Soils of the Serengeti Woodlands, Tanzania

Promotor: dr.ir. J. Bennema, hoogleraar in de tropische bodemkunde

Tjapko Jager

Soils of the Serengeti Woodlands, Tanzania

Proefschrift
ter verkrijging van de graad van
doctor in de landbouwwetenschappen,
op gezag van de rector magnificus,
dr. C.C. Oosterlee,
hoogleraar in de veeteeltwetenschap,
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Abstract

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Also: Doctoral thesis, Wageningen.

Soils were surveyed in the woodlands of the Serengeti National Park in north-west Tanzania. The Serengeti Woodlands have been covered by volcanic deposits that have influenced chemical properties to a large extent. Physical characteristics were studied too in detail. The distribution of woodland and grassland correlated with infiltration rate and depth the moisture front reached after infiltration. A neutron probe was used for the soil moisture study. Especially in grassland areas frequented by large herds of herbivores, effective rainfall was less than half the actual rainfall. Mineralogical studies revealed that the clay fraction of the soils of the Serengeti Woodlands consisted almost entirely of X-ray amorphous material.

Free descriptors: infiltration, rainfall, volcanic deposits, mineralogy.

Serengeti Research Institute Publication No. 301.

This thesis will also be published as Agricultural Research Reports 912.

Aan mijn ouders
Aan Marjolijn, Jeroen en Rozemarijn

Acknowledgments

I am greatly indebted to Professor Dr Ir J. Bennema for all his pleasant guidance, stimulation and support received during and after completion of the fieldwork, and for inviting me to carry out research in that wonderful part of Africa called the Serengeti.

Thanks are also due to the Director and Trustees of Tanzania National Parks and the Director of the Serengeti Research Institute, Dr T. Mcharo, for permission to carry out the study.

Also I am very greatful to the following people:

- Marjolijn, my wife, who turned to many tasks, including field assistant and cartographer in the Serengeti and as corrector of the final manuscript
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- O.D. Jeronimus for preparing the soil maps
- G. Buurman, P.G.M. Versteeg and O.D. Jeronimus for the drawings

Stellingen

1. Infiltratiekarakteristieken van een bodem dienen bekend te zijn wil men zich een oordeel kunnen vormen omtrent de effectieve regenval in een bepaald gebied.

2. De snelle groei van de herbivoren-populatie in de Serengeti is mede veroorzaakt door een toename van de effectieve regenval bij gelijkblijvende totale jaarlijkse regenval.

A.R.E. Sinclair & M. Norton-Griffiths, 1979. Serengeti, dynamics of an ecosystem. Chicago University Press.

3. De veronderstelling als zouden de gronden van de Serengeti Woodlands voornamelijk gevormd zijn in verweringsprodukten van precambrische gesteenten is niet juist.

H.A. de Wit, 1978. Ph.D. Thesis, Wageningen.
D.J. Herlocker, 1976. Ph.D. Thesis, Texas A. and M. University.

4. De gronden van de Serengeti Woodlands zijn merendeels ontstaan in asafzettingen die ouder zijn dan die waarin de gronden van de Serengeti Plain zijn ontstaan.

Dit proefschrift.

5. De conclusie van Butzer als zou de Serengeti Plain een schoolvoorbeeld zijn van Büdel's model, waarin diepe verwering als belangrijkste factor van de planatie in semi-aride gebieden wordt gezien, is uiterst twijfelachtig.

K.W. Butzer, 1976. Geomorphology from the earth. Harper and Row.

6. Maar al te vaak wordt de invloed van de oorspronkelijke menselijke bevolking van wildparken niet op de juiste ecologische waarde geschat.

7. Dierlijke activiteiten kunnen in een "natuurlijk ecosysteem" tot erosie leiden die niet minder snel verloopt als door menselijke activiteit veroorzaakte erosie, die dikwijls als "accelerated erosion" wordt aangemerkt.

8. Men dient er voor te waken dat in het natuurwetenschappelijk onderzoek het veldwerk, als gevolg van een sterk toenemende modelmatige benadering, niet degradeert tot het routinematig verzamelen van gegevens.

9. Gewasbeschermingsmiddelen dienen in gestandaardiseerde en duidelijk herkenbare verpakking afgeleverd te worden.

10. Het is opmerkelijk dat in Nederland, waar de natuurbeschermingsorganisaties zo'n grote aanhang hebben, de sportvisserij het meest populaire tijdverdrijf is.

11. Het is onjuist te veronderstellen dat mensen die gymschoenen dragen ook sneller vooruit komen.

Proefschrift van Tjapko Jager
Soils of the Serengeti Woodlands, Tanzania
Wageningen, 8 januari 1982

- Z. van Druten and W.C.W.A. Bomer for photography
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- The Stichting 'Fonds Landbouw Export Bureau 1916/1918' for providing funds for the preparation of the soil map.

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Curriculum vitae

De auteur werd geboren in 1946 te Veendam. Hier verkreeg hij in 1963 het diploma HBS-B aan het Winkler Prins Lyceum. In datzelfde jaar begon hij zijn studie aan de Landbouwhogeschool. In 1971 studeerde hij af in de tropische bodemkunde met als keuzevakken luchtfoto-interpretatie, bemestingsleer en meteorologie.

Na zijn afstuderen was hij werkzaam als wetenschappelijk ambtenaar bij de NIWARS, een interdepartementale werkgroep die zich bezighield met de toepassingsmogelijkheden van de moderne luchtwaarnemingstechnieken.

In 1974 vertrok hij naar Tanzania waar hij verbonden was als onderzoeker aan het Serengeti Research Institute. Hier verrichtte hij zijn promotieonderzoek onder supervisie van prof.dr.ir. J. Bennema. Het onderzoek werd gefinancierd door de Stichting voor Wetenschappelijk Onderzoek van de Tropen (WOTRO).

Gedurende 1978 en 1979 was hij teamleider van een "range and wildlife survey" van de Kalahari (Botswana) in dienst van DHV Raadgevend Ingenieursbureau.

Vanaf 1980 is de auteur landbouwer.

Preface

The Serengeti National Park lies in the north-west of Tanzania to the south-east of Lake Victoria.

The Serengeti Research Institute, founded in 1966 to provide scientific information for conservation and management of the National Parks, lies in the centre of the Park.

The soil survey was one of a series of studies on major aspects of the Serengeti National Park. Initially emphasis was laid on large mammals. To understand factors determining amount, quality and distribution of food for the herbivores, soils were surveyed in the Serengeti Plain and the Serengeti Woodlands.

In 1970 de Wit (1978) started to study the soil-vegetation interrelationships on the Serengeti Plain. He equipped a laboratory for soil chemistry, which I used too during the survey of the Serengeti Woodlands.

Differences in chemical composition turned out to be crucial on the Serengeti Plain, since the area lies close to a region of recent volcanic activity and is frequently covered with alkaline volcanic ash. Volcanic deposits have covered the Woodlands too but to a lesser extent. So I laid more emphasis on physical properties. Available soil moisture proved to be the major factor in distribution of woody vegetation. Moisture was measured monthly with a neutron probe.

In 1974 a photointerpretation map was prepared of the Woodlands. In 1976 two test areas were surveyed in detail. Numerous soil pits were dug and described, and sampled for chemical analysis. About 260 soil samples and 100 water samples were analysed in the laboratories of the Serengeti Research Institute and of the Agricultural University in Wageningen.

The boundaries fixed in the photointerpretation map were checked and the soil units delineated were described during the study.

In September 1976 fieldwork was finished. Analytical work and preparation of the manuscript were completed at the Agricultural University and the International Soil Museum.

Contents

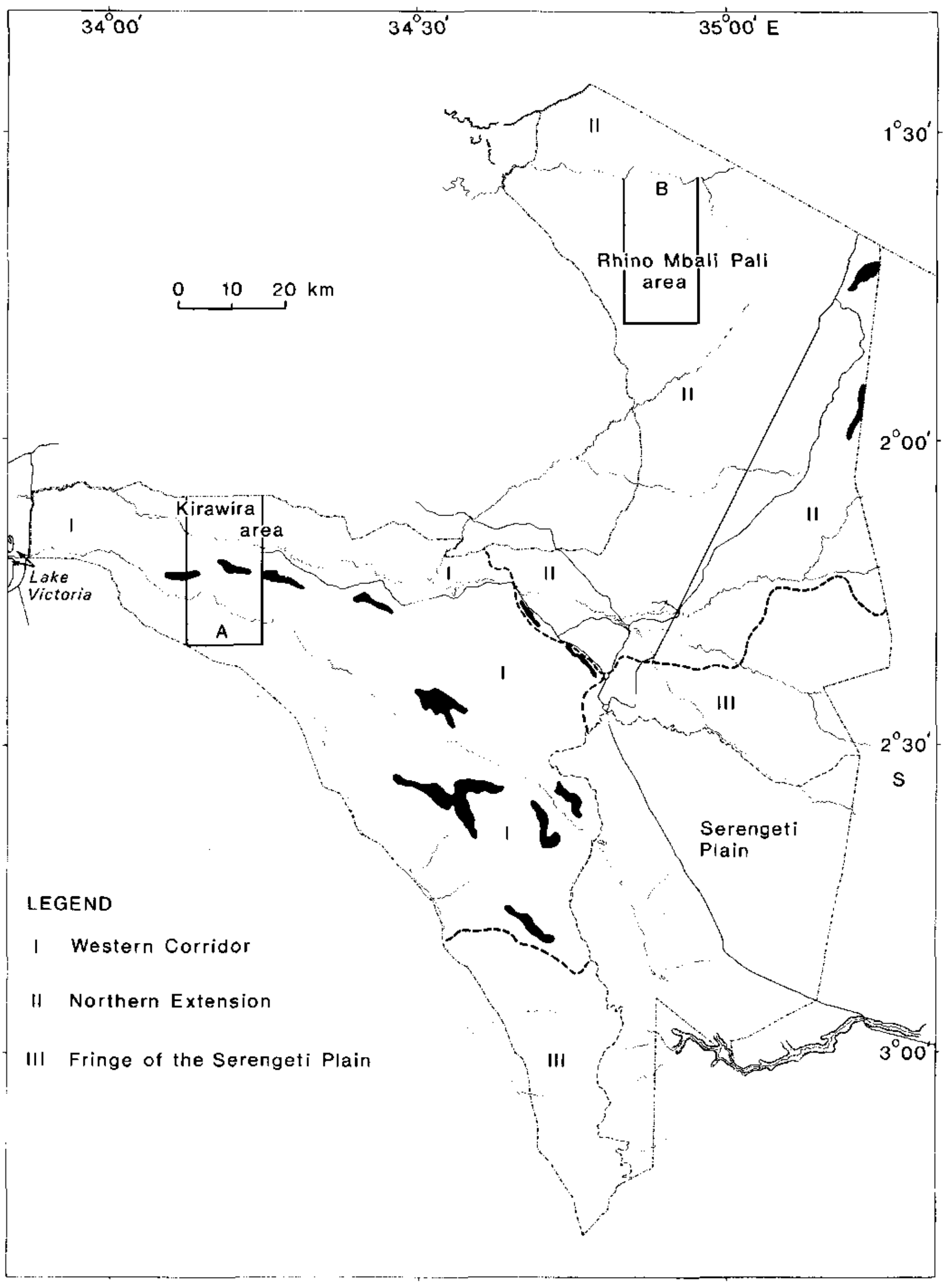


Figure 1. Map of the Serengeti National Park showing the 3 soil landscapes of the Serengeti Woodlands and approximate location of detailed study areas.

1 Introduction

The Serengeti National Park comprises an area of about 13 250 km^2 since the last boundary changes in 1968 between latitudes 1°30' and 3°30' and longitudes 33°80' and 35°30'.

The altitude ranges from 1140 m at Lake Victoria to 2090 m in the extreme north-east (Kuka Hills). The average altitude is about 1500 m.

The Park consists of the Serengeti Plain and the Serengeti Woodlands, which comprise about a quarter and three quarters of the area. De Wit (1978) has described the soils of the Serengeti Plain. This report describes the soils of the Serengeti Woodlands. The Serengeti Woodlands were subdivided into three regions by physiographic characteristics and by differences in impact of volcanic deposits: the Fringe of the Serengeti Plain, the Western Corridor and the Northern Extension (Figure 1). The area is predominantly under woody vegetation; a third of the Western Corridor, however, consists of grassy plains.

1.1 CLIMATE

1.1.1 Introduction

In 1975 Norton-Griffiths et al. published an article about the rainfall patterns in the Serengeti ecosystem based on ten years of data, 1962-1972. De Wit (1978) described the climate of the Serengeti Plain and surroundings.

1.1.2 Rainfall

Annual rainfall

According to Norton-Griffiths et al. (1975) total annual rainfall showed a clear gradient from 500 mm in the south-east to 1200 mm in the north-west. In the Serengeti Woodlands, rainfall ranged from 700 mm to 1200 mm (Figure 2). Norton-Griffiths et al. calculated annual rainfall for periods from 1 November of one year to 31 October of the following year. They are considered to be more relevant ecologically for they represent complete seasonal cycles. At Seronera it made hardly any difference whether the starting point was November 1974 or January 1975: 635 and 655 mm respectively (Figure 3).

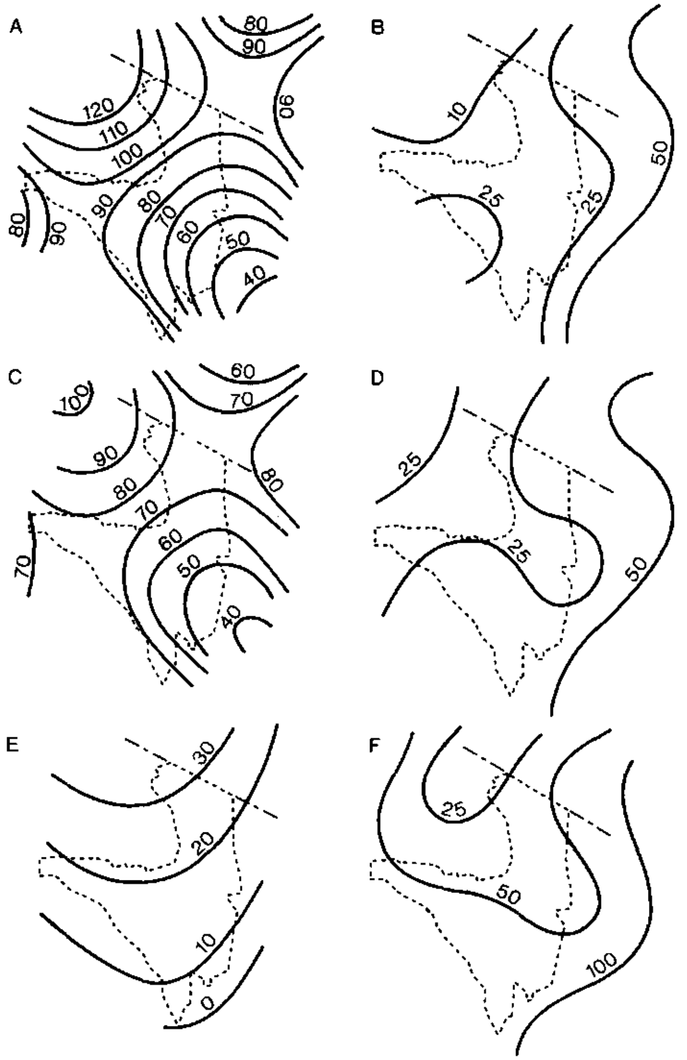


Figure 2. Isohyets for the Serengeti ecosystem. A. Annual total (cm). B. Annual variability (%). C. Wet season total (cm). D. Wet season variability (%). E. Dry season total (cm). F. Dry season variability (%). (from Norton-Griffiths et al., 1975).

According to Braun (1973) an average rainfall of 50 mm per month will sustain grassland productivity. This is the lower boundary of the intermediate growing season (Figure 4). I confirmed this limit with data on soil moisture.

Rainfall patterns

The rainfall pattern in the Park demonstrates two clear peaks in December and April (Norton-Griffiths et al.). July is the driest month (Figure 4)

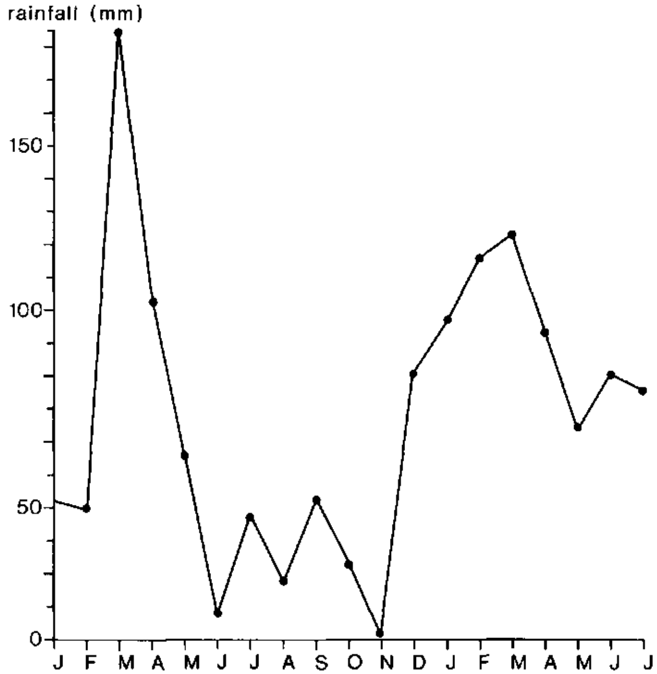


Figure 3. Monthly rainfall from January 1975 - July 1976 at the Serengeti Research Institute.

with rainfall approaching zero. Differences in rainfall patterns and the from south-east to north-west gradient are caused by:

- Shift in the Inter Tropical Convergence Zone. In July, the zone reaches its most northerly point, which coincides with the driest month. In April and in October, the region is in the centre of the zone. Differences in rainfall between the two months are related to differences in winds.
- The Ngorongoro Highlands in whose rain shadow the eastern part of the Serengeti is situated.
- Lake Victoria. Temperature differences are generated between the Lake and the surroundings. In the daytime, the Lake is cooler than the surroundings, so creating a pressure gradient. At night the reverse occurs.

During 1975 and 1976 out-of-season rainfall was higher and wet-season rainfall less than in previous years.

Rainfall rate

Out of 80 rainy days during 1975, more than 40 had a rainfall from 1 to 5 mm (Tables 1 and 2). Heavy showers yielding more than 5 mm are rare; most of the showers were at a rate of 1-5 mm/h.

Showers brought the daily rainfall to 20 mm only on less than 1 rainy day in 10.

