 | medium to fine A, WC |
| 1016 | 29 | 30 | 65 | 75 | 76.7 | large to medium A, loose |
| | 30 | 50 | 100 | 100 | 100.0 | large to medium A, loose. |

Large aggregates (A) = 2mm
Medium A = 2-½ mm
fine A = ½ mm

loose = no crust
WC = weak crust
C = crust





$$\text{surface} = 2\left|\frac{e+f}{2}\right| a$$

For two leaves the maximum amount of water is calculated.

| Big leaf | Small leaf |
|---|---|
| b = 30 cm | b = 13 cm |
| c = 12 | c = 9 |
| D = 10 | d = 7 |
| IS = 330 $cm^2$ | IS = 94 $cm^2$ (IS = interception surface) |

Field observation: about 90% of the intercepted rain reach the box with a surface of 70 $cm^2$.

A big leaf: $\frac{9}{10} \cdot \frac{330}{70}$ = 4.1 times the free precipitation reach the box

For the small leaf this is 1.2

About the half of the free precipitation reach the box.

so total precipitation for a big leaf = 4.6 times the free precipitation
small " = 1.7 " " " "

These values agree with the field observation.

Coverings percentage.

The crop cover percentage will be calculated of two plots, the values used are the maximum and the minimum values observed in the field during the field study period.

| Field I | | Field II | |
|---|---|---|---|
| S = 100 $m^2$ | | S = 100 $m^2$ | |
| P = 40 cm | | P = 90 cm | |
| R = 70 cm | T = 350 | R = 130 cm | T = 82.5 |
| a = 30 cm | | a = 30 cm | |
| e = 30 cm | | e = 10 cm | |
| f = 12 cm | | f = 10 cm | |
| Sp/plant = 0.21 $m^2$ | | Sp/plant = 0.06 $m^2$ | |
| Sp = 73.5 $m^2$ | | Sp = 4.95 $m^2$ | |
| C = 75.5 % | | C = 4.95 $m^2$ | |

The coverings percentage of the most plots during the study period will be between 10 - 30 %.

## Appendix VI Values of the LS-factor, H and AII-AI at the different fieldplots.

All terraces have been numbered according to their position on the slope (low numbers at the upperside)

TABLE XIX Values of the LS-factor, H and AII-AI at the MASAI fieldplot

| TERRACE | LS-factor | H(cm) | AII-AI(cm) |
|---|---|---|---|
| I | 1.0 | 30 | 20 |
| II | 1.0 | - | 15 |
| III | 1.6 | 90 | - |
| IV | 0.7 | 30 | 15 |
| V | 0.3 | - | 15 |
| VI | 0.2 | - | 5 |
| VII | 0.1 | - | 5 |

TABLE XX Values of the LS-factor, H and AII-AI at the MAGENCHE fieldplot.

| TERRACE | LS-factor | H(cm) | AII-AI(cm) |
|---|---|---|---|
| I | 0.8 | 60 | 20 |
| II | 3.5 | 60 | 10 |
| III | 0.7 | 80 | - |
| IV | 0.8 | 65 | 30 |
| V | 0.8 | 50 | 15 |
| VI | 0.4 | 40 | 5 |
| VII | 0.8 | 60 | 15 |
| VIII | 1.0 | 20 | 15 |

TABLE XXI Values of the LS-factor, H and AII-AI at the fieldplot IKOBA/RIOSIRI

| TERRACE | LS-factor | H(cm) | AII-AI (cm) |
|---|---|---|---|
| I | 2.2 | 100 | - |
| II | 2.6 | 90 | 8 |
| III | 3.0 | 80 | 35 |
| IV | 1.3 | 90 | 25 |
| V | 1.4 | 65 | 35 |
| VI | 1.8 | 80 | 35 |
| VII | 1.6 | 50 | 20 |

TABLE XXII IKOBA II/III

| | | | |
|---|---|---|---|
| I | 1.2 | 110 | 60 |
| II | 1.7 | 80 | 40 |
| III | 2.2 | 120 | 65 |
| IV | 2.7 | 100 | 20 |
| V | 5.1 | 80 | 30 |