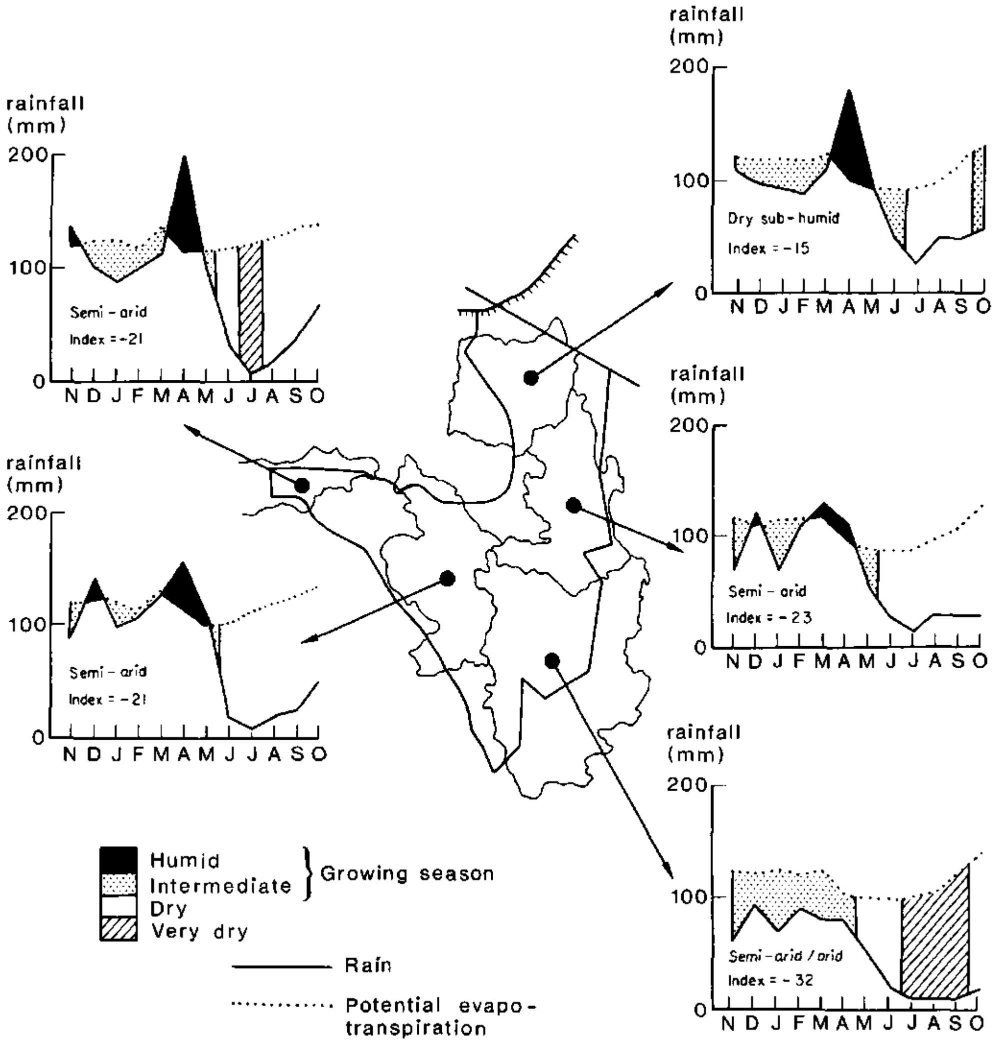


Figure 4. Climatograms for 5 selected land regions (from Norton-Griffiths et al., 1975).

There seemed to be a relation between rainfall rate and daily rainfall during 1975. For 1976, data were available only for the first 7 months.

The maximum rate measured was 130 mm/h over half an hour. Since infiltration rates for the Woodlands soils were 1-40 mm/h, rainfall rates need to be known if available soil moisture is calculated from rainfall data. The interpretations given by Norton-Griffiths et al. in the climatograms, especially the length of the growing season, should therefore be reexamined.

Table 1. Correlation of rate and amount of rainfall of showers during 1975 at the Serengeti Research Institute. There were 78 days with rain.

Rainfall rate (mm/h)	Amount of rainfall of a shower (mm)				
	1-5	5-10	10-20	20-50	>50
<1	+xo				
1- 5	++++****xxxx xxxxxxxoooo oo½o½o½o½*)	+**xo	*½o		
5-10	++**xxxoo	++½*xxooo	+½x		
10-20	*xxx	+++	++*x	+	
20-50	x	+*o½o½o½o½	+++	++*½	
>50			***		x

½ two showers in one day
+ rainy days in first quarter 1975
x rainy days in second quarter 1975
* rainy days in third quarter 1975
o rainy days in last quarter 1975

Table 2. Correlation of rate and amount of rainfall of showers from January to July 1976 at the Serengeti Research Insitute.

Rainfall rate (mm/h)	Amount of rainfall of a shower (mm)				
	1-5	5-10	10-20	20-50	>50
<1	++++x*				
1- 5	+++++++xxxx xx	++xx	+		
5-10	++xxxxxx*	++xxx			
10-20	++xx	xxx	+xxxxx*	++	
20-50		++xx	++x	+x	
>50			++x	++	*

+ rainy days in first quarter 1976
x rainy days in second quarter 1976
* rainy days in third quarter 1976

1.1.3 Temperature

Air temperature

The mean air temperature during 1975, measured in a Stevenson screen (Figure 5) at the Serengeti Research Institute was 21.0 °C (Figure 6). Results reported by de Wit for a three year period were similar. Mean weekly air temperatures were calculated from the average of the weekly maximum and minimum. The warm season coincides with the wet season and the cold season with the dry season. Temperature variations for a typical week in the dry season are depicted in Figure 7. Temperature variations throughout the Park were related mainly to altitude. No data were available on them from other stations than the Institute.

Soil temperature

Soil temperature was measured at a number of sites, one permanent at the research station, to get an impression of variation within the year, which governs soil classification.

Annual temperature variations

At the research station soil temperature was measured every 2 weeks at a depth of 50 cm. The mean temperature at 50 cm for the period October 1975 to August 1976 (10 months) was about 25 °C, the maximum 27.0 and the minimum 22.5 °C.

According to Soil Taxonomy (1975) the soil temperature regime can be classified isohyperthermic (mean annual soil temperature is 22° C or higher and mean 'summer and winter' temperature differ less than 5 °C.

The mean annual air temperature was 21 °C, the difference from mean annual soil temperature (1975 and 1976 data) being 4 °C, which is rather high but close to data from elsewhere in East Africa (Table 3). In other parts

Table 3. Temperatures in air and soil at sites in East Africa. Data other than from the Serengeti Research Institute are from Griffiths (1962).

Place	Altitude (m)	Mean air temp. (°C)	Mean soil temp. (°C)	Mean range soil temp. at			Excess of soil temp. over air temp.
				15 cm	50 cm	122 cm	
Dar es Salaam	0	26	29	7	.	4	3
Entebbe	1189	22	24	.	.	1	2
Kabete (Nairobi)	1829	18	22	5	.	2	4
Muguga (near Nairobi)	2103	16	21	6	.	2	5
Serengeti Research Instit.	1545	21	25	.	4,5	.	4

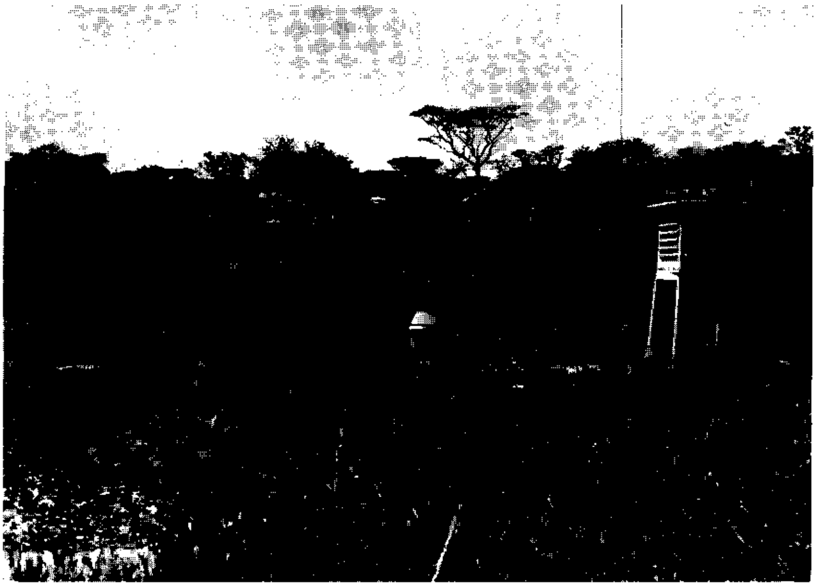


Figure 5. Meteorological station established at the Serengeti Research Institute.

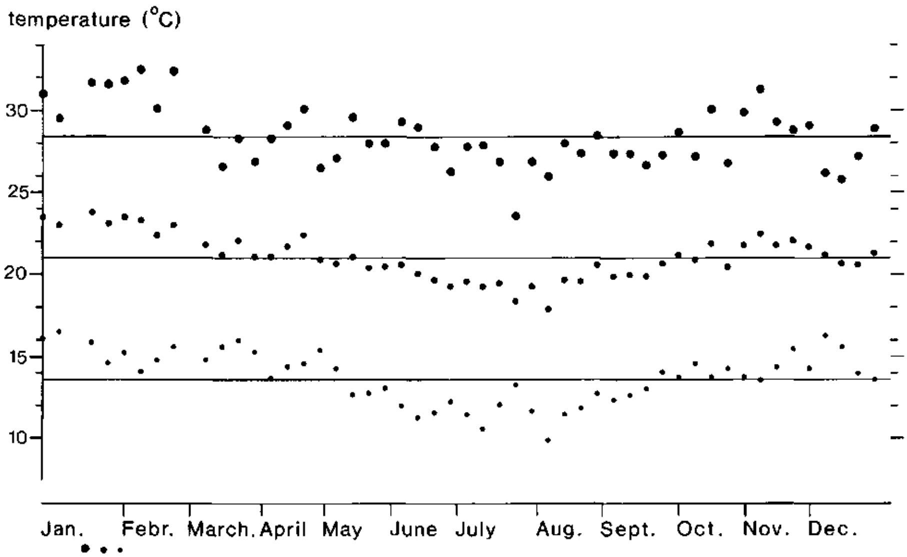


Figure 6. Mean weekly maximum, mean and minimum air temperatures for 1975.

of the tropics and semi-tropics values were 2 °C in Turkey (Jager, 1972), and 3.5 °C in Indonesia (Mohr et al., 1972). Soil temperature regime and soil classification are discussed by Smith et al. (1964).

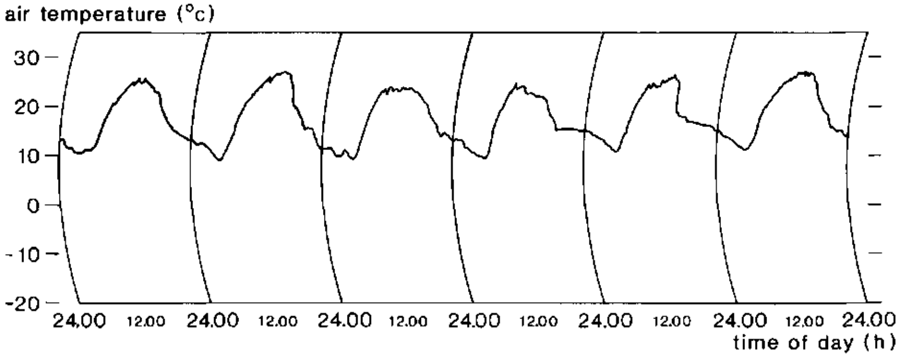


Figure 7. Air temperature during a typical dry season week in August 1975.

Diurnal temperature variations

Diurnal variations were calculated for 5 sites at depths of 2, 5, 10, 20 and 50 cm. At most sites, the depth in which the temperature variation decreased by a factor e (damping depth), was between 9 and 10 cm (Figure 8 and 9), as would be expected in dry clayey soils.

At site Rhino 5, a fine sandy soil, a decrease by e occurred in 8 cm in

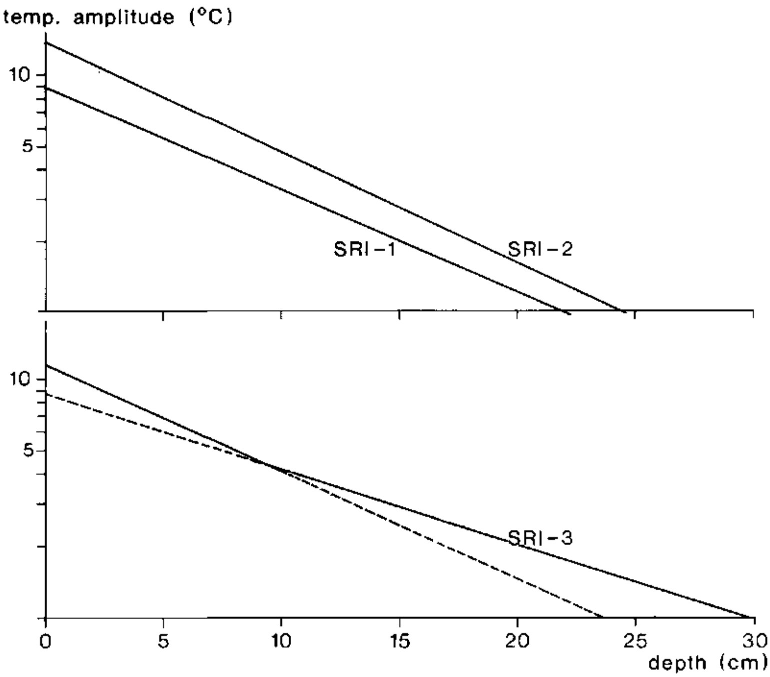


Figure 8. Calculation of damping depth for the daily variation in temperature at site SRI-1 (D = 9.9 cm), SRI-2 (D = 9.3 cm) and SRI-3 (D = 9.5-14.5 cm).

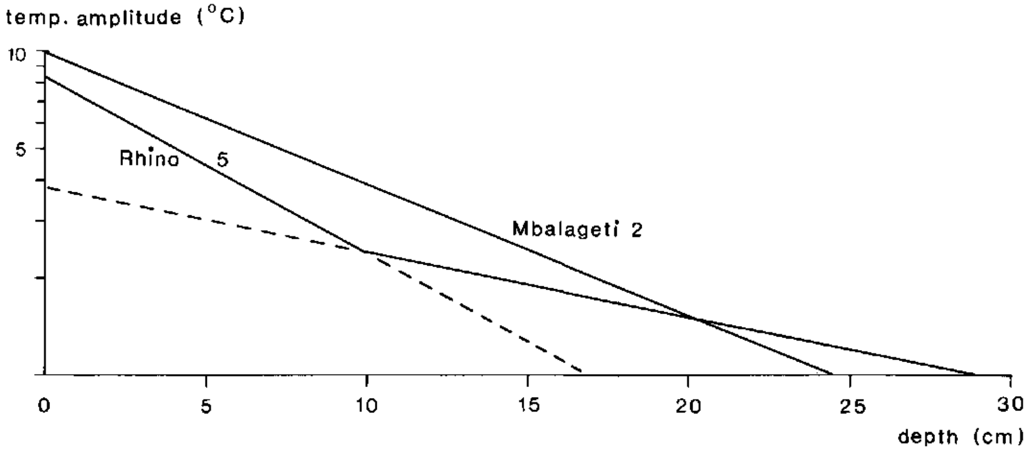


Figure 9. Calculation of damping depth for the daily variation in temperature at site Rhino 5 (D = 8.0-21.7 cm) and Mbalageti 2 (D = 10.7 cm).

topsoil, but in 21.7 cm in moist subsoil. This example illustrates that soils are not necessarily homogeneous in thermal properties. At site SRI-3 damping depth was calculated for two dates (Figure 8).

If a soil is thermally homogeneous, depth and temperature amplitude on a logarithmic scale should form a straight line. The value of damping depth is the reciprocal of the temperature gradient. A difference in damping depth between topsoil and subsoil is often caused by a change in moisture content or in soil texture.

Diurnal temperature variations are shown in Figure 10 and 11. Little information can be extracted from these graphs, because atmospheric conditions and soil moisture were not uniform.

1.1.4 Evaporation and evapotranspiration

Data on potential evaporation are given by Norton-Griffiths et al. (1975), Braun (1973) and de Wit (1978).

De Wit discusses the reliability of the method generally used at the Serengeti Research Institute. Small cans were used to measure 'pan' evaporation each month. De Wit estimated an underestimate by about 30% due to reduced advection and reduced solar radiation as the level fell by evaporation. Nieuwholt (1973) estimated this so-called oasis effect, evaporation due to advection, as 35% of the total.

De Wit estimated an annual potential evaporation of 1800 mm at the Institute (altitude 1545 m), Norton-Griffiths et al. 1930 mm for Kogatende at altitude 1402 m in the north-west of the Park. Woodhead (1968) gave similar values. Regression equations between altitude and potential evaporation from Woodheads data for areas similar to the Park were calculated by Nor-

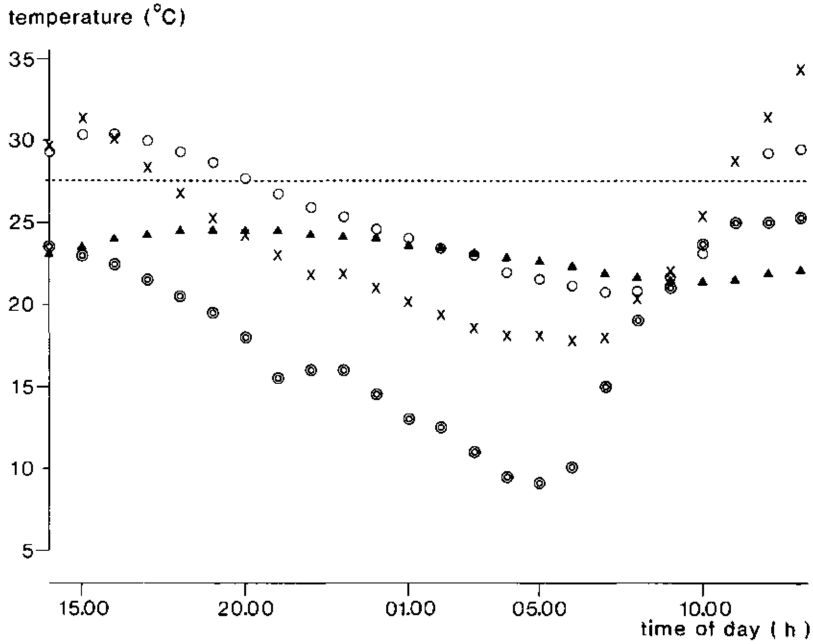


Figure 10. Daily variation in temperature at SRI-2, in air (height 1.50 m, O) and at 5 (◎), 10 (x), 20 (▲) and 50 cm (---------) depth.

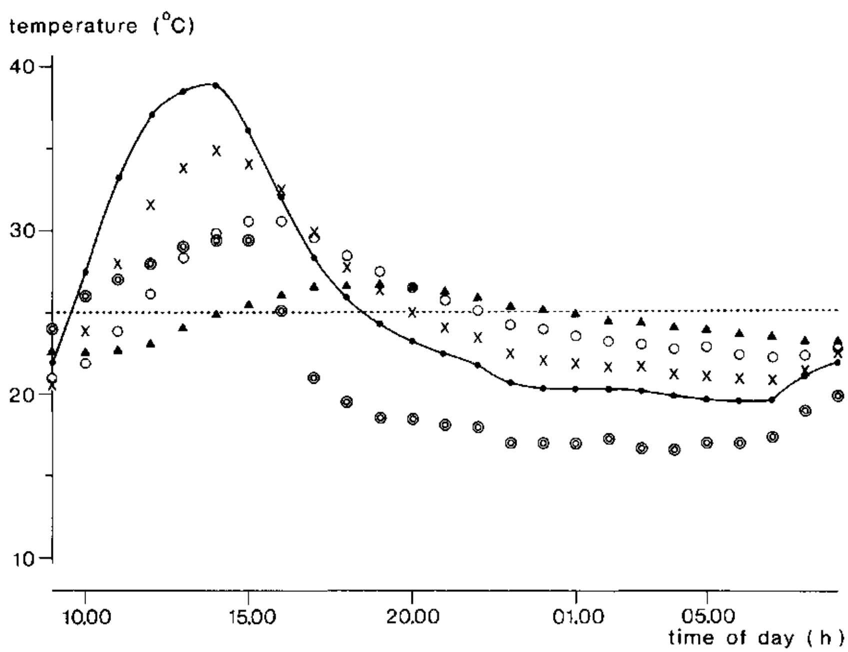


Figure 11. Daily variation in temperature at SRI-3, in air (height 1.50 m, O) and at 2 (———), 5 (◎), 10 (x), 20 (▲) and 50 cm (-------) depth.

ton-Griffiths et al. Potential evaporation was calculated for each rain-gauge site in the Serengeti. Potential evapotranspiration can be calculated from potential evaporation by multiplying with a factor 0.75 (Brown & Cocheme, 1973), as was done also by Norton-Griffiths et al. Actual evapotranspiration is discussed in Section 7.4.5.

1.2 GEOLOGY

The geology of the area is described by Thomas (1966), Lounsberry & Thomas (1967), Macfarlane (1967), Pickering (1960), Taylor (1965), and Horne (1962).

The oldest rocks present in the Serengeti are pre-Nyanzian gneisses, Nyanzian quartzites and metamorphosed volcanics (Figure 12). Granites, common throughout the Park, and most of the gneisses are assumed to be somewhat younger, but still Precambrian. During Bukoban times (late Precambrium), siltstones, sandstones and quartzites were deposited in a large basin and have since altered by metamorphosis and diagenesis. North of the Mara River, in the Northern Extension, trachitic phonolites covered the area in late Tertiary times, after the early Miocene.

Rifting started in the Tertiary, but culminated in the Pleistocene as the Great Rift Valley (east of the Park), the Eyasi Rift Valley (south of the Park). Lake Victoria originated by backponding (Kendall, 1969). The uplift to the west in Uganda relative to the Rift Valley exceeds 700 m (Doornkamp & Temple, 1966), perhaps beginning in the Miocene and continuing to late Pleistocene times. The Crater Highlands (including Ngorongoro, Kerimasi, Oldoinyo Lengai and other volcanoes) and the Isuria escarpment (the northeastern Park boundary) also originated in Pleistocene times. The volcano Oldoinyo Lengai is still active and periodically enriches the area to the west with fresh carbonatitic ash (Dawson, 1962; Guest, 1954). The Park thus consists of very old rocks and is surrounded by recent geological structures and covered with fresh volcanic deposits.

1.3 GEOMORPHOLOGY

The Serengeti Woodlands contain many different land-forms creating habitats for the diverse animal population of the Serengeti National Park. The most distinct features are 'kopjes', in granitic and gneissic rocks throughout the Park. Kopjes stand out from the surroundings. As is described by Handley (1952), kopjes on ridge tops result from incomplete planation; on slopes and along drainage lines, they originate after dissection or slope retreat of the planation surface, which ultimately will result in a new planation surface.

In the Serengeti four such planation surfaces can be distinguished. The plateau of the major ranges in the Western Corridor and the summits of the

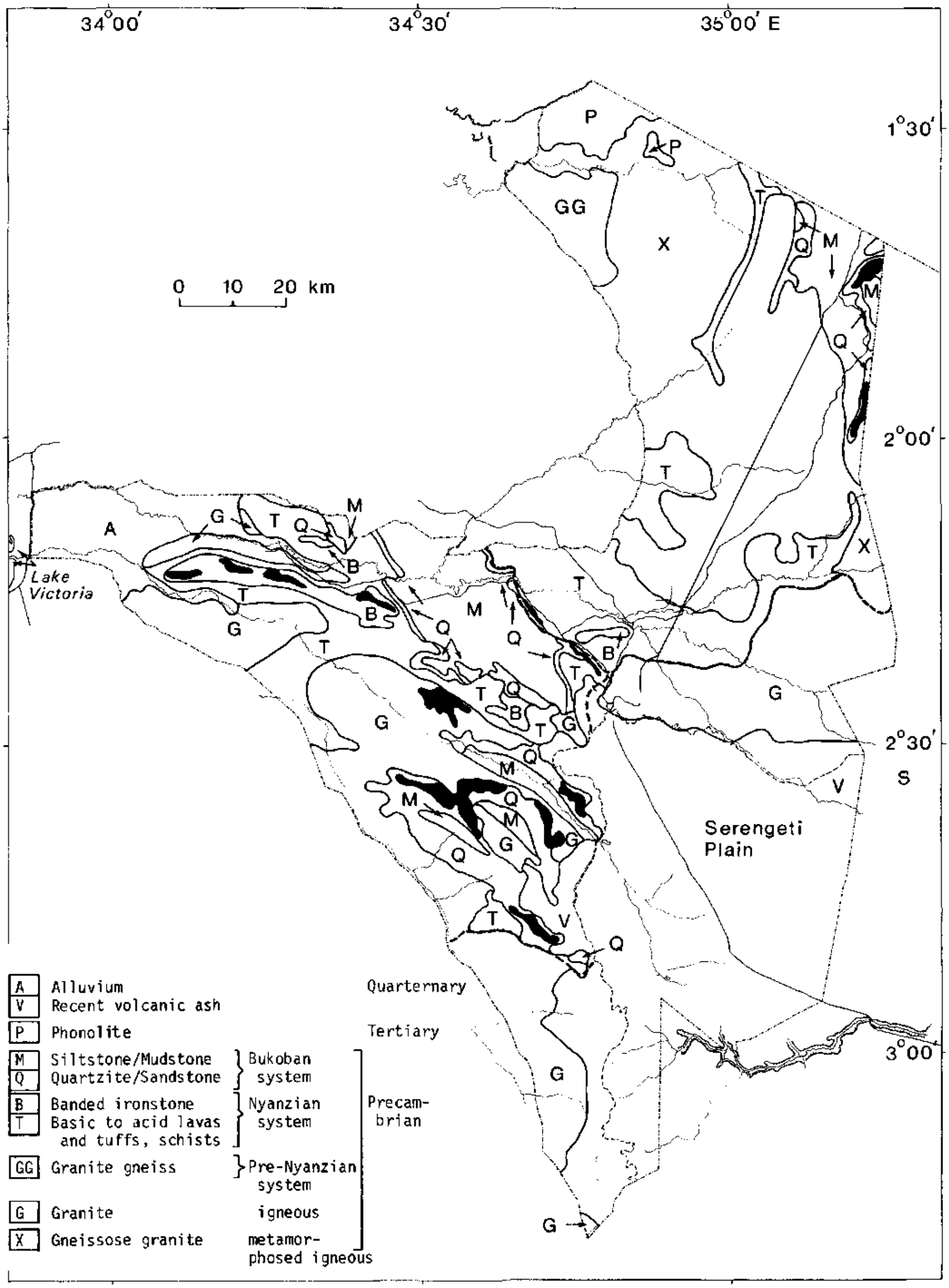


Figure 12. Geological map of the Serengeti Woodlands (adapted from Macfarlane, unpublished).

hills in the north-west of the Northern Extension are probably remnants of the oldest erosion surface. Relicts of a younger erosion surface have the largest extension in the Western Corridor (e.g. Kirawira Plains and Dutwa Plains etc.).

The transition zones between the different surfaces often contain distinct belts of kopjes (particularly if granitic or gneissic rocks are present). Section 10.1 describes the distribution of erosion surfaces in the Park.

1.4 VEGETATION

Within the Serengeti Woodlands Herlocker (1974) distinguished six vegetation types:

- evergreen forest and evergreen to semi-deciduous bushland
- semi-deciduous bushland and deciduous bushland
- semi-deciduous woodland
- semi-deciduous thorn tree wooded grassland
- inselberg vegetation
- deciduous to semi-deciduous thorn tree woodland

Only deciduous to semi-deciduous thorn tree woodland contains more than one typifying species. This vegetation type is the most important type in the Serengeti, occupying 7260 km^2 or almost 90% of the area under woody vegetation (Herlocker, 1974). He subdivided the type into 16 subtypes by dominant species.

The next major type is semi-deciduous woodland, which occupies 390 km^2, or about 5% of the area under woody vegetation. This type is confined to the north-west of the Northern Extension. Locally the vegetation types include patches of grassplains throughout the Serengeti Woodlands.

Woody vegetation is almost limited to areas with favourable physical characteristics such as infiltration rate and water retention.

1.5 WILDLIFE

The Serengeti Park houses a wide range of game animals.

The Western Corridor contains the richest fauna because of the variety of land-form and soil; the fauna there includes both grazing animals typical of the plain and browsing animals typical of the woodlands.

Resident herds of topi and wildebeest live in the Dutwa and Kirawira Plain in the Western Corridor.

In the Northern Extension, buffalo and elephant are more numerous. Grazing game, however, is almost completely absent there. Wildebeest stay on the grassland slopes in the northern part only to break their migration. They tend to stay in the Western Corridor as long as food and water persists. Kreulen (1974) correlated the wildebeest distribution on the Serengeti Plain with the calcium content and the calcium-phosphorus ratio of the grass. Correlations between game distribution and soil properties were obvious in the Serengeti Woodlands too (Sections 2.7 and 3.7).

1.6 HYDROLOGY

1.6.1 Surface drainage

The Serengeti Woodlands drain through three major rivers, the Mara, Grumeti and Mbalageti, into Lake Victoria (Figure 1). In the dry season, discharge is low or ceases, but pools are always present, especially if the bottom consists of bedrock.

The drainage pattern is predominantly dendritic, but also angular patterns were observed, for instance in the Grumeti River where it cuts through gneissic and granitic rocks. The latter pattern represents an early stage in river development. This and other evidence, such as the presence of steep banks along the main rivers, suggests that rifting is still active. Apparently the erosion base of the main rivers is still lowering, either by uplift of the Serengeti area or subsidence of Lake Victoria.

The sediment load and chemical composition of the discharge of the Mara, Orangi, Nyabogati and Grumeti Rivers were monitored each month (Section 10.2).

1.6.2 Soil moisture

Soil moisture will be discussed in detail in Chapter 7. Only a few remarks need be made here.

Soil moisture classification

According to Soil Taxonomy the moisture regime of the Woodlands soils is generally Ustic: if the mean annual soil temperature is 22 °C or higher or the mean summer and winter soil temperature differ less than 5 °C at a depth of 50 cm, the soil moisture control section is dry in some or all parts for 90 or more cumulative days in most years. But the moisture control section is moist in some part for more than 180 cumulative days, or it is continuously moist in some part for at least 90 consecutive days.

The upper boundary of the control section is the depth to which a dry soil (moisture tension 1600 kPa) will be moistened by 2.5 cm of water within 24 h, while the lower boundary is the depth to which a dry soil will be moistened by 7.5 cm of water within 48 h (after Soil Taxonomy).

Some soils in the north-west of the Northern Extension (Ustalfs and Ustolls) and soils that receive big amounts of run-off fall into the Udic subgroup, because a ca horizon is present at a greater depth than in the Typic subgroup.

Soil moisture storage

Norton-Griffiths et al. and de Wit estimated the amount of water stored in the Serengeti soils at about 100 mm. Soil moisture storage was used in calculating surplus (s) and deficit (d), which are components of the Thornthwaite Climatic Index (I).

$$I = (100s - 60d)/n$$

Soil moisture storage hardly ever exceeds 50 mm in the Woodlands (Chapter 7), whereas Norton-Griffiths et al. and de Wit both assumed a value of 100 mm. The error does not change the climatic index drastically, because the Thornthwaite index is not directly determined by soil characteristics.

Indirectly soil factors influence the surplus and deficit, because they equal rainfall minus potential evapotranspiration, minus (or plus) soil moisture storage. In such calculations, run-off was ignored. Over much of the Woodlands it greatly reduces effective rainfall (Section 7.4.7).

Infiltration rates and water retention are given in the site descriptions. Ground-water was not detected in the Serengeti. Bottomlands like Ndabaka Plain, drainage lines and other depressions are flooded in the wet season.

1.7 SOILS

Little work has been done on the soils of the Serengeti Woodlands sofar. Bell (1969) carried out ecological research in the Western Corridor and distinguished four soil groups:

- black cotton soils
- alluvial soils
- granitic soils, underlain by granitic rocks
- lateritic soils, underlain by metamorphous Nyanzian rocks.

Gerresheim (1974) prepared a landscape map of the Serengeti ecosystem. Within the park he distinguished 9 different land regions (Figure 13), based on similarities in geology, land-form, hydrology, vegetation and soil. The regions were subdivided into subregions, which were subdivided into land system associations. The smallest units represented on the map were land systems. Discussing his landscape classification system is not possible, because sofar no comprehensive descriptions are available. Generally speaking some of the boundaries will also emerge on the soil map, others do not represent major soil differences.

The aim of the landscape map was to combine different approaches for the purpose of integrated ecological research (Gerresheim, 1972 and 1974). As such the map should become a basis for ecological monitoring and research for different disciplines. However, when this method is followed, information about one discipline is less complete and always obscured by other information. For the soil scientist it is hard to get an impression about the

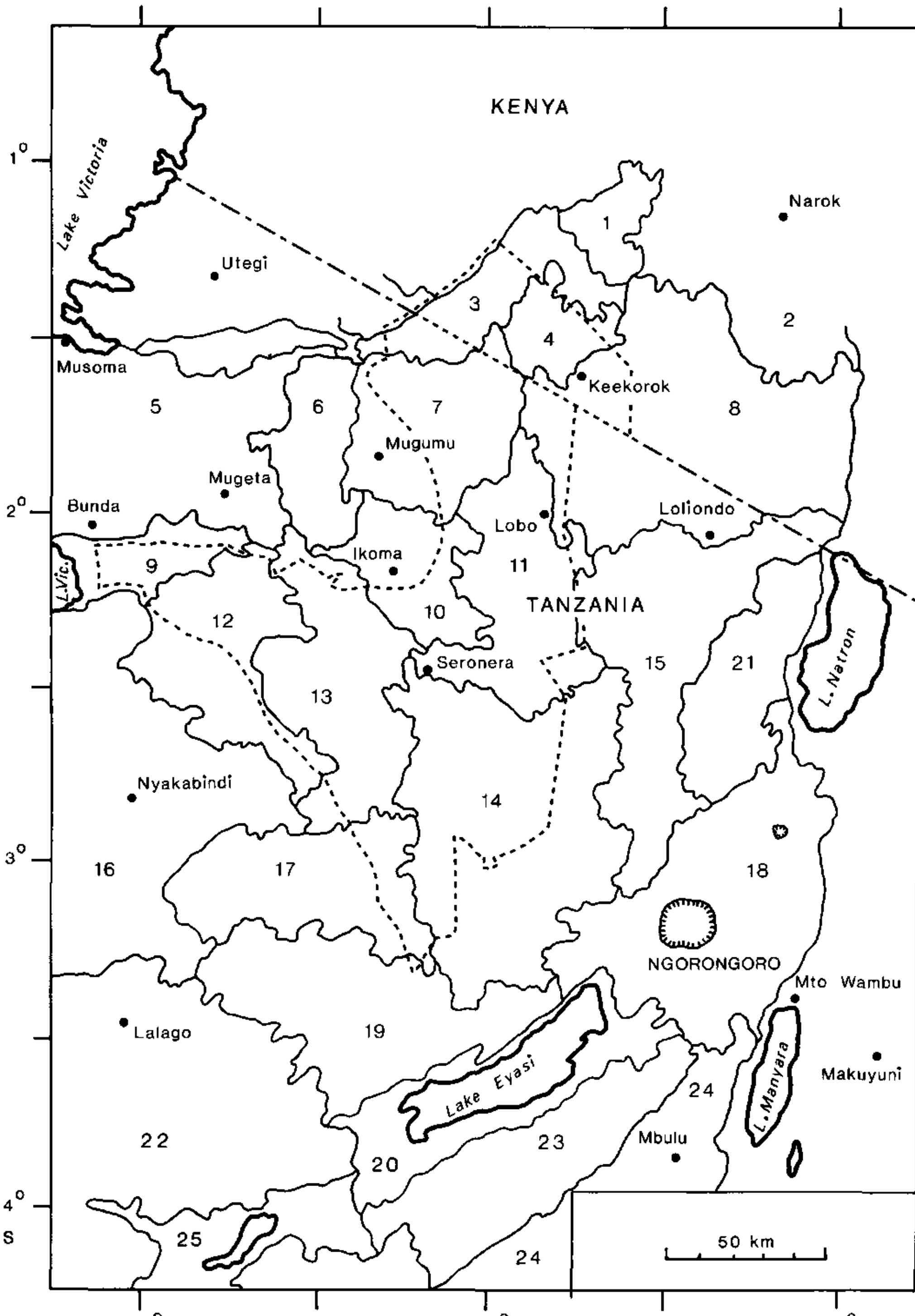


Figure 13. Land regions of the Serengeti ecosystem (from Gerresheim, 1974).

soils; for the vegetation specialist is is hard to get an idea about the vegetation types. The same is true for the geologist, the geomorphologist and so on. As a result of research in the different disciplines, the maps can be compiled of course, for the sake of simplicity and to get an overall view, but this is always coupled with a loss of information.

De Wit (1978) did some work around the edge of the Serengeti Plain. He considered the Woodlands soils residual, containing up to 50% volcanic ash. At a lower level he grouped the soils on physiographic criteria.

2 Landscape of the Western Corridor

2.1 INTRODUCTION

The Western Corridor comprises the area west of the Serengeti Plain as far as Lake Victoria. The altitude ranges from 1140 m in the western part of the Ndabaka Plain where it borders Lake Victoria to 2000 m (top of the Nyaroboro Plateau). The variety in land-forms is striking. Hillranges surrounded by pediments traverse it from east to west. But there are also extensive plains formed by erosion or sedimentation.

The diverse landscapes and the volcanic ash deposits give rise to a great diversity of soils, vegetation and wildlife, making it one of the most attractive areas of the Serengeti National Park.

2.2 GEOLOGY

2.2.1 Crystalline rocks

The soils are underlain by Nyanzian metamorphic sediments and volcanics, granites and Bukoban siltstones, mudstones and quartzites.

Nyanzian rocks are the oldest rocks, followed by the granites and finally the Bukoban rocks. All, however, are of Precambrian age. This differentiation into Nyanzian, granitic and Bukoban rocks will be used in future. This is maintained firstly because the age of the granitic rocks is not always known and secondly because the mineralogical composition of the three groups of rocks is quite different.

Nyanzian rocks: Simiti, Varichoro and Nyakaromo Hills consist mainly of phyllites, chlorite and amphibole schists, banded ironstone and jaspillites. Especially jaspillite and banded ironstone are very resistant to weathering. Most of these rocks are rich in iron as reflected by the soil colour.

Granitic rocks: They underlie extensive erosion plains (Dutwa Plain, Nangangwe Plain, Kirawira Plain), and hills such as Nyaroboro, Nyamuma and Itonjo. In the hills, the granite massifs are covered by the younger more resistant Bukoban quartzites and sandstones, that protect the granites from weathering.

Bukoban rocks: They are found as caps over older granites and underlying extensive plains (Musabi Plain, Figure 14).

Figure 14. Outcrop of siltstone at Musabi Plain.

2.2.2 Superfical deposits

Chemical data on the soils (high pH and exchangeable sodium values) and the mineralogical data (hardly any crystalline clay minerals), suggest that the area was covered by volcanic deposits (Chapter 8), like the Serengeti Plain, but the literature does not mention it. For instance, Anderson & Talbot (1965) stated that the brown calcareous soils from the north-west of the Serengeti Plain were essentially from a calcareous conglomerate with little if any ash addition.