TABLE XXIII IKOBA I

| | | | |
|---|---|---|---|
| I | 1.6 | 90 | 45 |
| II | 3.3 | 90 | 60 |
| III | 3.5 | 80 | 45 |

TABLE XXIV ITUMBI II.

| | | | |
|---|---|---|---|
| I | 5.5 | 100 | 20 |
| II | 2.0 | 120 | 20 |
| III | 3.6 | 110 | 50 |
| IV | 1.8 | 100 | 50 |

TABLE XXV Values of the LS-factor , H and AII-AI at OGEMBO

| TERRACE | LS-factor | H(cm) | AII-AI (cm) |
|---|---|---|---|
| I | 5.6 | 160 | 30 |
| II | 3.9 | 140 | 20 |
| III | 4.1 | 140 | 20 |
| IV | 3.2 | 150 | 25 |
| V | 2.5 | 100 | 25 |
| VI | 3.3 | 170 | 40 |
| VII | 5.5 | 200- | 60 |
| VIII | 6 | 100 | 50 |

TABLE XXVI ITUMBI I

| | | | |
|---|---|---|---|
| I | 2.6 | 100 | 25 |
| II | Over 6 | 110 | 20 |
| III | Over 6 | 100 | 35 |
| IV | Over 6 | 150 | 20 |
| V | 3.4 | 120 | 30 |
| VI | 3.4 | 100 | 25 |
| VII | 4.6 | 100 | 35 |
| VIII | 3.2 | 90 | 45 |
| IX | 5.5 | 70 | 20 |
| X | 4.2 | 70 | 45 |

## Appendix VII - Profile Descriptions

Profile no. 1000

Classification : Soil Taxonomy 1970 - Humoxic Tropohumult or Typic Rhodudult.

Location : Wanjare

Coordinates : 9930.30 N, 689.80 E

Elevation : 5050 ft.

Described by : Hennemann and Kauffman on

Geomorphology : upper part of a convex slope

Parent material : Granite

Slope : class 3 (sloping)

Stoniness : knickpoints of convex slopes are many outcrops

Moistness : surface and subsoil moist

Drainage : well drained

Biology : depth of the undisturbed soil at about 1 m

Landuse : maize and beans

Soil profile:

Ap 0 - 10 cm: Dark reddish brown ( 5 YR 2,5/2) moist; gravelly clay; weak, very fine to fine crumbs; slightly hard, very friable, non-sticky, non-plastic; clear , smooth to wavy boundary.

A1 10 - 30 cm: Dark reddish brown (5 YR 3/2) moist; gravelly clay weak, very fine to fine subangular blocky; slightly hard, very friable, non-sticky, non-plastic; clear, irregular boundary.

A3 30 - 55 cm: Dark reddish brown ( 2,5 YR 3/2) moist; gravelly clay weak, very fine to fine angular blocky; slightly loose non-sticky, non-plastic; gradual, wavy boundary;

B1 55- 105 cm: Dark red (2,5 YR 3/6) moist; gravelly clay weak very fine to fine angular blocky; slightly hard, loose, non-sticky, non-plastic; broken humus clay cutans; clear and wavy boundary;

R 105$^+$ cm: Rotten rock.

Profile no. 1001

Classification : Typic Fragiaquept

Location : in the neighbourhood of Bondo

Coordinates : 99 43.50 N, 680.50 E ,

Elevation : 42 30 ft.

Described by : Henneman and Kauffman on 29-5-1974

Geomorphology : straight uniform slope

Parent material : Kitere Granite

Relief and slope : flat relief and slope class 2, very gentle sloping 5%

Stoniness : no stones (class 0)

Moistness : surface and subsoil moist

Drainage : imperfectly

Biology : depth of undisturbed soil more than 70 cm.