From the history of the volcanoes in the Ngorongoro Highlands (Hay, 1976), the majority of the deposits in the Western Corridor would seem to originate from Oldoinyo Lengai (Figure 76), a still active volcano. Data on an ash sample from near the Mbalageti River suggest an age of about 40 000 years, the composition corresponding to Hay's Upper Ndutu beds. Hay has confirmed this identification. Detailed study revealed that the ash was eolian because the material was well sorted, homogeneous and fine grained. Besides the grains were angular.

If easterly winds prevailed during eruptions as they do now, ash would be blown well into the Western Corridor. The ash differed somewhat in mineralogy from that of the Plain. In the heavy minerals of the sand fraction of the Serengeti Plain, augite was present in large amounts decreasing westwards from the Crater Highlands (de Wit, 1978); in the Western Corridor it was almost absent. Possibly, ash in the Plain resulted from more recent eruptions, with different mineral composition (Chapter 8).

2.2.3 Faulting

Faults of considerable age are present around the Musabi Plain, which was a large basin in Nyanzian times. More recent faults also occur in the area and are related to plio-Pleistocene rifting (Macfarlane, 1967).

2.3 GEOMORPHOLOGY

2.3.1 Pediment and pediplain

In the legend of the soil map, the terms pediment and pediplain are used frequently.

Mensching (1973) distinguishes pediments and glacis. 'Pediments are erosional forms in the solid rock of the bedrock of mountains, mountain ranges or other high parts of the relief, often in crystalline rocks. Glacis are forms in sediments which are less solid and show a stratigraphy in sedimentation'.

In most parts the soil cover is a result of weathering, and sedimentation. Much of the sediment is of volcanic origin. Stratification is absent, and erosion is the major acting process.

During the wet season, the run-off can be enormous because of the low infiltration rates of the pediment and pediplain soils, 1 to 5 mm/h, in combination with heavy showers: up to 130 mm/h was measured. Often gravel and cobbles with a size up to 20 cm were found downslope.

Other evidence of erosion by run-off was:
- presence of a sand veneer on the surface
- presence of raised tussocks of grass by removal of the soil material between

Although sedimentation of volcanic ash largely determines the soil conditions, the term pediplain is preferred to 'glacis' because the soils were not stratified and because there was need for distinction from the Serengeti Plain, a sediment plain much more influenced by recent volcanic ash (de Wit, 1978).

Most of the pediments and pediplains are nearly level to gently undulating. North of Ndoho Plain the pediplain has been dissected by the Mbalageti River and its tributaries, perhaps by uplift of that area.

2.3.2 Flood plain

The eastern part of the Corridor, up to the shore of Lake Victoria, is occupied by the Ndabaka Flood Plain. Usually this area is briefly flooded during the wet season. Flooding starts if the Grumeti and Mbalageti rivers overflow their banks. On aerial photographs, the intricate pattern of levees and swamps is clearly visible. In contrast to the pediplain formed by erosion, the Ndabaka Flood Plain was formed by sedimentation.

2.4 LEGEND

Geomorphological features are used to differentiate great soil groups (Uplands, Pediments, Pediplain, Dissected Pediplain, Bottomlands) and the underlying rock for soil groups (Nyanzian, granitic and Bukoban rocks). Soil slope and soil depth distinguish the lowest categories.

Landscape of the Western Corridor

1 Ash covered pediments on Nyanzian rocks
- 1.1 Upper pediments
  - 1.1.1 Sloping, shallow to moderately deep and deep, reddish-brown loamy soils.
- 1.2 Lower pediments
  - 1.2.1 Very gently sloping, deep dark brown clayey soils.

2 Ash covered pediplain
- 2.1 Pediplain on granitic rocks
  - 2.1.1 Shallow, (very) dark grey sandy loam soils.
  - 2.1.2 Shallow to moderately deep, (very) dark grey loamy soils.
  - 2.1.3 Moderately deep to deep, (very) dark grey clay and clay-loam soils.
  - 2.1.4 Deep to very deep, (very) dark grey clay and clay-loam soils.
- 2.2 Pediplain on Nyanzian rocks
  - 2.2.1 Shallow, reddish-brown sandy loam soils with a petroferric contact.
  - 2.2.2 Shallow, to moderately deep, dark brown to reddish-brown loamy soils.
  - 2.2.3 Moderately deep to deep, (dark) reddish-brown clay-loam soils.
  - 2.2.4 Deep to very deep, very dark grey to black clay soils.
- 2.3 Pediplain on Bukoban rocks
  - 2.3.1 Shallow to moderately deep, reddish-brown loamy soils.
  - 2.3.2 Moderately deep to deep, (very dark) brown clay-loam soils.
  - 2.3.3 Deep to very deep, (very dark) grey-brown clay-loam and clay soils.

3 Ash covered dissected pediplain

3.1 Pediplain on granitic rocks

3.1.1 Moderately deep to deep, (very) dark grey clay and clay-loam soils.

Features common to all landscapes

7 Stony uplands

7.1 Hilltops, hillslopes and outcrops

7.1.1 Nyanzian, granitic and Bukoban rocks.

7.2 Kopjes

8 Bottomlands

8.1 Complex deep and very deep, sandy, loamy and clayey flood plain, river and depression sediments.

2.5 SOIL DESCRIPTION (Site locations are given in Figure 15)

2.5.1 Upper pediment soils

Upper pediment soils are found throughout the Western Corridor around the ranges between the slope and the lower pediment soils. Usually in the terrain, there are two changes of slope: one between the slope and the upper pediment and one between the upper and lower pediment. The slope of the upper pediment ranges from 4 to about 10%. If the slope is more than 5%, soils are usually moderately deep or less. Directly related to slope is the soil texture: the steeper the slope, the coarser the texture.

Mapping the soil depth, the underlying type of rock and the presence or absence of hardened plinthite would involve much detailed work and was undertaken only in the Kirawira area (Chapter 5).

Profile characteristics

Four sites were described in detail: Mukoma 1, Mbalageti 1, Nyara Swiga 2 and Kamarishe 1. They all possessed an argillic horizon (Appendix B1, B6, B8 and B12) with clear clay and pressure cutans; at one site (Mukoma 1), there were weakly developed prisms and high exchangeable sodium.

Soils at Mukoma 1, Mbalageti 1 and Nyara Swiga 2 showed an initial increase in clay content with depth but at greater depths mass fraction of clay decreased and loamy textures were found (Appendix C) because of a decrease in weathering with depth. The same phenomenon was observed at Kamarishe 1.

In many upper and lower pediment soils, soil colours changed with depth. In the subsoil, lower hues were encountered. One possible explanation is that the parent material is different, as would happen if ash layers of a

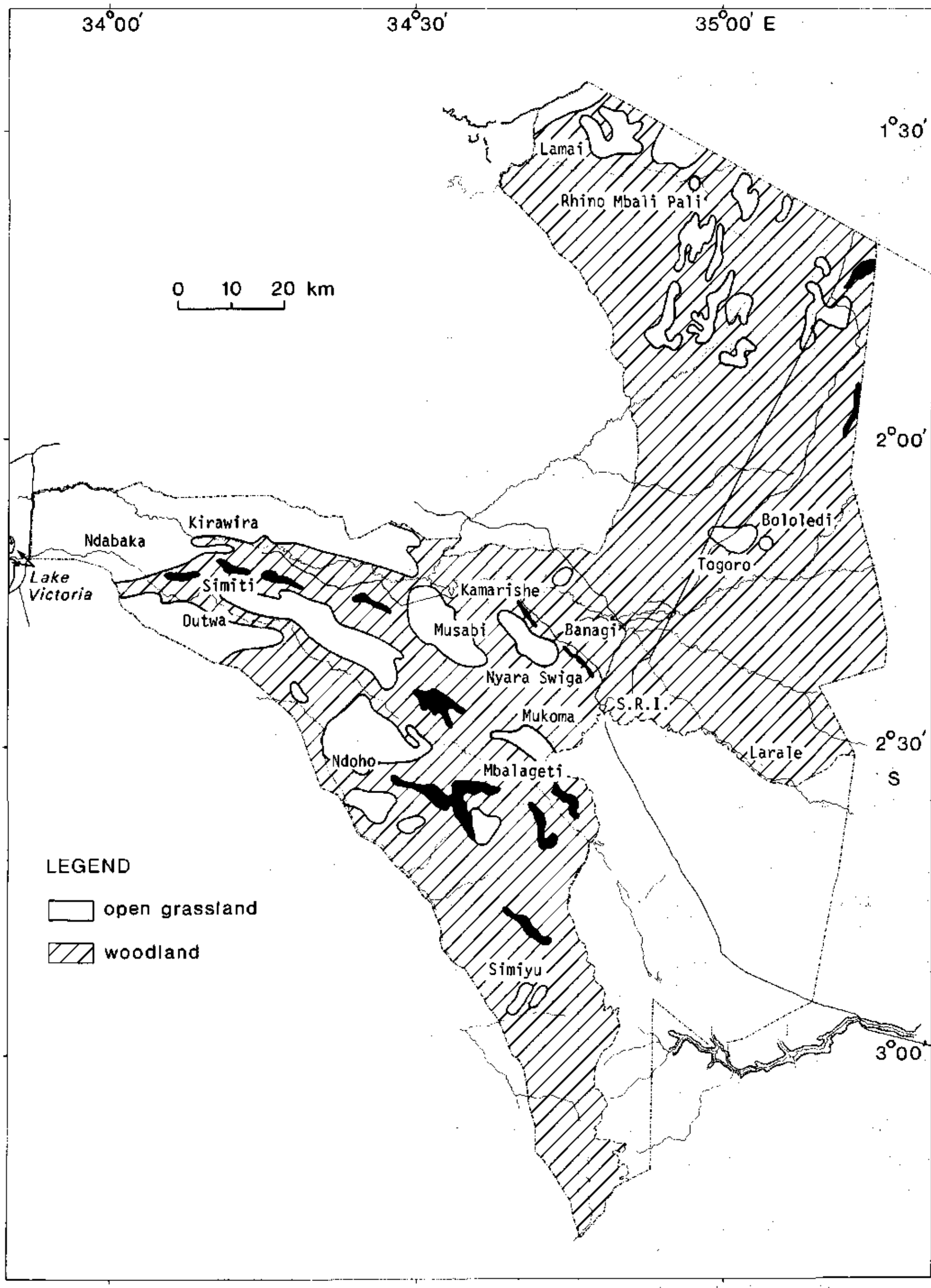


Figure 15. Location of soil pits in the Serengeti Woodlands.

different composition had been laid down on top of one other. An alternative explanation is that the organic matter content in the topsoil, possibly partly originated under different climatic conditions, caused the colour change.

The chemical data (Appendix F) suggested no abrupt change in composition.

Usually the lower boundary of the darker topsoil coincided with a marked change in weathering, as revealed by the presence of larger amounts of relatively fresh volcanic ash and by the more silty texture of the subsoil.

Climatic changes could nevertheless have played a role too. Climatic changes in East Africa are well documented (Bishop & Clark, 1968; Lind & Morrison, 1974; Kendall, 1969; Moreau, 1933) and especially for the Olduvai Gorge just south of the Serengeti National Park (Leaky, 1965; Hay, 1976).

Termite activity is common. Mounds built up by *Macrotermes* species to a height of about 2 m are frequent. *Macrotermes* species are confined to the better drained soils. In the lower pediment soils, *Odontotermes* is the dominant species.

Dependent on alkalinity and texture of the soil, roots penetrated from 30 (Mukoma 1) to 80 cm (Kamarishe 2), which can be considered favourable compared with the lower pediment and pediplain soils.

Chemical composition

At Mukoma 1, alkalinity increased strongly with depth. In the B2.1t horizon (15-30 cm), exchangeable sodium reached 26%. Sodium was by far the predominant ion in the saturation extract (Appendix D1) and pH was high to very high, because of the high concentration of alkaline ash. Similar to site Mukoma 1 was Mbalageti 1 (Appendix D6), but the concentration of salts in the saturation extract was much less, as was also exchangeable sodium.

Site Nyara Swiga 2 had even lower pH and exchangeable sodium values (Appendix D8). In the saturation extract, sodium predominated only for the subsoil. Sodium was almost absent from the exchange complex.

Remarkable was the change in cation-exchange capacity (CEC) of the clay fraction at site Mukoma 1. The mass fraction of clay decreased considerably with depth below 50 cm. The CEC (at pH 8.2), however, remained rather constant, reaching 1060 to 1850 mmol/kg, which is very high. The bottom horizon (120-150 cm) even reached the requirements for dominance of amorphous material in the exchange complex (Soil Taxonomy, 1975) but for two conditions: the mass fraction of organic carbon was too low and secondly the bulk density was too high (1180 against the required 850 or less).

These data too provide evidence of considerable amounts of volcanic deposit in the eastern part of the Western Corridor. At Mbalageti 1, CEC of the clay fraction was high too. At Nyara Swiga 2, it was lower because weathering proceeded to greater depths.

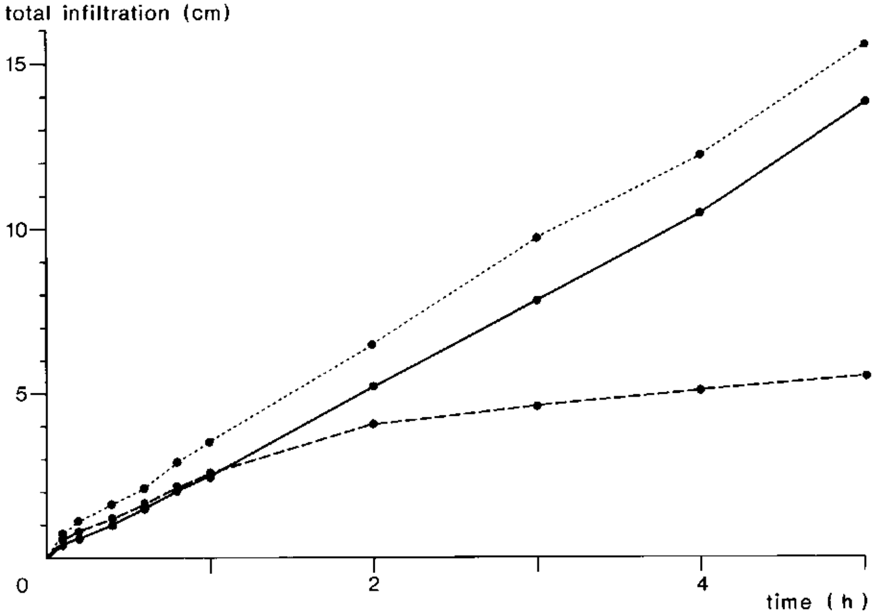


Figure 16. Infiltration characteristics for 3 upper pediment sites: Mbalageti 1 (........), Nyara Swiga 2 (———) and Mukoma 1 (-----). Depth of penetration after 5 h was 100, 75 and 40 cm, respectively.

Physical characteristics

Granular size distribution: The mass fraction of clay showed an initial increase with depth of about 20% in all three profiles. At Mukoma 1, the texture tended towards loamy below 60 cm. As a result of deeper weathering, clay contents increased with depth in the other profiles, till finally the texture of the unweathered material should be reached.

Infiltration rates: Deeper weathering is initiated by higher infiltration rates. Figure 16 shows clearly the great difference in infiltration rate at the sites. At Mukoma 1 infiltration and leaching was hampered by the weak prismatic structure of the B2.1 horizon.

Depth of penetration: Values close to the maximum depth of soil moisture fluctuation, (Table 4) as established by neutron measurements were measured.

Moisture retention and availability: Table 4 gives the moisture content at pF 1, 2, 3.4 and 4.2 of three upper pediment soils, bulk density and the Coefficient of Linear Extension (Appendix A).

The maximum available soil moisture was lower at Mukoma 1 than at Nyara Swiga 2 and Mbalageti 1 (Table 4).

Weathering was also strongly influenced by soil moisture. Relatively low bulk densities at Mukoma 1 can be explained by the slower weathering than at the other sites.

Table 4. Moisture retention, maximum available moisture, bulk density and coefficient of linear extension for three upper pediment sites. For methods of calculation see Appendix A.

	Depth (cm)	Volume fraction of moisture (%) pF				Bulk density (kg/m^3)	Coefficient of linear extension	Maximum depth of fluctuation in moisture (cm)	V(pF2)-V(pF4.2) (cm)	Maximum available moisture (cm)
		1	2	3.4	4.2					
Mukoma 1	0- 15	32.9	23.0	11.8	8.7	1570	<0.02	35	2.1	4.4
	15- 30	43.8	39.6	38.4	27.4	1410	<0.02			
	30- 45	42.0	36.8	35.3	27.2	1410	<0.02		1.8	
	45- 60	44.8	37.3	37.2	26.9	1340	<0.02			
	60- 90	45.5	37.4	30.7	21.2	1270	<0.02			
	90-115	45.6	37.0	36.1	27.6	1220	<0.02			
	115-150	44.8	36.5	34.4	25.4	1180	<0.02			
Nyara Swiga 2	9- 19	35.0	25.2	12.6	7.8	1660	<0.02	35	3.3	10.8
	19- 62	37.6	32.7	23.3	16.2	1580	<0.02		7.0	
	62- 95	39.6	34.3	25.9	17.1	1500	<0.02		0.5	
	95-120	43.6	33.9	25.6	18.6	1370	<0.02			
Mbalageti 1	0- 14	35.5	24.4	30.6	20.0	1420	0.02	95	0.6	9.4
	14- 40	40.4	32.9	30.6	22.8	1400	0.04		2.6	
	40- 70	43.6	40.4	34.6	29.5	1450	0.06		3.2	
	70-100	43.5	42.2	38.0	30.5	1420	0.06		3.0	

Low infiltration rates result in little available moisture, as reflected in differences in vegetation. Sites Nyara Swiga 2, Kamarishe 1 and Mbalageti 1 were under rather dense woodland (*Acacia clavigera* and *Acacia seyal*) with many regenerating trees, whereas at Mukoma 1 only a few mature trees (*Acacia tortilis* and *Balanites aegyptiaca*) are present.

Diagnostic horizons

The upper pediment soils usually possessed a mollic epipedon and an argillic horizon. A natric horizon was sometimes present in upper pediment soils close to the Serengeti Plain.

Part of the observed cutans in the illuvial horizons were pressure cutans as revealed by microscopic study of some thin sections. The illuvial horizons were argillic, because they met the requirements given in Soil Taxonomy (1975):

- The clay content increased between eluvial and illuval horizon
- The horizon was sufficiently thick, and peds were obvious
- Clay skins or oriented clay was present.

In addition a natric horizon has (Soil Taxonomy):

- Prisms or columns in some part, and
- Exchangeable $Na^+ \geq 15\%$, within 40 cm of the upper boundary, or more exchangeable $\frac{1}{2}Mg^{2+} + Na^+$ than $\frac{1}{2}Ca^{2+}$ (at pH 8.2), within 40 cm of the upper boundary if exchangeable $Na^+ \geq 15\%$ within 2 m depth.

For classification see Chapter 9.

Soil erosion

Evidence for soil erosion was ubiquitous, the most dramatic being gully erosion (Figure 17). Also root exposure was often observed (compare Dunne et al., 1978). Sometimes roots with a diameter of 15 cm or more are completely exposed. Animals are active in the process. However, root exposure is not due solely to removal of topsoil.

Sand veneers and hollowed out wildlife tracks (Figure 18) are frequent. All but a few erosive processes in the Serengeti National Park should be called 'geological erosion', despite their dramatic impact on the landscape. Erosion is often accelerated by 'overgrazing', elephant activity and burning. It are not only human activities that cause strong erosion.

2.5.2 Lower pediment soils

Lower pediment soils occupy a much greater area of the Western Corridor than the upper pediment soils. They are found between the upper pediment and the pediplain soils. Slopes are less than 4%, usually about 2%. The lower pediment soils are deeper, but textures are similar to those of the upper pediment soils. Differences in underlying rock were not mapped because they have less influence than for instance in the pediplain soils, except on soil

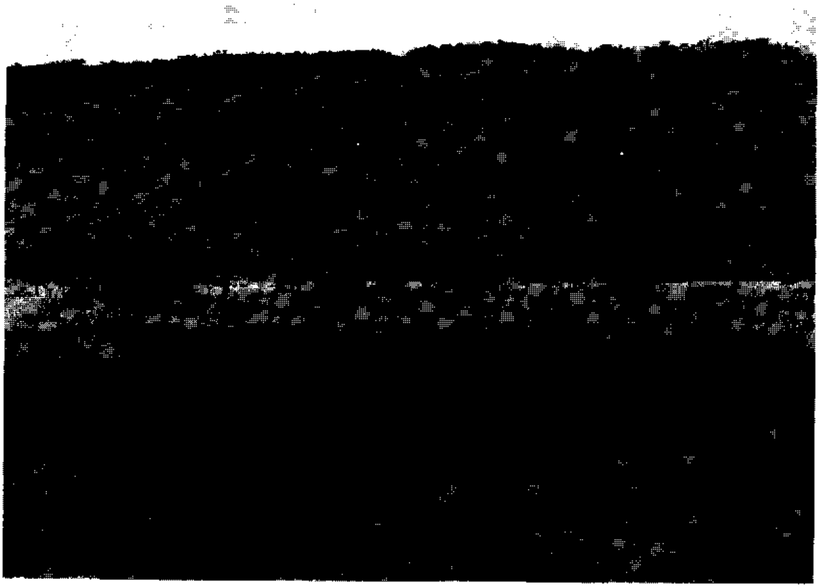


Figure 17. Gully erosion at Nyara Swiga (upper pediment).

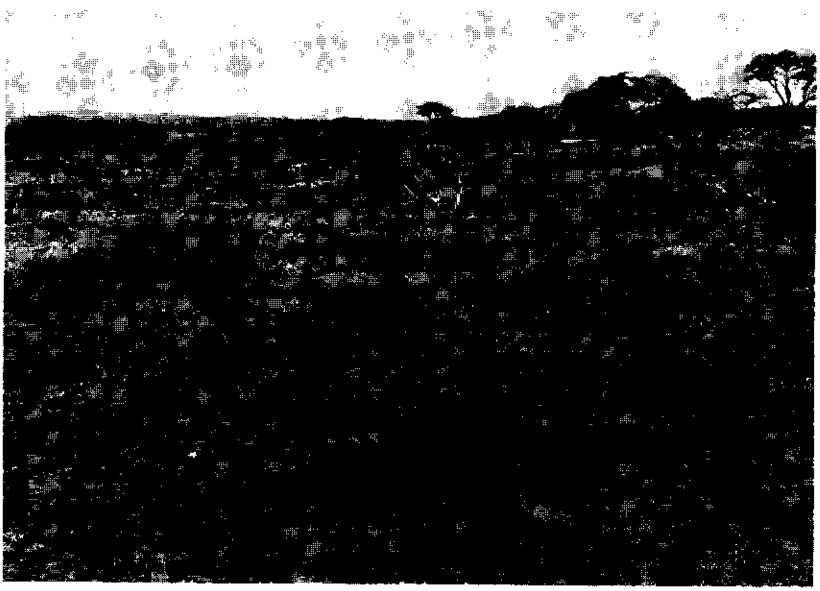


Figure 18. Hollowed out wildlife tracks near Mukoma Hill.

colour. Less water is available because of unfavourable physical characteristics, so lower pediment soils are predominantly under grassland.

Profile characteristics

The profiles of ten soil pits were descrbied in detail: Nyara Swiga 3, Kamarishe 2 and 3, Mukoma 2, 3 and 5, Mbalageti 2, Kirawira 4 and 5 and Simiti 1 (Appendix B).

Prominent clay and pressure cutans were present at all sites. Prismatic or columnar structures in the B2 horizon were encountered near the Serengeti Plain, and also in the extreme west of the Corridor (Simiti 1). Colour change with depth was also common, as in upper pediment soils (Section 2.5.1).

Termite activity was less obvious than in upper pediment soils, because of the presence of *Odontotermes* species only, which build small mounds with many small chimneys. Evidence of termite activity has been found in many soils, especially in the subsoil. *Odontotermes* species occur mainly in poorly to imperfectly drained soils.

In general, roots were present only at rather shallow depths, except at Mukoma 3, where the pit was at a relative favourable site, on a small interfluve.

Numbers of roots decreased sharply with depth. Site Mukoma 3 was better drained than Mukoma 2 and 5, resulting in deeper infiltration and more intensive leaching. Properties of Kirawira 4 and 5 and Simiti 1 will be discussed in Chapter 5.

Chemical characteristics

Soils at all sites were rich in exchangeable Na^+ (Appendix D). The critical value for agricultural purposes of 15% was reached at all sites except Simiti 1 (Soil Survey Staff, 1951).

Locally high electrical conductivity of soil extract (EC_e) was found in the subsoil (Mukoma 2, 3 and 5, Simiti 1; Appendix D2, D3, D5 and D30). Generally EC_e values are significantly higher than in the upper pediment soils, as a result of impeded drainage (low infiltration rate) and slow leaching. According to Richards et al. (1954), most soils are salt-free (EC_e: 0-4 mS/cm) and some subsoils are slightly saline (EC_e: 4-8 mS/cm).

Sodium was the dominant ion in the saturation extract. The pH was usually higher than in upper pediment soils. Base saturation of the exchange complex was usually 100%, except for the A1 horizon. Sometimes 100% was exceeded if the soil contained calcium carbonate, which is slightly soluble in the percolation solution (ammonium acetate).

In the subsoil of the Mukoma sites and also at Mbalageti 2, cation-exchange capacity of the clay fraction was about 1 mol/kg. The same phenomenon was observed in the upper pediment soils (Section 2.5.1).

Physical characteristics

Granular size distribution: Clay contents were similar to those of the deep upper pediment soils (Appendix C). Upper pediment soils were, however, deeper weathered and so had a finer texture at greater depths. The topsoil of the upper pediment soils was somewhat coarser textured by eluviation. At given depth, a moderately deep upper pediment soil was usually less clayey than a lower pediment soil, because part of the clay had been removed by weathering and eluviation. So the degree of weathering and eluviation are the main factors influencing soil texture. Site Mukoma 3, on an interfluve, still had a high clay content at 100 cm, being better drained and deeper weathered than the other lower pediment soils. Salinity and alkalinity in the subsoil, however, were much higher than in upper pediment soils.

Infiltration rates: The total infiltration (Figure 19) was usually lower compared with the upper pediment soils. Infiltration rate in the fifth hour was significantly less favourable for lower pediment sites Mbalageti 2 and Nyara Swiga 3 than upper pediment sites Mbalageti 1 and Nyara Swiga 2. Mbalageti 2 had the lowest infiltration rate in the fifth hour, followed by Mukoma 5, 2 and 3 and finally Nyara Swiga 3.

Depth of penetration: Penetration depths were fairly uniform. The high value for site Nyara Swiga 3 could have resulted from breaking the platy topsoil when the rings were installed; it was much higher than the maximum depth of fluctuation in moisture as measured with the neutron probe (Table 5). The disturbance could also contribute to the rather high infiltration rate.

Moisture retention and available moisture: As shown in Table 5, water

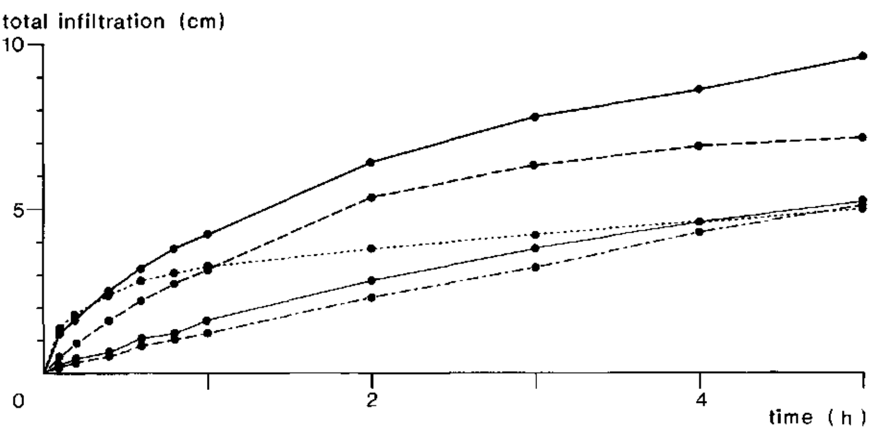


Figure 19. Infiltration characteristics for 5 lower pediment sites: Nyara Swiga 3 (———), Mbalageti 2 (– – – –), Mukoma 2 (———), Mukoma 3 (–·–·–) and Mukoma 5 (········). Depth of penetration after 5 h was 20, 30, 40, 40 and 20 cm, respectively.

Table 5. Moisture retention, maximum available moisture, bulk density and coefficient of linear extension for the lower pediment soils.

	Depth (cm)	Volume fraction of moisture (%) pF				Bulk density (kg/m³)	Coefficient of linear extension	Maximum depth of fluctuation in moisture (cm)	V(pF2)-V(pF4.2) (cm)	Maximum available moisture (cm)
		1	2	3.4	4.2					
Mukoma 2	0- 10	33.2	23.4	23.0	13.3	1630	0.02	35	1.0	3.8
	10- 32	47.4	42.8	32.4	31.2	1340	0.04		2.5	
	32- 56	49.9	45.3	36.4	33.8	1230	0.04		0.3	
	56- 81	49.0	41.2	41.0	38.6	1280	0.02			
Nyara Swiga 3	0- 16	47.0	36.3	26.7	14.3	1220	0.02	25	3.5	5.4
	16- 65	44.2	43.8	32.0	21.7	1260	0.05		1.9	
	65- 90	50.2	42.4	34.6	22.3	1220	0.04			
Mbalageti 2	0- 6	39.8	28.9	21.3	12.7	1430	0.02	35	1.3	4.5
	6- 20	44.1	42.9	38.2	31.9	1310	0.08		1.5	
	20- 60	48.0	45.0	41.0	33.4	1300	0.05		1.7	
	60-102	45.6	42.5	38.8	29.7	1330	0.02			
Mukoma 3	0- 10	52.4	48.8	36.3	29.8	1150	0.09	45	1.9	6.8
	10- 30	45.2	44.6	39.7	31.5	1240	0.04		2.6	
	30- 60	52.0	47.6	40.5	32.4	1230	0.07		2.3	
	60- 80	57.0	51.5	38.8	30.6	1160	0.06			
	80-110	56.0	49.5	38.5	29.9	1080	0.06			
Mukoma 5	0- 10	58.1	52.0	42.9	30.2	990	0.14	20 (estimated)	2.2	4.0
	10- 30	60.2	59.6	58.1	41.7	1060	0.15		1.8	
	30- 60	57.6	55.9	54.8	46.2	1170	0.08			
	60-110	55.5	53.6	52.9	45.0	1240	0.03			

availability was lower than of the upper pediment soils.

Except at Mukoma 5, bulk density decreased with depth. If the densities were estimated for ovendry soil, so that differences in swell and shrink were excluded, the decrease with depth was general. Apparently the bulk density of the original volcanic deposits must have been less than after slight weathering. The upper horizons were more weathered and eluviated than the lower horizons and generally contained less non-crystalline minerals.

The lower pediment soils had less favourable moisture conditions than the upper pediment soils. Maximum available moisture was less, as were infiltration rates, except at Mukoma 3. Lower pediment soils were predominantly under grassland (*Pennisetum mezianum* and *Themeda triandra*). At site Nyara Swiga 3 regenerating woodland of *Acacia tortilis* was present too.

Breaking of the platy topsoil by animals improves the infiltration rate and penetration depth, as was demonstrated by the infiltration experiment at Nyara Swiga 3, possibly explaining the *Acacia* woodland. On poorly drained, periodically flooded soils (Simiti 1) *Acacia seyal* appears.

Diagnostic horizons

All the lower pediment soils described had prismatic or columnar structures. A natric horizon was present in all but one case. Simiti 1, a very deep black to brown swelling clay soil, did not reach an exchangeable Na^+ value of 15% in the B2.2 horizon nor did the sum of exchangeable $\frac{1}{2}Mg^{2+}$ and Na^+ exceed exchangeable $\frac{1}{2}Ca^{2+}$. Topsoils of all lower pediment soils described meet the requirements of a mollic epipedon.

Soil erosion

Soil erosion is widespread on the lower pediment. The presence of a sand veneer on the surface and raised tussocks of grass are evidence of erosion. Sheet wash has been the dominant process (Figure 20). Wildlife tracks excavated by running water traverse the area.

2.5.3 Pediplain soils

Pediplain soils will be described in detail in Chapter 5, with special emphasis on the pediplain soils underlain by granitic and Nyanzian rocks. This section only deals with three pediment sites: two underlain by siltstones, (Musabi 1 and 3) and one by granitic rocks (Ndoho). Pediplain soils are found widely in the Western Corridor.

Profile characteristics

The soils are deep to very deep and the soil slope amounts to 1% or less. The Ndoho site is underlain by granitic rocks but is quite different from the 'granitic' pediplain soils described in Chapter 5. Numbers and distri-

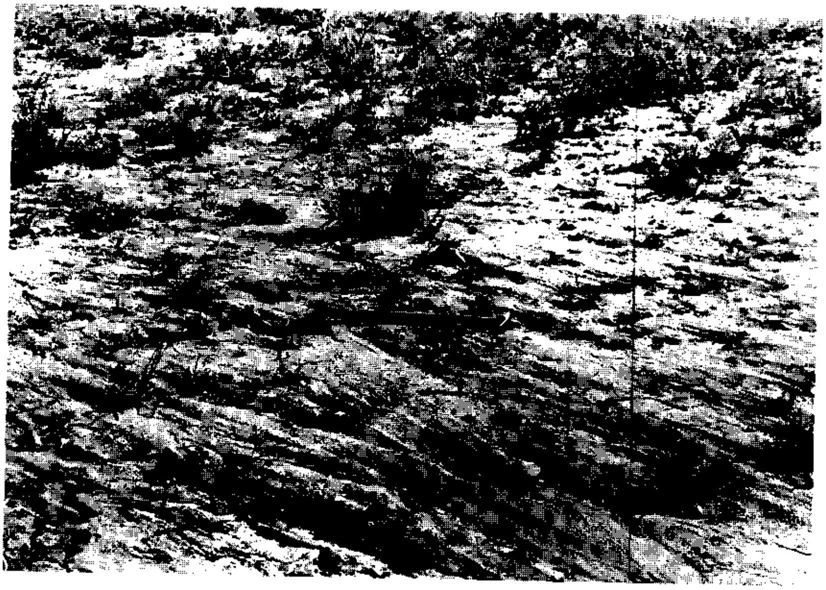


Figure 20. Sheet wash at Nyara Swiga (lower pediment).

bution of roots are very favourable (Appendix B16, B18 and B15). Termite activity was traced throughout the profile: both harvesting ants (*Holotermes* spp.) and *Macrotermes* spp.. Long grass, in contrast to the short to medium long grass of 'granitic pediplain soils', is found all over Ndoho Plain. Soil colours change with depth towards lower hues. At several depths, pieces of angular gravel were excavated, especially at a depth of 110 cm, resembling artifacts. Perhaps these layers represent buried surfaces, but they are not considered in the horizon nomenclature and classification, since all sites have been covered from time to time to different degrees by volcanic deposits.

Sites Musabi 1 and 3 were on siltstones. Musabi 1 is surrounded by trees and shrubs; Musabi 3 by medium long grass. Termite activity was more striking around Musabi 1, the better drained of the two Musabi sites, because of a difference in species: mound-building *Macrotermes* spp. in contrast to *Odontotermes* and *Holotermes* spp. at Musabi 3. *Sansevieria* sp. and shrubs like *Salvadora persica* grew lush on and around the mounds. The colour change with depth was very clear at Musabi 1: from 10YR2/2 in the topsoil to 5YR3/6 at 150 cm. Below 150 cm, either hardened plinthite or bedrock was present, since further augering proved impossible. The presence of iron-manganese concretions indicated stagnation of drainage. If drainage were free roots would be present also at greater depths. Lateral movement of water over the rock or hardened plinthite surface would account for the iron-manganese concretions. The presence of water at some depth would also meet the needs of termites.

The topsoil of Musabi 3, in the centre of a grass plain, contained much iron-manganese-clay pellets, suggesting poor permeability of the B2.2 horizon.

From 140 cm down to at least 400 cm fragments of rotten rock were encountered. The subsoil below 220 cm contained much carbonates, probably leached from the solum which consisted of weathering products of siltstones and volcanic deposits. Alternatively carbonate could have accumulated by lateral movement of water. Since many deep augerings revealed a high content of carbonate in subsoil, leaching and redeposition seem to explain the carbonate enrichment.

Chemical characteristics

Of the three sites, Ndoho had least exchangeable Na^+, followed by Musabi 3 (the grassland site) and Musabi 1 (Appendix D15, D18 and D16). Cation-exchange capacity was remarkably high at Musabi 3. Two possible explanations for the high CEC but low exchangeable Na^+ compared with the woodland site Musabi 1, could be as follows:

- At Musabi 1, termites may transport to the surface fine particles which are washed downhill towards the bottomlands, and may add alkaline subsoil to the topsoil. Lateral movement of water may renew the supply of Na^+ in the subsoil.
- Musabi 3 receives more run-off from the hinterland and therefore more water infiltrates despite the lower infiltration rate than at Musabi 1. This may account for the lower exchangeable Na^+. The high cation-exchange capacity would result from the higher content of clay. There was no clear relation between CEC and clay content. Cation-exchange capacity of the clay fraction was higher in the subsoil, obviously as a result of the presence of higher quantities of unweathered X-ray amorphous materials.

Nitrate was detected in the subsoil of both Musabi sites. Since termite activity often leads to higher nitrate contents (Lapperre, 1971), termite activity must have influenced both Musabi sites.

Physical characteristics

Granular size distribution: Below 26 cm, the clay content was uniform at Musabi 1 (Appendix C). Illuviation was responsible for the higher content of clay in the B2.2 horizon. Since the content of clay in the subsoil was rather low, a high content of volcanic ash was assumed to be present.

Infiltration rates: Infiltration rates were estimated for Musabi 3 and Ndoho (Figure 21). Ndoho had a high infiltration rate, in contrast to Musabi 3. The rate for Musabi 1 would probably be intermediate.

Depth of penetration: After 5 hours of infiltration the moisture front had reached to 95 cm at Ndoho and 45 cm at Musabi 3.

Moisture retention and availability: Calculations could be made only for Ndoho (Table 6). Because of favourable retention characteristics and great

Table 6. Moisture retention, maximum available moisture, bulk density and coefficient of linear extension for a pediplain soil on granitic rocks.