Land use : maize

Soil profile:

A11 0 - 18 cm: Dark brown (7,5 YR 4/2) moist; loamy sand; very weak, very fine subangular blocky, (single grain structure) many very fine, few fine biopores; common, fine, distinct, clear, 7,5 YR 5/8 mottles; gradual to smooth boundary; soft, very friable, non-sticky, non-plastic;

A12 18 - 28 cm: Dark brown (10 YR 3/2) moist; loamy sand very weak, very fine subangular blocky; many very fine, common fine biopores; common, fine distinct, clear 7,5 YR 5/8 mottles; soft, very friable, non-sticky, non-plastic; abrupt and wavy boundary;

28 - 60 cm: Grey (10 YR 5/1) moist; loamy sand; many very fine and few fine biopores; few, fine, distinct, diffuse, 10 YR 5/2 mottles; very many, small + large, hard, irregular, black , Mn-Fe concretions with Fe-oxide skin (colour 7,5 YR 5/8); gradual and smooth boundary;

60+ cm: Gray (10 YR 5/1) moist; loamy sand; common very fine biopores; very many, small and large, hard, irregular, black, MN and Fe concretions.

Profile no. 1002

Classification : Typic Topaquent (planosol)
Location : in the neighbourhood of Bondo
Coordinates : 9942.30 N, 680.70 E.
Elevation : 4240 ft.
Described : Henneman and Kauffman, on 29-5-1974
Geomorphology : straight uniform slope
Parent material : Kitere Granite
Relief material : sloping (4%) flat relief and slope class 2, very gently
Stoniness : class 0 (no stones), on relatively small spots many big boulders.
Moistness : surface - and subsoil moist
Erosion : common, shallow gullies
Drainage : poorly to imperfectly drained
Biology : root development, few fine roots mainly at a depth of 0 - 70 cm.
Land use : natural grassland

A 0 - 1cm: Thin layers of fine and coarse sand, caused by erosion

B 1 -70cm: Very dark gray (10 YR 3/1) moist; massive; sandy clay; few very fine biopores; hard, friable, slightly sticky to sticky and plastic; common, distinct, irregular, light gray to gray (10 YR 6/1) mottles humus-clay cutans

Profile no. 1003

Classification : Typic Plinthaquent
Location : Noth Nyokal, 2 km S of Ndiru,
Coordinates : 9937.50 N, 680.30 E.
Elevation : 4600 ft.
Described : Henneman and Kauffman on 31-5-1974
Geomorphology : flat topped low ridges, pit on a straight uniform slope
Parent material : Nyanzian porfyritic Basalt
Relief and slope : subnormal relief and slope class 1 (2%). nearly level.
Stoniness : class 1 (interferes tillages)
Moistness : surface and subsoil moist
Drainage : moderately well drained
Biology : depth of the undisturbed soil at 60 cm
Land use : maize, millet, groundnuts and few cotton

Soil profile:

A1 0 - 18 cm: Dark reddish brown (5 YR 3/2) moist; clay loam; weak very fine subangular blocky; many fine and few fine biopores; slightly sticky and slightly plastic; clear and wavy boundary;

B1 18 - 37 cm: Dark reddish brown (5 YR 3/3) moist; clay loam; weak very fine subangular and angular blocky; many very fine and few fine biopores; slightly sticky and slightly plastic; patchy, thin, humus-clay skins; abrupt and wavy boundary;

B2cn 37-60 cm: Reddish brown (5 YR 4/3) moist; clay loam; moderate very fine angular blocky; common very fine and common medium biopores; slightly sticky and slightly plastic; few small and large, soft, irregular, black Mn concretions; many, rounded, quartz gravels; thin, broken clay cutans; abrupt, irregular boundary;

B2cn+m 60-80 cm: Reddish brown (5 YR 4/3) moist; clay; few very fine and fine biopores; slightly sticky and slightly plastic; many, large, soft, irregular, black Mn concretions cemented by Fe (red); many, rounded, fresh, quartz gravel; clay-iron cutans (very red); abrupt and smooth .