	Depth (cm)	Volume fraction of moisture (%) pF				Bulk density (kg/m³)	Coefficient of linear extension	Maximum depth of fluctuation in moisture (cm)	V(pF2)-V(pF4.2) (cm)	Maximum available moisture (cm)
		1	2	3.4	4.2					
Ndoho	0- 10	42.5	31.2	20.7	11.6	1370	<0.02	105	2.0	15.5
	10- 40	42.8	31.5	28.4	19.8	1320	<0.02		3.5	
	40- 80	45.6	39.2	32.2	25.3	1280	0.02		5.5	
	80-110	52.0	41.4	28.9	23.4	1070	0.03		4.5	

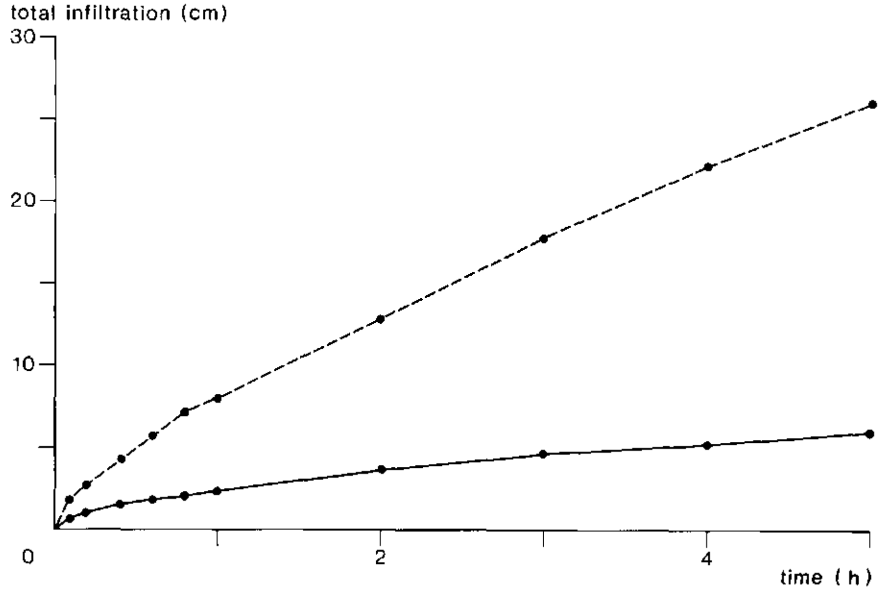


Figure 21. Infiltration characteristics for 2 pediplain sites: Ndoho (-----) and Musabi 3 (———). Depth of penetration after 5 h was 95 and 45 cm, respectively.

depth of fluctuation in moisture, maximum available moisture was very high, 15.5 cm, the highest value found in the Serengeti Woodlands. One would expect lush woodland instead of grassland. Probable explanations are given in Section 2.6.1. Maximum available moisture would probably be less at Musabi 1 and 3.

Bulk density values decreased gradually with depth, with decrease in weathering or different composition of the volcanic components.

Typical pediplain soils (Chapter 5) usually have poor physical properties if underlain by granitic rocks. In that way, Ndoho can be considered an exception.

Ndoho had a deep solum with extremely favourable physical characteristics over granite, yet was under (long) grassland: *Digitaria macroblephara* and *Themeda triandra*. Musabi 1, a relatively well drained deep pediplain soil underlain by silt stones of Bukoban age (Map Unit 2.3.2), was covered with woodland (*Acacia tortilis, Acacia mellifera, Salvadora persica*).

Musabi 3 had a very deep solum underlain by Bukoban rocks (Map Unit 2.3.3) in an area where run-off was concentrated (pediment wash), resulting in higher clay contents. The solum was deeper than at Musabi 1 and was under medium-long grassland (*Chrysochloa orientalis*). Physical conditions were poor.

Diagnostic horizons

Sites Ndoho and Musabi 1, both with good physical properties, had a mollic epipedon and an argillic horizon. The B2.2 horizon at Musabi 1 did not meet the natric requirements, since no prismatic or columnar structures were present. Musabi 3 did not meet the colour requirements for a mollic epipedon and so has an ochric epipedon as well as an argillic horizon.

Soil erosion

Sheet wash was the dominant process of erosion in pediplain soils (Chapter 5). At Ndoho no evidence was found of erosion. Probably run-off was low because of high infiltration.

2.5.4 Upland soils

Upland soils are very shallow to moderately deep. Slope ranges from level and nearly level for the plateau of Nyaroboro, Nyamuma, and Itonjo Hills to moderately steep and steep for the slopes and escarpments.

The soils are loamy and stony. Woody vegetation prevails, because of the good drainage. Moisture is available to the tree roots, not only in the soil, but also in cracks in the bedrock.

Acacia clavigera is the dominant tree, being common on well drained soils. Especially around kopjes a rich and diverse vegetation is found because of varied soil conditions. In the Corridor, kopje complexes (inselbergs) are present around Handajega and south of Itonjo Hill.

Infiltration is high, as is probably the maximum available moisture (if water in the cracks is included). The soils had little exchangeable Na^+ and contained less salts than the soils further downhill, because of continuous leaching. Weathering and subsequent transport of the finer particles lead to loamy-textured soils. Erosion is obviously the process keeping the soils shallow, because of the position in the landscape.

2.5.5 Bottomland soils

All bottomland sites are rather alike, no subdivisions were made. Of course, locally coarser-textured soils do occur, but usually these areas are too small to be mapped. In the Kirawira area (Chapter 5) flood plain, and river and depression sediments are distinguished. Six sites were described in detail: Ndabaka 1 and 2, Dutwa 2 and 3, Musabi 2 and Mukoma 4 (Appendix B). Ndabaka 1 and 2 lie in the Ndabaka Flood Plain while the other sites are close to, or in drainage lines.

Profile characteristics

Bottomland soils are all very dark grey to black, and have a clearly developed argillic or natric horizon, and carbonate concretions in the subsoil. Clayey textures are dominant. Deep wide cracks were observed at some sites (Ndabaka 1 and Dutwa 3), but are not common. Roots reached to depths between 50 and 75 cm.

Chemical characteristics

Much run-off water is transported towards the bottomlands, thus enriching the nutrient status and explaining the often high exchangeable Na^+ values (Appendix D). Cation-exchange capacity was far above average and either increased (Ndabaka 1 and 2, Musabi 2) or decreased (Dutwa 2 and 3, Mukoma 4) somewhat with depth.

Physical characteristics

Granular size distribution: Clay contents of the bottomlands usually exceed 50%. Topsoils are finer textured than the subsoils.

Infiltration rates: Infiltration was measured at four sites. Rates varied considerably (Figure 22). Even between Ndabaka 1 and Dutwa 3, both Vertisols, there was a difference by a factor of 8. No replicates were made for any of these sites, so variation may be great at one site. Swelling clayey bottomland soils can become almost completely impermeable after saturation. So little significance can be attached to the high rates.

Depth of penetration: Because of cracks, the moisture front reached to great depths. But only the faces of the peds, places where roots were con-

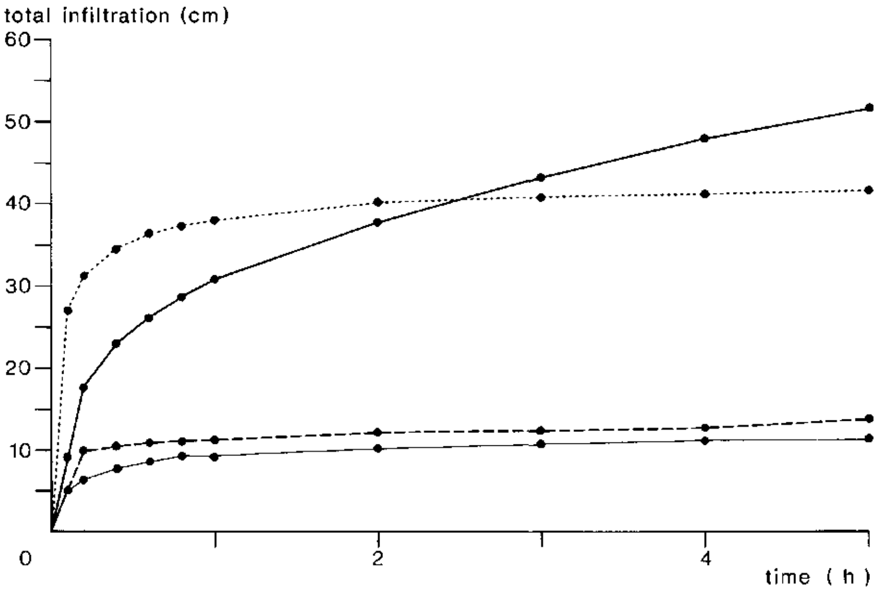


Figure 22. Infiltration characteristics for 4 bottomland sites: Dutwa 3 (———), Ndabaka 1 (·········), Mukoma 4 (– – – –) and Ndabaka 2 (———). Depth of penetration after 5 h was 70, 60, 60 and 50 cm, respectively.

Table 7. Moisture retention, maximum available moisture, bulk density and coefficient of linear extension for four bottomland soils.

	Depth (cm)	Volume fraction of moisture (%) pF				Bulk density (kg/m^3)	Coefficient of linear extension	Maximum depth of fluctuation in moisture (cm)	V(pF2)-V(pF4.2) (cm)	Maximum available moisture (cm)
		1	2	3.4	4.2					
Mukoma 4	0- 20	53.1	50.8	43.4	34.1	1110	0.10	60	3.3	10.0
	20- 48	53.9	50.6	40.1	35.9	1140	0.10		4.1	
	48- 75	56.8	52.4	34.7	30.9	1030	0.12		2.6	
	75- 91	51.5	45.0	29.2	26.2	1130	0.08			
	91-131	48.9	42.9	29.7	28.6	1240	0.04			
Dutwa 3	0- 10	49.5	43.4	38.4	29.9	1350	0.04	70	1.4	12.8
	10- 75	51.4	48.7	37.7	29.7	1270	0.08		11.4	
Ndabaka 1	0- 45	48.3	47.6	41.1	33.7	1050	0.11	60	6.3	8.6
	45- 75	46.8	46.6	40.5	31.5	1050	0.11		2.3	
Ndabaka 2	0- 10	41.6	34.5	34.2	27.1	1370	<0.02	50	0.7	7.0
	10- 55	50.1	48.4	41.0	32.6	1310	0.06		6.3	
	> 55	50.3	49.6	47.2	37.2	1350	0.05			

centrated, became moistened. After swelling of the topsoil, no more water was transported to lower horizons.

Moisture retention and availability: Table 7 shows the retention and maximum available moisture. In the subsoil water was only available in cracks between the peds, so maximum available moisture values are grossly overestimated.

Bulk densities were rather constant to the depth sampled, especially when corrected for shrinkage.

Sandy topsoils occurred along the main rivers as river levees. They were much better drained, being coarser in texture and lying at the edge of river channels. They were under woody vegetation (riverine forest) with *Ficus*, *Tamarindus* and *Ekebergia* species. On clayey bottomlands, one finds either long grassland (e.g. *Pennisetum mezianum*, *Themeda triandra*, *Echinochloa haploclada* and *Panicum coloratum*) or woodland (*Acacia drepanolobium*, *Acacia seyal* and sometimes also *Balanites aegyptiaca* and *Acacia xanthophloea*). *Acacia drepanolobium* and *Acacia seyal* are characteristic of poorly drained soils.

Diagnostic horizons

Deep wide cracks, and gilgai and some wedge-shaped tilted aggregates, characteristic for Vertisols, were observed at Ndabaka 1 and Dutwa 3 (Figure 23). Chromas were less than 1.5. An argillic and a natric (exchangeable $Na^+ \geq 15\%$) horizon were present at Ndabaka 2 and Dutwa 2, respectively.

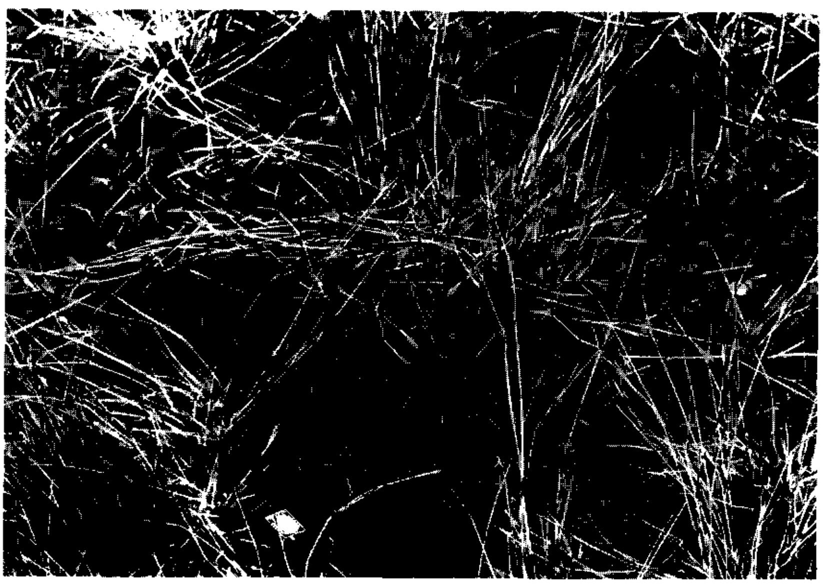


Figure 23. Wide open cracks encountered in the Ndabaka Flood Plain.

Figure 24. River bank erosion caused by wildebeest when crossing the rivers (Grumeti River).

Soil erosion

On the flood plain sedimentation dominated and erosion was negligible. Along the drainage lines sheet wash was observed (sand veneer on surface), and riverbank erosion by streaming water and by tracks of animals was common. Beside the Grumeti River, for instance, trenches had been excavated by hippo. Also crocodiles had scratched their way towards dry ground. Wildebeest, buffalo and elephants frequently crossed the waterways, leaving their mark (Figure 24). More dramatic, of course, was the erosion by streaming water in the wet season. In the small drainage lines buffaloes wallow to seek relief from the high temperatures. Their activities sometimes widen the drainage channels considerably.

2.6 SOIL AND VEGETATION

2.6.1 Distribution of woodland and grassland

The distribution of woodland and grassland was largely determined by soil characteristics. Figure 25 helps to explain the distribution. All the woodland sites had higher infiltration rates, more than 2.5 cm/h, and greater depth of penetration, 50 cm or more in 5 h. Infiltration rate and depth of penetration were the main factors determining the amount of available moisture. Moisture retention characteristics were of lesser significance, being similar for woodland and grassland soils.

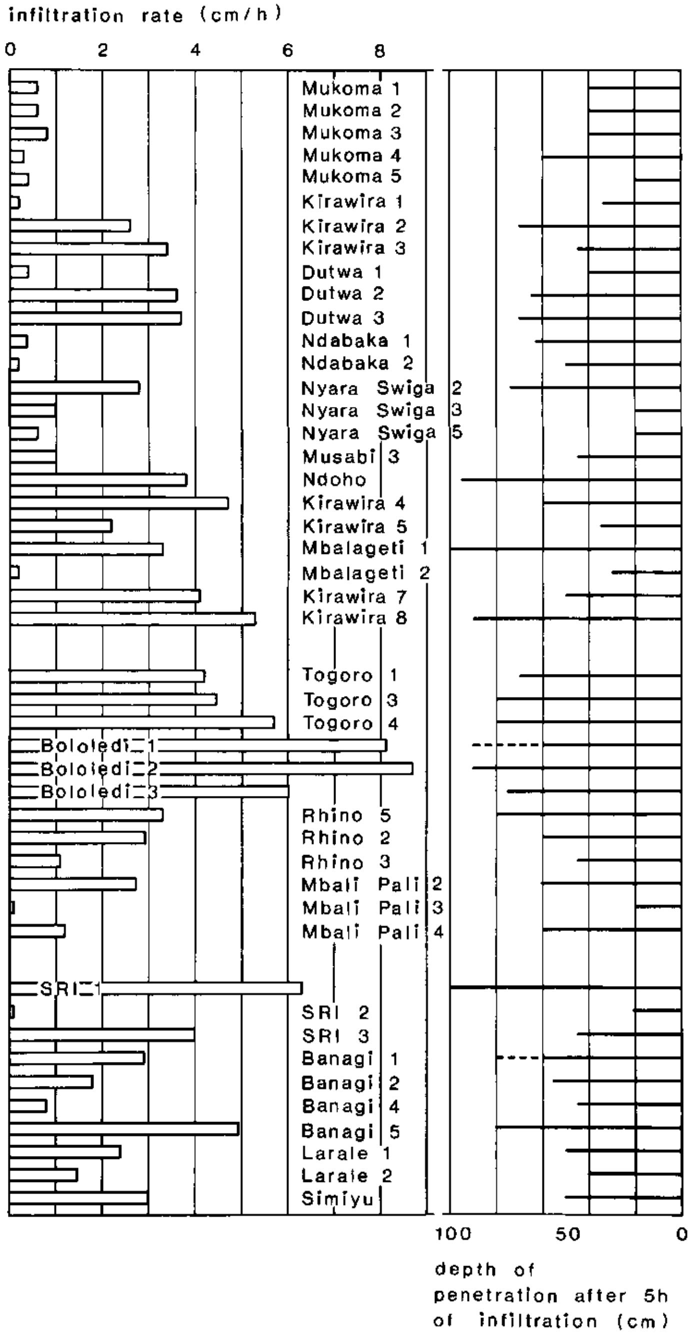


Figure 25. Summary of infiltration characteristics of the Serengeti Woodlands soils.

Four grassland sites combined a high infiltration rate and a depth of penetration of 50 cm or more. Two of them (Kirawira 3 and 7) had strongly developed prismatic structures in the topsoil. Moistening (and swelling) of the strong prisms was slow, so rain disappeared into the subsoil, leaving the topsoil relatively dry.

The absence of woody vegetation at Ndoho and Kirawira 8 was rather puzzling. It was certainly not caused by unfavourable soil conditions. At Kirawira 8, termites had greatly improved the physical characteristics compared with Kirawira 7. The strong prismatic structures had been broken up completely. If grazing pressure or fire allowed young seedlings to establish, they would have a good chance of survival at Kirawira 8. In the Ndoho Plain, soil conditions were favourable over a large area but there was no woody vegetation. Perhaps fire had destroyed an original woody vegetation and grazing pressure or fire had prevented seedlings from establishing. With the dense root system of the grasses and competition for moisture, tree seeds would now have difficulty in establishing themselves.

Sites with infiltration rates less than 2.5 cm/h and a depth of penetration of less than 50 cm were predominantly under grassland. Sometimes a few mature trees were present but no young ones. In parts of the bottomlands that were under woody vegetation the trees were probably adapted to flooding, waterlogging and anaeroby. Moisture availability, grazing pressure and fire must have determined the distribution of woodland and grassland in the Western Corridor. More volcanic material has been sedimented in the lowlands than in the uplands, resulting in unfavourable conditions such as poorly permeable natric horizons. Because of differences in drainage of underlying rock (Section 10.3) physical properties are much more favourable at Kirawira 2 than at Kirawira 1 a few hundred meters away. The former has woody vegetation and the latter grassland.

2.6.2 Distribution of woodland species

Herlocker (1976) surveyed the woody vegetation of the Serengeti National Park. In the Western Corridor, *Acacia drepanolobium* and *Acacia seyal* woodland were always associated with poor drainage. Apparently they can withstand periodic flooding. All the bottomland soils described had one of the two species, here and there associated with *Balanites aegyptiaca*.

In the Northern Extension, *Acacia drepanolobium* was also present at one well drained site, Bololedi 3, (Chapter 3). Herlocker also reported a well drained site covered with the species. Herlocker (1976) often observed dead stands of *Acacia drepanolobium*, and suggested that this might be due to a short-term extreme variation in edaphic conditions, such as waterlogging.

Balanites aegyptiaca was predominantly found on highly alkaline upper and lower pediment and pediplain soils. The chemical composition of the soils seemed to be the main factor in the distribution of this species. *Balanites*

Figure 26. Mature trees (*Acacia tortilis*) in the Mukoma area.

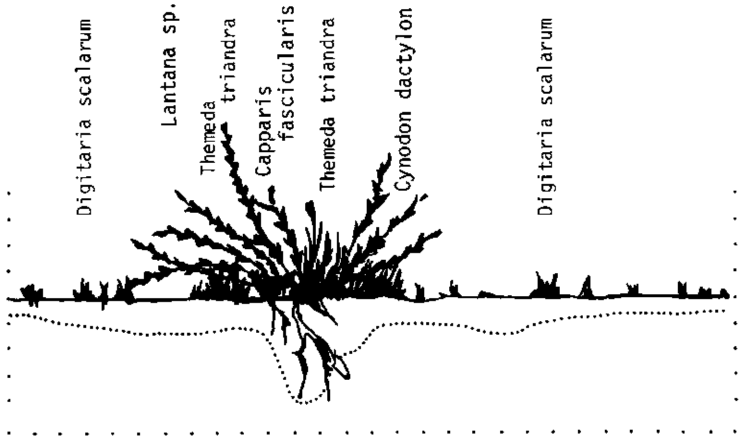
was often associated with *Acacia tortilis*. They can withstand both saline (EC_e from 2.7 mS/cm in the topsoil to 9.2 mS/cm in the subsoil) and alkaline (exchangeable Na^+ often more than 30%) conditions. In the saline and strongly alkaline areas only mature trees were present (Figure 26). Perhaps soil conditions have deteriorated or grazing or fire have prevented seedlings from becoming established.

According to Herlocker (1976) *Acacia tortilis* can reach an age of several hundred years. With the frequent and recent eruptions of Oldoinyo Lengai, the soils could become more alkaline within a few hundred years, resulting in the development of prismatic structures in the B2. horizon. Chemical and physical properties could so have deteriorated, hampering the establishment of seedlings.

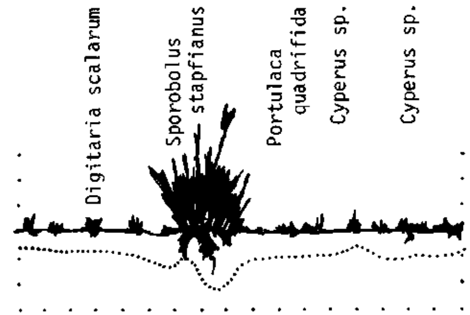
Acacia clavigera was found predominantly on the (moderately) well drained upper pediments and slopes. Its distribution seemed directly related to physical characteristics.

2.6.3 Distribution of grassland species

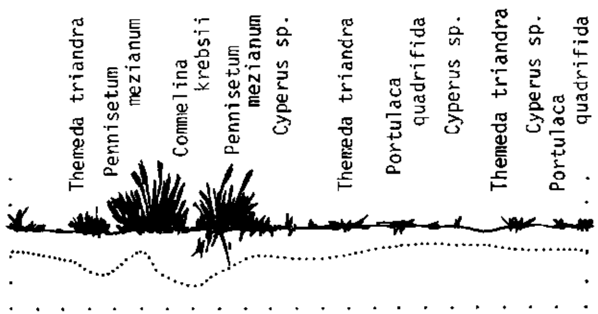
The grasses of the bottomlands included tall grasses like *Pennisetum mezianum, Themeda triandra, Echinochloa haploclada, Sporobolus fimbriatus* and occasionally *Chrysochloa orientalis*. The lower pediments also carried long grasses, especially *Pennisetum mezianum* and *Themeda triandra*. On the better drained upper pediments *Themeda triandra* was more abundant. The short-grass plains in the Corridor (Dutwa Plain, Kirawira Plain, Nangangwe Plain) con-



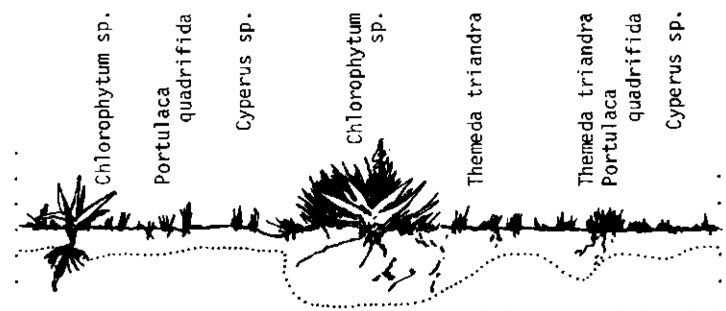
Aitong, Masailand. Twenty hours after 1.5 cm of rain had fallen. The top of the Capparis rootstock is badly fire scarred. Frequent bare patches of soil occur.



Aitong, Masailand. Thirty-nine hours after 1.5 cm of rain had fallen. The thickened tussocks of Sporobolus has prevented water penetration of the soil immediately below it.



Aitong, Masailand. Thirty-nine hours after 1.5 cm of rain had fallen. The soil surface is compacted with a thin-layer of loose sand on top.



Aitong, Masailand. Thirty-nine hours after 1.5 cm of rain had fallen. The top soil is deeper and the grass cover better than in either of the profiles in the centre row.

Figure 27. **Rainwater penetration and grass length in the Aitong area, Kenya (from Glover et al., 1962).**

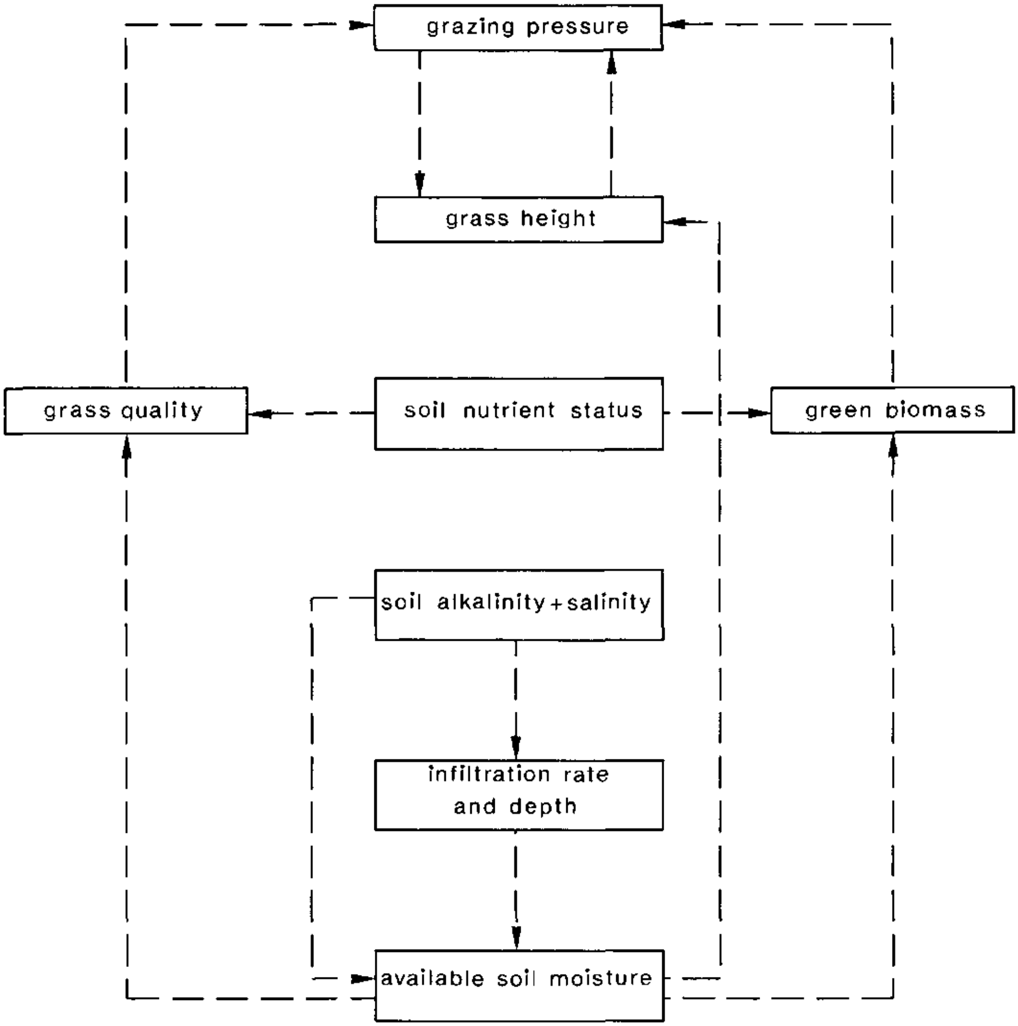


Figure 28. Factors in grass height.

sisted almost entirely of *Chrysochloa orientalis*, also a common species of Musabi Plain (medium-long grassland). All soils with *Chrysochloa orientalis* had high to very high exchangeable Na^+ values.

The same was true for bottomlands with *Chrysochloa*. Available moisture seemed to determine the length of the grass to a great extent. At first sight this seems to contradict the hypothesis that differences in grass height largely result from differences in grazing pressure (Schmidt, 1975). Grazing pressure is certainly an important factor, since enclosure of short-grass areas of the Serengeti Plain allows the grass to become considerably taller. Glover et al. (1962) reported the relation of physical properties with grass length in an area north of the Serengeti (Aitong). They studied penetration of rainwater under a number of dry grassland communities (Figure 27) and found a linear relation between depth of penetration (d) and plant height (h): $d = k + 0.96 h$, in which the constant (k) was determined by penetration of a bare surface. Certain grass species like *Sporobolus* spp. prevented water from penetrating because of the development of thick tussocks.

Available moisture, determined by soil characteristics, certainly plays an important role in plant height. However, other factors have an influence too. In the Western Corridor, areas rich in nutrients had poor physical soil properties. Animals would be attracted by the favourable nutrient status of the soils (and vegetation) and would exert a high grazing pressure, which would keep the grass short. Poor physical soil conditions would promote this process (Figure 28).

2.7 WILDLIFE DISTRIBUTION IN RELATION TO SOIL AND VEGETATION

The distribution of the most abundant ungulate species other than predators will be discussed briefly in relation to soil conditions and vegetation. Buffalo, topis and hartebeest graze on slopes and upper pediments (under woody vegetation) in the wet season. Impalas are resident there. During the dry season, buffalo, topis and hartebeest can be found on the

Table 8. Mean mass ratios of Ca to P in Serengeti Plain grasses (from Kreulen, 1975). Ratios smaller than one enclosed by box.

Vegetation type	Species	Mean / 95% interval	Range	Number of samples
Short	Kyllinga-Melhania*	3.88 ± 0.76	5.45 - 2.77	9
	Digitaria macroblephara	2.38 ± 0.52	3.50 - 1.37	8
	Sporobolus ioclados	1.73 ± 0.27	3.03 - 1.00	17
	Other grass species	1.86 ± 0.35	2.76 - 1.05	14
Medium	Andropogon greenwayi	1.80 ± 0.27	2.51 - 1.43	9
	Digitaria macroblephara	0.86 ± 0.37	1.03 - 0.76	3
	Other grass species	0.81 ± 0.08	1.07 - 0.41	22
Long	Digitaria macroblephara	0.76 ± 0.09	1.44 - 0.45	29
	Pennisetum mezianum	0.79 ± 0.15	1.50 - 0.57	14
	Themeda triandra	1.19 ± 0.17	2.43 - 0.48	24
	Other grass species	1.02 ± 0.17	3.31 - 0.45	42

* Kyllinga nervosa Steud. (sedge) and Melhania ovata (Cav.) Spreng (herb).

lower pediments (under long grass), just like Thomson's gazelle (Bell, 1971).

Migratory wildebeest much prefer the short-grass pediplains. Many explanations have been suggested for this phenomenon. Feeding adaptations may play a role (Bell, 1969). Kreulen (1975) showed that amount and availability of calcium are correlated with wildebeest habitat selection on the Serengeti Plain. Results of chemical analysis of grass species of the Serengeti Plain are given in Figure 29 and Table 8.

On the short-grass plains in the Western Corridor, calcium content in the dry matter of the leaves of the dominant species *Chrysochloa orientalis* ranges from 2.8-3.7 g/kg at Musabi Plain to 4.6 g/kg at Kirawira Plain (mean value 3.7 g/kg). Kreulen estimated the minimum calcium content of dry leaves required by wildebeest during maximum milk production at 4.3 g/kg. Ca/P mass ratio of the vegetation should preferably exceed 1, because other-

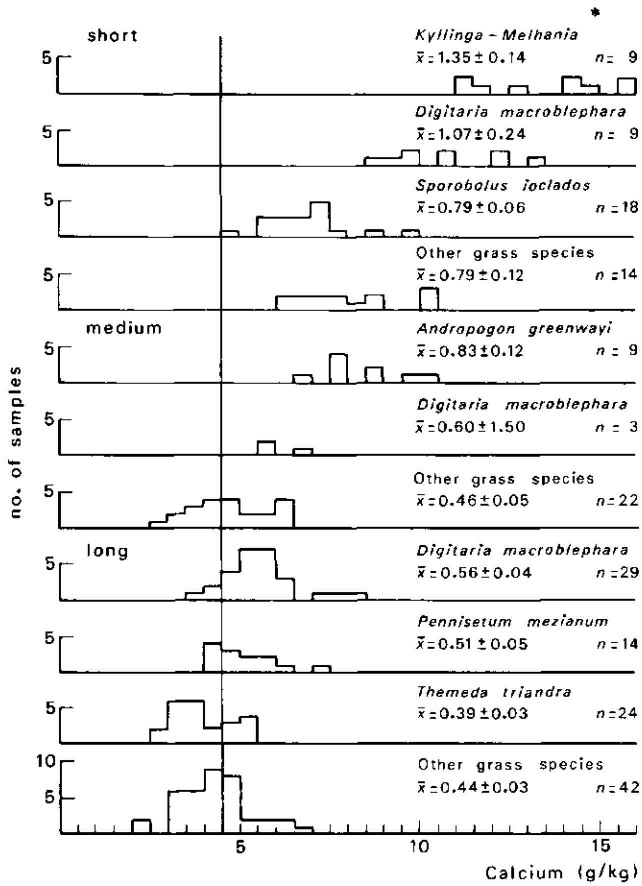


Figure 29. Calcium content of dry matter of leaves from common grass species in long, medium and short grassland on the Serengeti Plain (from Kreulen, 1975).

Table 9. Phosphorus and calcium content in dry matter of leaves and mass ratios of Ca to P in common grasses in three areas of the Serengeti Woodlands.

Species	Number of samples	P (g/kg)	Ca (g/kg)	Ca/P
Togoro-Bololedi area				
Digitaria macroblephara	6	5.5	5.7	1.03
Themeda triandra	2	3.1	4.7	1.52
Rhino Mbali Pali area				
Themeda triandra	11	2.5	5.0	2.00
Western Corridor and Fringe of the Serengeti Plain				
Digitaria macroblephara	15	5.7	5.2	0.91
Themeda triandra	6	3.1	4.1	1.32
Pennisetum mezianum	9	5.8	4.3	0.74
Chrysochloa orientalis	6	4.4	3.8	0.86

wise the calcium absorption by the gut may be hindered (Kreulen, 1975).

As is shown (Table 9) mean Ca/P mass ratios usually do not exceed 1 in the Western Corridor. Ca/P mass ratio for the *Chrysochloa* grasslands ranges from 0.71-0.90 at Musabi to approximately 1 at Kirawira Plain (mean value 0.86). From the scarce data presented it appears that Ca supply in the Kirawira area is sufficient to satisfy tha Ca-requirements of the resident wildebeest population during lactation and that that Ca-absorption in the gut is not hindered by relatively high P-contents. Certain plains in the Northern Extension, like Togoro Plain, where the grasses have higher calcium contents and more favourable Ca/P ratios, lack a resident wildebeest population. There soil conditions were more favourable for plant growth and consequently long grass was present.

3 Landscape of the Northern Extension

3.1 INTRODUCTION

The Northern Extension essentially consists of a number of plains, dissected to different degrees, resulting in a rather uniform undulating area. An exception is the northeastern part which is more hilly. Apart from a few small grassland plains, the area is predominantly under woody vegetation.

The altitude ranges from about 1300 m in the southwestern to about 2000 m in the northwestern part of the area.

3.2 GEOLOGY (Figure 12)

3.2.1 Crystalline rocks

Except for the Lamai wedge, the most northern part of the Park, where Tertiary volcanics (trachitic phonolites) are found, the soils are exclusively underlain by Precambrian basement rocks.

The hilly part consists of Usagaran metasediments (Thomas, 1966). These rocks are 'slightly' younger than the Nyanzian and granitic rocks. Usagaran sediments were deposited on the Mozambiquian foreland floor. During the Mozambiquian orogeny (late Precambrium to mid Ordovicium), the Usagaran sediments were folded, together with the basement rocks (Thomas 1966). The Usagaran metamorphosed sediments are predominantly muscovite quartzites, quartzo-feldspathic gneisses and biotite gneisses.

Granitic and gneissic rocks are the most widespread rocks. The composition is variable: granitic and granodioritic gneisses, biotite-granodiorites and leucogranites.

Probably the oldest rocks present in the Serengeti Park are the granitic gneisses of the pre-Nyanzian system in the northwestern part. On the soil map, this area appears as a more dissected area. The near absence of kopjes in this area is striking and could result from structural differences with respect to the granitic and gneissic rocks.

Nyanzian rocks are found in the southwestern part. They include metamorphosed volcanics and sediments. Especially sericite and chlorite schists are common. Some of the schists contain calcite and have been carbonated (Macfarlane, 1967). After weathering and the subsequent action of soil-forming processes, a petrocalcic horizon originated on these rocks. By erosion of the topsoil the petrocalcic horizon is exposed over wide areas. This petrocalcic horizon or kunkar is exclusively underlain by rocks of the Nyanzian system.

3.2.2 Tertiary volcanics

The Tertiary volcanics found in the Lamai wedge, the area north of the Mara River, were described by Williams (1964) in the area of Mara River and Sianna. According to Shackleton (1951) these volcanics are Miocene. The underlying surface is called the early Miocene planation surface (Section 10.1.4). In post-Miocene times, after the eruption of the trachytic phonolites, the Isuria Fault, forming the Park boundary in the extreme northwest, originated, creating an escarpment of about 250 m.

3.2.3 Superficial deposits

The high pH and exchangeable Na^+ of the Western Corridor soils were caused by alkaline volcanic deposits (Section 2.5.1). In the Northern Extension, pH and exchangeable Na^+ are lower, suggesting less frequent coverage with volcanic deposits, faster removal or more intensive weathering of the deposits.

Probably all the explanations are correct to some extent. Prevailing easterly winds would have deposited more ash from the Ngorongoro Highlands in the Western Corridor. In the Northern Extension, greater dissection and steeper slopes would favour removal. Weathering has presumably been more intensive in the northeastern part of the Northern Extension than anywhere else in the Serengeti Park because of high rainfall figures (up to 1200 mm per year).