B2cn+m 80+ The same as B2cn+m 60-80, however, this horizon contains also many, weathered, basalt gravels and stones.

Profile no. 1004 : Masai 30
Classification : Soil Taxonomy - Humoxic Palehumult
Location : Bomachoge, 1.5 km E. of Magenche
Coordinates : 9896.20 N, 693.70 E.
Elevation : 5850 ft.
Described by : Henneman and Kauffman on 6-6-1974
Geomorphology : straight uniform midslope of a low hill
Parent material : basalt
Relief and slope : normal relief and slope class 3 (sloping)
Stoniness : class 0 (no stones)
Moistness : surface and subsoil moist
Drainage : well drained
Biology : depth of the undisturbed soil more than 90 cm
Land use : wimbi, maize, oranges (37 year cultivation)

Soil profile:

Ap 0 - 8 cm: Dark reddish brown (5 YR 3/2) moist; very fine clay weak very fine crumbs; many very fine and fine biopores; slightly hard, soft, non- sticky and non- or slightly plastic; clear and smooth boundary;

A3 8 - 30 cm: Dark reddish brown (5 YR 3/2) moist; very fine clay weak very fine crumbs and subangular blocky; many very fine and few fine biopores; very hard, friable non- sticky and non- or slightly plastic; clear and wavy (plow influence) boundary; continuous, humus-clay cutans;

B21 30-60 cm: Dusky red (2,5 YR 3/2) moist; very fine clay; weak to moderate, very fine to fine subangular blocky; many very fine biopores; hard, slightly friable, slightly sticky and slightly plastic; continuous to broken humus-clay cutans; clear and gradual boundary;

B22 60-90 cm: Dark red (2,5 YR 3/6) moist; very fine clay; moderate very fine to fine angular blocky; many very fine and few fine biopores; hard, slightly sticky and slightly plastic; broken humus-clay cutans;

Profile no. 1005 : Magenche B
Classification : Soil Taxonomy - Humoxic Palehumult
Location : S. Mugirango, between Magenche and Kenyenya
Coordinates : 9894.60 N, 690.30 E.
Elevation : 6050 ft.
Described by : Henneman and Kauffman on 5-6-1974
Geomorphology : straight footslope below escarpment
Parent material : Quartzites
Relief and slope : normal relief and slope class 2 (gently sloping)
Stoniness : class 0 (no stones)
Moistness : surface and subsoil moist
Erosion : class 1 (few rills)
Drianage : well drained
Biology : depth of the undisturbed soil more than 1m
Land use : maize

Soil profile:

A1 0 - 19 cm: Dark reddish brown ( 5 YR 3/2) moist; very fine clay; weak very fine subangular blocky; many very fine and common fine biopores; soft to slightly hard, very friable, non- sticky and non- or slightly plastic; clear and smooth boundary.

B1 19- 34 cm: Dark reddish brown (5 YR 3/4) moist; very fine clay weak to moderate fine to very fine to very fine subangular blocky; many very fine and common fine biopores; broken , humus-clay cutans; gradual and smooth boundary; (X)

B2 34- 90 cm: Dark red (2,5 YR 3/5) moist; very fine clay; weak to moderate, very fine angular blocky; many very fine and many fine biopores; slightly hard, very friable, non-sticky and non- or slightly plastic; broken to patchy humus-clay cutans;

X) slightly hard, friable, non- sticky and non- or slightly plastic

Profile no. 1006 : Magenche C
Classification : Soil Taxonomy - Humoxic Palehumult
Location : South Mugirango, between Magenche and Kenyenya
Coordinates : 9894.60 N, 689.25 E.
Elevation : 6100 ft.
Described by : Henneman and Kauffman
Geomorphology : straight footslope below escarpment
Parent material : Quartzites
Relief and slope : normal relief and slope class 3, sloping (15%)
Stoniness : class 0 (no stones)
Erosion : class 2 (shallow gullies trash lines)
Drainage : well drained
Biology : depth of undisturbed soil more than 70 cm.
Land use : maize

Soil profile:

B3 0 - 20 cm: Dark reddish brown (5 YR 3/4) moist; very fine clay moderately weak very fine subangular blocky; many very fine and few fine biopores; patchy to broken humus-clay cutans; gradual and smooth boundary.

B2 20 - 70 cm: Dark red (2,5 YR 3/5) moist; very fine clay; weak (sub) angular blocky; many very fine and common fine biopores patchy clay skins.

Profile no. 1007 : Masai O
Classification : Soil Taxonomy - Pachic Humoxic Palehumult
Location : Bomachoge, between Magenche and Nyabitunwa,
Coordinates : 9894.60 N. 695.30 E.
Elevation : 6150 ft.
Described by : Henneman and Kauffman, on 6-6- 1974
Geomorphology : slightly convex upper slope
Parent material : non- porfyritic basalt
Relief and slope : normal relief and slope class 3 (sloping)
Stoniness : class 0 (no stones)
Drainage : well drained
Biology : depth of undisturbed soil more than 90 cm
Land use : natural grassland

Soil profile:

A 0 - 9 cm: Dark reddish brown (5 YR 3/2) moist; very fine clay; weak very fine crumbs and weak very fine subangular blocky; many very fine and common fine biopores; very hard, firm, non- sticky and non- or slightly plastic; clear and smooth boundary.

A3 9 -55 cm: Dark reddish brown (5 YR 3/2,5) moist; very fine clay; moderate, very fine to fine subangular blocky; many very fine and few fine biopores; very hard, friable, non- sticky and non- plastic; broken to continuous, moderately thick clay cutans; plastered channels, Ø 1-1½ cm, 1-2/m$^2$;
plastered holes, Ø 2-5 cm, sometimes filled up with dark A or red B2 material; clear and wavy boundary.

B2 55-150 cm; Dark red (2,5 YR 3/5) moist; very fine clay; moderate very fine to fine angular blocky; many very fine biopores (diminishing with depth); hard, very friable slightly sticky and slightly plastic; broken to continuous, moderately thick clay cutans.

Profile no. 1008 : Masai 10
Classification : Soil Taxonomy - Humoxic Palehumult
Location : Bomachoge, 1.5 km E or Magenche,
Coordinates : 9894.60 N, 694.80 E.
Elevation : 6120 ft.
Described by : Henneman and Kauffman on 7-6- 1974
Geomorphology : nearly flat top of a low hill
Parent material : Basalt
Relief and slope : normal relief and slope class 1 (nearly level)
Stoniness : class 0 (no stones)
Drainage : well drained
Biology : depth of the unditurbed soil more than 1.40 m
Land use : maize

Soil profile:

Ap 0 - 11 cm: Dark reddish brown ( 5 YR 3/2) moist; very fine clay; mainly, weak very fine to fine crumbs and few subangular blocky; many very fine and few fine biopores; hard, very friable, non-sticky and non- or slightly plastic;clear and smooth boundary.

A1 11 - 34 cm: Dark reddish brown (5 YR 3/2,5) moist; very fine clay; few, moderately fine crumbs and mainly moderate very fine to fine sub-angular blocky; common very fine and few fine biopores; few, fine, prominent black mottles (charcoal ?); hard, friable non- sticky and non- or slightly plastic; gradual and smooth boundary.

B1 34 - 85 cm: Dusky red (2,5 YR 3/4) moist; very fine clay; moderate to strong, very fine to fine (sub) angular blocky; many very fine and few fine biopores, slightly hard to hard, very friable, non- or slightly plastic; continuous humus-clay cutans; gradual and smooth boundary.

B2 85 -140 cm: Dark red (2,5 YR 3/5) moist; very fine clay; moderate to strong, very fine angular blocky; many very fine and few fine biopores; continuous clay cutans.

Profile no. 1009 : Ogembo
Classification : Soil Taxonomy, Humoxic Palehumult
Location : Bomachoge 1 mile east of Nyamasege,
Coordinates : 5075 ft.
Described by : Henneman on 11-6-1974
Geomorphology : straight midslope (along Gucha river)
Parent material : Bukoban basalt
Relief and slope : normal - moderately steep
Stoniness : class 0 (no stones)
Moistness : surface and subsoil moist
Drainage : well drained
Biology : depth of undisturbed soil more than 70 cm
Land use : maize fallow

<u>Soil profile:</u>

A 0 - 34 cm: Dark reddish brown (5 YR 2.5/2) moist; very fine clay weak very fine crumbs; many very fine and common fine biopores; very friable, slightly sticky and slighgly plastic ; clear and wavy boundary.

B1 34 - 70 cm: Dark reddish brown (5 YR 3/4) when moist; very fine clay moderate fine to very fine angular to subangular blocky; many very fine, few to common fine biopores; moderately thick broken and continuous humus clay cutans; friable, slightly sticky and slightly plastic; krontovinas common filled up with A-material, Ø 10 - 20 cm; gradual and wavy boundary.

B2 70 -90 cm: Dark reddish brown (2,5 YR 3/4) when moist; very fine clay, moderate to strong fine to very fine angular blocky; many very fine, common fine biopores; firm, slightly sticky, slightly plastic ; moderately thick continuous clay cutans.

Remarks: depth of subsoil 2.00 cm.

Profile no. 1009A : Ogembo A
Classification : Humoxic Pale humult
Location : Bomachoge, E. of Nyamasege,
Coordinates : 9908.80 N, 687.40 E
Elevation : 5100 ft.
Described by : Kauffman on 11-6- 1974
Geomorphology : straight midslope along the Gucha river
Parent material : Basalt
Relief and slope : normal relief and slope class 3, (sloping)
Stoniness : class 0 (no stones)
Moistness : surface and subsoil moist
Drainage : well drained
Biology : depth of the undisturbed soil more than 80 cm
Land use : fallow (maize)

Soil profile:

Ap 0 - 10 cm: Dark brown (7.5 YR 3/2) moist; very fine clay; weak fine crumbs and very fine subangular blocky; many very fine and common fine biopores; slightly hard, friable, non-sticky and non- or slightly plastic; clear and wavy boundary;

A3 10 - 25 cm: Dark reddish brown (5 YR 3/2) moist; very fine clay; moderately weak very fine to fine subangular blocky; many very fine biopores; hard, very friable non-sticky and non- or plastic; patchy clay cutans; clear and smooth boundary;

B1 25 - 50 cm: Dark reddish brown ( 5 YR 3/2,5) moist; very fine clay; moderately weak very fine to fine (sub) angular blocky; many very fine biopores; hard, very friable, non- sticky and non- or slightly plastic; patchy to broken clay cutans; gradual and smooth boundary;

B2 50 - 80 cm: Dark reddish brown (2,5 YR 3/4) moist; very fine clay; strong very fine angular blocky; many very fine biopores; slightly hard, firm, slightly sticky and slightly plastic

Profile no. 1010 : Ikoba I
Classification : Soil Taxonomy - Humoxic Palehumult
Location : South Mugirango, 1 km south of Ikoba
Coordinates : 9914.00 N, 686.25 E.
Elevation : 5800 ft.
Described by : Henneman on 20-6-1974
Geomorphology : convex midslope of low hill
Parent material : Bukoban basalt (mainly) and quartzitic
Relief and slope : normal - strongly sloping (15%)
Stoniness : class 0 (no stones)
Moistness : surface and subsoil moist
Drainage : well drained
Biology : depth of undisturbed soil more than 85 cm.
Land use : maize

Soil profile:

Ap 0 - 17 cm: Dark reddish brown (5 YR 3/3) moist; very fine clay; weak very fine crumbs; many fine and many very biopores; very friable; slightly sticky and slightly plastic; boundary smooth and abrupt

B1 17- 50 cm: Dark reddish brown (5 YR 3/4) moist; very fine clay moderate to strong fine to very fine subangular blocky; many very fine biopores; friable to firm, slightly sticky and slightly plastic; moderately thick continuous clay humus cutans; boundary smooth and gradual.

B2 50 -85 cm: Dark red (2,5 YR 3/6) moist; very fine clay; moderate to strong fine to very fine angular blocky many very fine biopores; friable; slightly sticky and slightly plastic; thin broken clay cutans krontovinas common, Ø = 6-8 cm, round, filled up with A- material.

Remarks: depth of subsoil 1.020 m

Profile no. 1011 : Ikoba/Riosiri
Classification : Soil Taxonomy - Cumulic pachic humoxic palehumult.
Location : South Mugirango, 3/4 mile south of Ikoba
Coordinates : 9914.00 N, 699.30 E.
Elevation : 5800 ft.
Described by : Henneman on 20-6-1974
Geomorphology : convex midslope of low hill; lower part of natural terrace.
Parent material : Bukoban basalt + Quartzite
Relief and slope : normal very gently sloping (slope of natural terrace)
Stoniness : class 0 (no stones)
Moistness : surface and subsoil moist
Drainage : well drained
Biology : depth of undisturbed soil more than 120 cm
Land use : maize (good quality 2.40 - 2.70 m)

Soil profile:

A (sedim.) 0 - 8 cm: Dark reddish brown (5 YR 3/2) moist; very fine clay; layers (¼ - ½ cm) of very fine subangular blocky; aggregates; varying in size ½ - 1mm no structure; many very fine and fine biopores; very fribale slightly sticky; slightly plastic; boundary clear and smooth.

A1 8 - 70 cm : : Dark reddish brown (5 YR 3/2) moist; very fine clay; weak very fine crumbs and very fine subangular blocky many very fine biopores; friable, slightly plastic, slightly sticky; krontovinas common, ∅ = 5-10 cm. elliptical, boundary clear and wavy.

B1 70 - 100 cm: : Dark reddish brown (2.5 YR 3/4) moist; very fine clay moderate fine to very fine subangular blocky; many very fine and common fine biopores; friable sl. sticky and slightly plastic; moderately thick continuous clay cutans; krontovinas few; boundary gradual and smooth.

B2 100 -118 cm: : Dark reddish brown (2.5 YR 3/4) moist; very fine clay moderate to strong very fine to fine angular blocky; many very fine and few fine biopores; firm, slightly plastic and slightly sticky; thick continuous clay cutans

Profile 1012 : Ikoba II + III

Classification: Soil Taxonomy - Cumulic Pachic Humoxic Palehumult

Location : South Mugirango, 3/4 mile south of Ikoba

Coordinates : 9914.00 N, 699.60 E

Elevation : 5850 ft.

Described by : Hennemann, on 20-6-1974

Geomorphology : convex lower slope - lower part of natural terrace

Parent material: Bukoban basalt (mainly) and quartzite)

Relief and slope: normal nearly level (mesorelief terrace)

Stoniness : class 0 no stones

Moistness : surface and subsoil moist.

Drainage : well drained

Biology : depth of undisturbed soil more than 115 cm

Land use : maize

<u>Soil profile</u>:

$A_{sed}$ 0 - 16 cm: Dark reddish brown (2.5 YR 3/4) moist; very fine clay no structure slightly coherent aggregates, very fine subangular blocky in sedimentation layers of 3 - 5 mm thickness; many very fine and many fine biopores; very friable, slightly sticky and slightly plastic; clear and smooth boundary.

A11 16 - 30 cm : Dark reddish brown (5 YR 3/2) moist; very fine clay; weak very fine crumbs; many very fine and fine biopores; friable slightly sticky, slightly plastic; gradual clear and smooth boundary.

A12 30 - 58 cm : Dark reddish brown (5 YR 3/2) moist; very fine clay; weak to moderate very fine subangular blocky; thin broken clay skins; clear and smooth boundary.

B1 58 - 84 cm : Dark reddish brown (2.5 YR 3/4) moist; very fine clay moderate fine to very fine angular blocky many very fine and few fine biopores; friable, slightly sticky and slightly plastic; moderately thick continous clay humus skins; gradual and smooth boundary.

B2 84 -112 cm : Dark reddish brown (2.5 YR 3/4) moist; very fine clay; moderate to strong fine to very fine angular blocky; many very fine biopores firm, slightly plastic, slightly sticky; moderate moderately thick continuous clay humus skins.

Profile no. 1014: Riosiri

Classification : Humoxic Tropohumult

Location : East Nyokal, about 1 km K.W of Riosiri

Coordinates : 9915.20 N, 679.90 E

Elevation : 4850 ft.

Described by : Kauffman, on 17-6-74

Geomorphology : upper slope of a flat topped low hill

Parent material : Kitere granite

Relief and slope: normal relief and slope class 1 (nearly level)

Stoniness : class 0 (no stones)

Moistness : surface and subsoil moist

Drainage : well drained

Biology : depth of the undisturbed soil more than 60 cm

Land use : maize

Soil profile:

A1 0 - 17 cm: Dark reddish brown (5 YR 3/3,5) moist; very fine clay; weak very fine subangular blocky; many very fine biopores soft to slightly hard, very friable non-sticky and non- or slightly plastic; clear and smooth boundary.

B2 17 - 55 cm: Dark red (2,5 YR 3/6) moist; very fine clay; weak very fine subangular blocky; many very fine and few fine biopores; soft to slightly hard, very friable, non- sticky and non- or slightly plastic broken clay cutans.

Profile no. 1015 : Ogembo B
Classification : Humic Pale humult
Location : Bomachoge, E. of Nyamasege,
Coordinates : 9908.80 N, 687.40 E
Elevation : 51.00 ft.
Described by : Kauffman on 11-6-1974
Geomorphology : convex slope along the Gucha river
Parent material : Basalt
Relief and slope : normal relief and slope class 4 (strongly sloping)
Stoniness : class 1 (interference tillage)
Moistness : surface and subsoil moist
Drainage : well drained
Biology : depth of the undisturbed soil at 30 cm
Land use : maize and beans.

Soil Profile:

A1 0 - 20 cm: Dark reddish brown (5 YR 3/3) moist; very fine clay; very fine to fine subangular blocky, weak; slightly hard, friable, non-sticky and or slightly plastic; clear and smooth boundary;

B1 20 - 45 cm: Dusky red (2,5 YR 3/2,5) moist; very fine clay; very fine to fine angular blocky; slightly hard, very friable to friable, slightly sticky and slightly plastic; patchy clay cutans;

Remark: for deeper horizon see Ogembo and Ogembo A.

Profile no. 1016: Itumbi
Clssification : Humic Tropohumult
Location : S. Mugirango, W-side of the Itumbi hill
Coordinates : 9918.60 N, 682.90 E
Elevation : 5050 ft.
Described by : Kauffman on 12-6-1974
Geomorphology : straight upper slope of the,hill
Parent material : Quartzites
Relief and slope: normal relief and slope class 3 (sloping)
Stoniness : class 0 (no stones)
Moistness : surface and subsoil moist
Biology : depth of the undisturbed soil more than 70 cm
Drainage : well drained
Landuse : maize and groundnuts

Soil profile:

Ap 0 - 20 cm: Dark reddish brown (2,5 YR 3/4) moist; fine clay; weak very fine (sub) angular blocky; soft to slightly hard, very friable, non-sticky and non-plastic; clear and wavy boundary.

B1 20 - 40 cm: Dark reddish brown (2,5 YR 3/4) moist; fine clay; weak very fine angular blocky; soft to slightly hard, very friable, non-sticky and non-plastic; patchy clay cutans; gradual and smooth boundary.

B2 40 - $70^+$cm: Dark red (2,5 YR 3/5) moist; fine clay; moderately weak, very fine to fine angular blocky; hard, firm, non-sticky and non- plastic; broken clay cutans.