Locally, high pH and exchangeable Na^+ can still be encountered in soils underlain by granitic and gneissic rocks, suggesting the presence of ash deposits. Supporting evidence forms the high base saturation of the Extension soils and emerges also from the mineralogical investigations (Chapter 8). Recognizable ash layers have not been found, so it is impossible to say, whether the ashes in the Extension have the same age or origin compared with the Corridor ashes.

3.3 GEOMORPHOLOGY

In the legend of the soil map, geomorphological features have been used at the high levels of classification for characterisation of soil groups.

3.3.1 Pediplain

Definitions and descriptions of pediplain have been given already in Section 2.3. The remnants of the pediplains in the Northern Extension are much smaller because of the more severe dissection than in the Western Corridor. The distribution of erosional plains will be given in Section 10.1. Several planation surfaces and transitions can be detected in the Northern Extension. However, for characterization of the soils, differentiation between older and younger pediplains proved sufficient. The older pediplains are of early Miocene age or older, the younger ones represent more recent planation.

3.3.2 Valley form

The older pediplains are subdivided into plains with trough valleys with local outcrops and plains with narrow-bottomed eroded valleys and flat-floored eroded valleys (Figure 30). This distinction is based on Louis (1964) and Young (1972). According to Louis, valley forms are climatically controlled. In the Northern Extension, the presence of trough valleys coincides with the presence of hardened pinthite. Narrow-bottomed eroded valleys are found in areas of lower rainfall and flat-floored eroded valleys in areas of medium rainfall.

Trough valleys with local outcrops. This valley profile is encountered especially in the Rhino Mbali Pali area (Section 6.3). On the ridges, soils are relatively shallow and there are occasional kopjes. Slope is about 5%. The size of the ridges decreases towards the main waterways as a result of stronger regressive erosion near the main rivers.

Narrow-bottomed eroded valleys and flat-floored eroded valleys find their widest distribution in the areas underlain by Nyanzian rocks, that are more susceptible to erosion than the granitic and gneissic rocks. Flat-floored

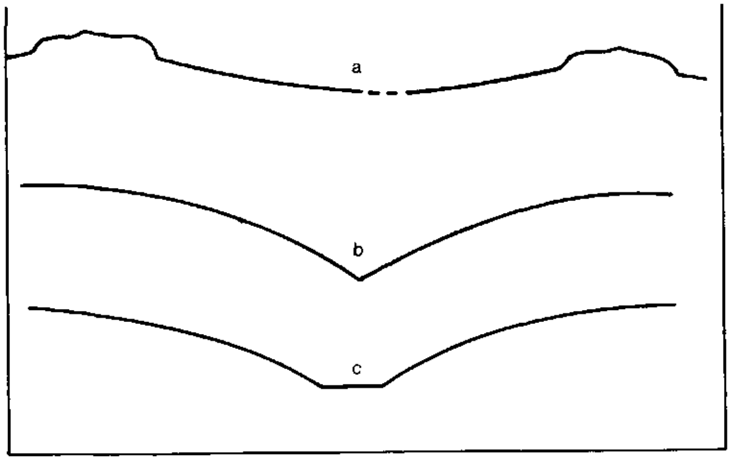


Figure 30. Schematic valley cross-sections (from Louis, 1964). a, Trough valley with local outcrops; b, Narrow-bottomed eroded valley; c, flat-floored eroded valley.

eroded valleys have developed in the part with medium rainfall on resistant types of rock. Thus besides to rainfall, the underlying type of rock helps to determine valley form.

3.3.3 Kopjes

Inselbergs and tors, both here called kopjes, can be observed throughout the Extension in granitic and gneissic rocks. Thomas (1974) argues that tors should be defined as spheroidally weathered boulders rooted in bedrock, which have been exposed by stripping of the basal weathering surface, whilst kopjes should be regarded as the outcome of subaerial joint collapse. Formation of kopjes is best explained by Figure 31. Differential weathering is caused by intensive chemical weathering due to joint spacing resulting in a 'basal platform' (Linton, 1955), or 'basal weathering platform (Small, 1978; Thomas, 1974). The wider the joint spacings, the bigger the boulders. Since joint spacing probably determines the size of the boulders, it is easily understood why kopjes consist of huge boulders in certain areas, and in other areas of smaller boulders (Figure 32 and 33). Soil colour is also closely associated with the spacing of joints because of its effect on the 'rock drainage' (Section 10.3).

Kopjes can be observed on ridges, ridge slopes and even valley bottoms. On ridges they are evidence of incomplete (pedi)planation. If a planation surface is 'attacked' by renewed pedimentation, kopjes are often exposed on slopes and in valley bottoms. Most numerous are the kopjes in the transitional zone between two planation surfaces. This phenomenon can be observed very well in the zone between the early Miocene and late Tertiary planation surfaces.

Also in river catchments close to main waterways, concentrations of kopjes can be found because of increased pedimentation.

Figure 31. Stages in the evolution of a granite tor (from Linton, 1955):
A. Vertical section of fresh granite with varied spacing of joints.
B. After a period of rotting by percolating ground-water down to the level of permanent saturation: decomposed rock, black.
C. Decomposed rock removed, leaving a tor rising abruptly from the surrounding surface.

Figure 32. A kopje complex of big spheroidal boulders (Moru kopjes). These boulders are resistant to weathering.

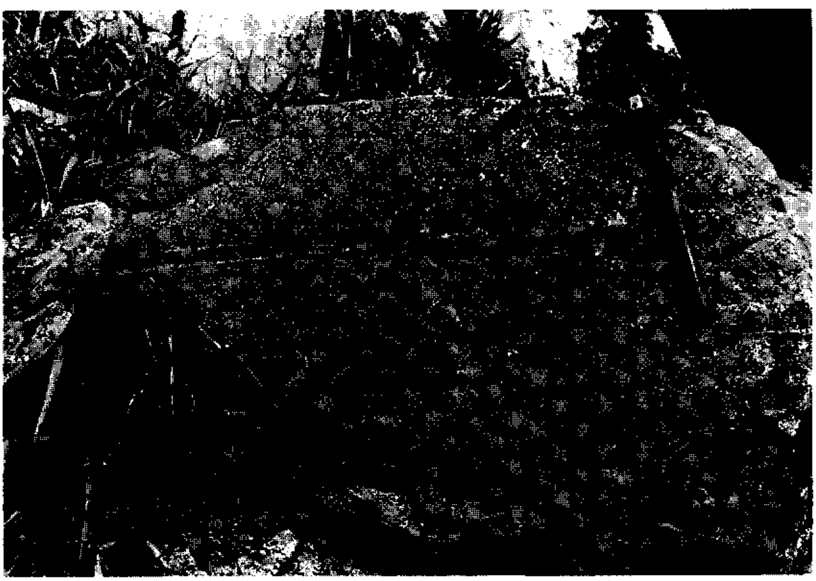


Figure 33. Boulders may fall apart into smaller angular segments (west of Togoro Plain).

3.4 LEGEND

The legend of the soil map of the Northern Extension is based almost entirely on geomorphological features. Only at the lowest level of classification are soil characteristics considered. Also the nature of the underlying rock, which is clearly related to the properties of the soil, has been included in the legend.

Landscape of the Northern Extension

4 Ash covered older pediplains on granites and gneisses
- 4.1 Older pediplain with trough valleys with local outcrops
  - 4.1.1 Ridges
    - 4.1.1.1 Undulating, shallow to moderately deep, (dark grey-) brown sandy loam soils, often with a petroferric contact
    - 4.1.1.2 Undulating, shallow to moderately deep, dark brown sandy soils, with a petroferric contact
    - 4.1.1.3 Gently undulating, moderately deep to deep, dark brown sandy soils, with a petroferric contact
  - 4.1.2 Ridge slopes
    - 4.1.2.1 Gently sloping, deep to very deep, dark grey clay-loam soils
    - 4.1.2.2 Very gently sloping, very deep, very dark grey to black clay soils
- 4.2 Older pediplains with narrow-bottomed eroded valleys and flat-floored eroded valleys
  - 4.2.1 Ridges
    - 4.2.1.1 Gently rolling, moderately deep, reddish-brown clay-loam soils
    - 4.2.1.2 Undulating, moderately deep, to deep, reddish-brown to dark grey loamy soils
    - 4.2.1.3 Flat to nearly level and gently undulating, deep, very dark grey clay-loam soils
  - 4.2.2 Ridge slopes
    - 4.2.2.1 Very gently sloping, deep, black to very dark grey and dark reddish-brown clay-loam soils

5 Ash covered younger pediplains
- 5.1 Strongly dissected pediplains on Nyanzian rocks
  - 5.1.1 Rolling to gently undulating, shallow to moderately deep, reddish-brown loamy soils
- 5.2 Slightly dissected pediplains
  - 5.2.1 Granitic rocks
    - 5.2.1.1 Ridges

5.2.1.1.1 Nearly level to flat, moderately deep to deep, dark grey and reddish-brown clay-loam soils

5.2.1.2 Ridge slopes

5.2.1.2.1 Gently sloping, deep, reddish-brown clay-loam soils

5.2.2 Nyanzian rocks

5.2.2.1 Ridges

5.2.2.1.1 Gently undulating, moderately deep, reddish-brown loam and clay-loam soils

5.2.2.1.2 Nearly level, moderately deep to deep, reddish-brown clay-loam soils

5.2.2.2 Ridge slopes

5.2.2.2.1 Gently sloping, deep, reddish-brown clay-loam soils

5.2.2.2.2 Very gently sloping, deep to very deep, very dark grey to black clay soils

5.2.3 Tertiary volcanics

5.2.3.1 Ridges

5.2.3.1.1 Nearly level to flat, shallow to moderately deep, clay-loam soils

5.2.3.2 Slopes

5.2.3.2.1 Very gently sloping, deep to very deep, dark grey clayey ridge slope soils

5.2.3.2.2 Sloping, moderately deep, loamy colluvial soils

Features common to all landscapes

7 Stony uplands

7.1 Hilltops, slopes and outcrops

7.1.1 On metamorphic, sedimentary and plutonic rocks

7.1.2 On Tertiary volcanics

7.2 Kopjes complex

8 Bottomlands

8.1 Complex deep and very deep, sandy, loamy and clayey flood plain, river and depression sediments

3.5 SOIL DESCRIPTION

Only a limited number of soil pits have been described in the Northern Extension, apart from the Rhino Mbali Pali area. Site locations are given in Figure 15.

3.5.1 Older pediplains with trough valleys with local outcrops (Map Unit 4.1)

The soils present on the pediplains with trough valleys with local outcrops are described in detail in Chapter 6. The nearly level to undulating and gently rolling topography is overlain by a range from deep to shallow soils. The more the area is dissected, the smaller the ridges and the shallower the soils. A petroferric contact, which is characteristic for this area only, can be observed nearly everywhere under the ridge soils.

3.5.2 Older pediplains with narrow-bottomed eroded valleys and flat-floored eroded valleys (Map Unit 4.2)

On the soil map the boundary between the pediplains with trough valleys and narrow-bottomed and flat-floored valleys is distinct. Flat bottoms are absent in the trough valleys, indicating that sedimentation here is a less important process. In the narrow-bottomed and flat-floored valley area, the loamy ridge soils are more susceptible to erosion than the stable sandy ridge soils of the pediplains with trough valleys, resulting in a higher sediment load of the rivers in narrow-bottomed valleys. Presence or absence of a flat bottom is caused by the sediment supply and the slope of the waterways.

The difference in soil texture between the ridge soils of the two types of pediplains could be caused by differences in age or climate. Probably the sandy ridge soils are considerably older than the loamy ridge soils. Also the presence of a petroferric contact in the ridge soils only of the older pediplains, suggests that soil-forming processes acted longer or more intensive upon these soils.

3.5.3 Undulating, moderately deep to deep, reddish-brown to dark grey loamy soils (Map Unit 4.2.1.2)

Profile characteristics

Two sites were described: Bololedi 1 and 2. Bololedi 1 was at the highest point of a ridge, Bololedi 2 somewhat lower. Bololedi 1 was moderately deep rather coarse-textured; Bololedi 2 was much deeper and finer textured. Both soils were underlain by gneisses. The reddish-brown colours result from rock composition and 'rock drainage', determined by the spacing of cracks in the bedrock (Section 10.3). Because of assumed changes in rock structure, variations in colour can be observed at short distances. Termites (*Macrotermes* sp.) are common.

Chemical characteristics

Chemical characteristics were favourable (Appendix D42, D43). The pH was about 7 and the potassium content of the saturation extract was relatively high. Exchangeable K^+ exceeded exchangeable Na^+.

Cation-exchange capacity was relatively low. Despite a clay content of 40% (Bololedi 2: 60-100 cm), CEC reached only 140 mmol/kg in soil, or 290 mmol/kg in the clay fraction.

Physical characteristics

Granular size distribution: At Bololedi 2 the clay content increased with depth to 100 cm (20%-28%-33%-40%) because of illuviation. Below 100 cm, the clay content decreased to 34% (Appendix C).

Infiltration rates: Infiltration rates in the fifth hour were high for both Bololedi 1 and 2: about 8 and 9 cm/h, respectively (Figure 34). The two infiltration curves are linear, so that swelling did not play an important role, as would be expected from the low coefficient of linear extension.

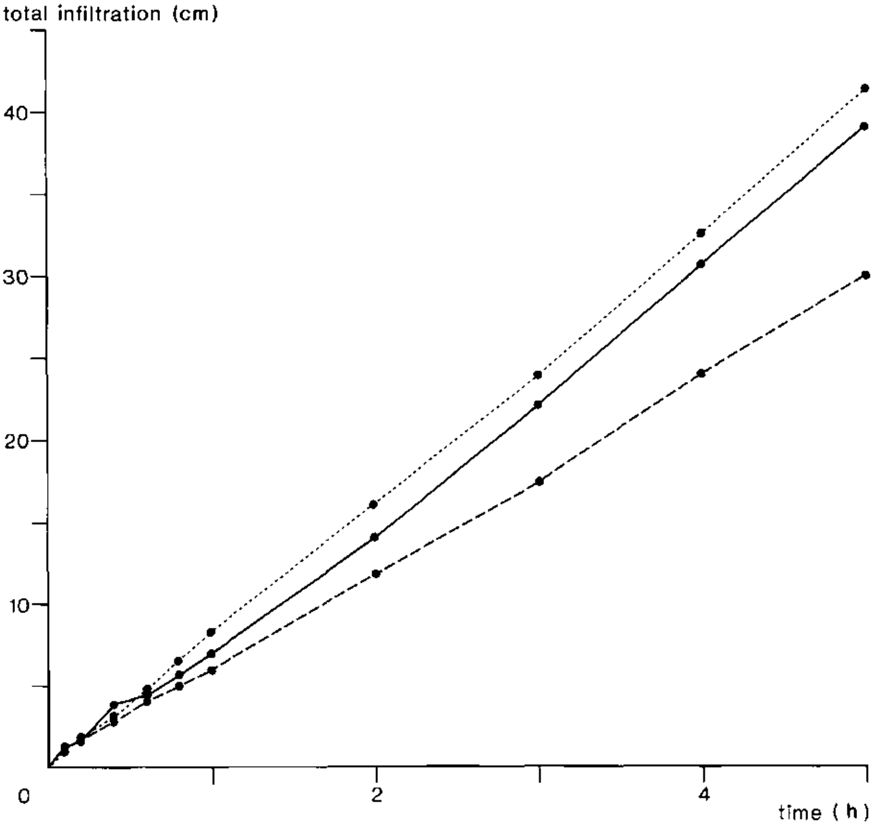


Figure 34. Infiltration characteristics for 3 sites in the Bololedi area (older pediplain). Bololedi 1 (———), Bololedi 2 (·········) and Bololedi 3 (– – – – –). Depth of penetration after 5 h was > 60, 90 and 75 cm, respectively.

Depth of penetration: Also the depth of penetration after 5 hours of infiltration was high. The water front reached the bedrock surface (at 60 cm) at Bololedi 1 and a depth of 90 cm at Bololedi 2.

Moisture retention and availability: For Bololedi 2 (Table 10) the maximum available moisture exceeds 7.4 cm. This is a gross underestimate, since the maximum depth of moisture fluctuation as calculated with the neutron probe proved to be deeper than the length of the inserted tube. If one takes the depth of penetration after 5 h of infiltration as basis, the calculated value is 9.3 cm.

Bulk density gradually increased with depth from 1370 to 1500 kg/m^3, as did the clay content, so probably clay illuvation had caused the increase in the bulk density. No data on bulk density were available for depths below 100 cm. To a small extent, the decrease in organic matter may have contributed to the increase in bulk density. Organic carbon contents, however, were low (from 1.19% in the topsoil to 0.35% below 100 cm).

Thus Map Unit 4.2.1.2 consisted of soils with good physical and chemical characteristics. The dominant vegetation was woody (Figure 35). Bololedi 2 was situated at a clearing (near an airstrip), however *Acacia tortilis, Acacia clavigera* and *Acacia senegal* had regenerated all around.

Diagnostic horizons

Mollic epipedons were encountered at all sites. Usually an argillic horizon was present as well. For classification see Chapter 9.

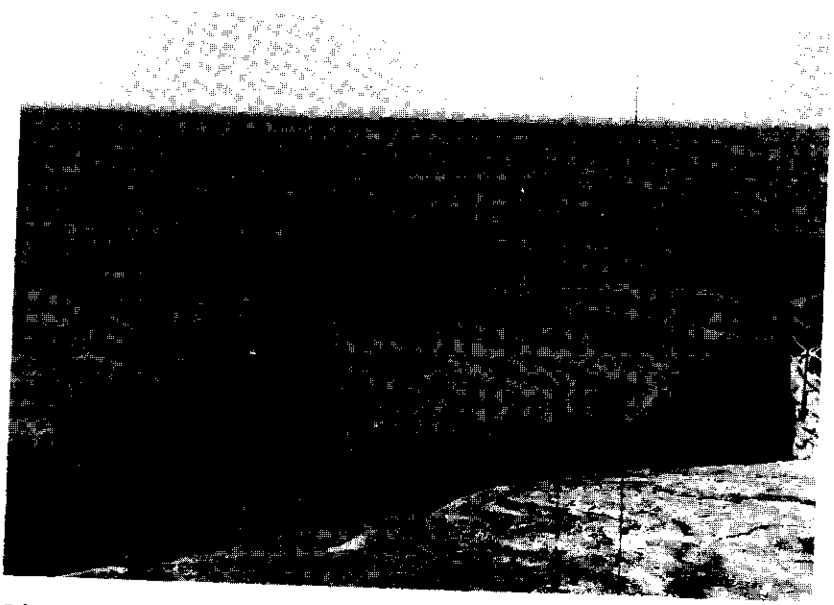


Figure 35. View from Lobo Lodge.

Table 10. Moisture retention, maximum available moisture, bulk density and coefficient of linear extension for two older pediplain soils.

	Depth (cm)	Volume fraction of moisture (%) pF				Bulk density (kg/m³)	Coefficient of linear extension	Maximum depth of fluctuation in moisture (cm)	V(pF2)-V(pF4.2) (cm)	Maximum available moisture (cm)
		1	2	3.4	4.2					
Togoro 1	0- 20	43.9	24.3	17.3	10.7	1340	<0.02	>80	2.7	10.4
	20- 40	37.6	26.3	20.7	14.8	1450	<0.02		2.3	
	40- 84	40.3	37.1	32.4	23.7	1410	0.04		5.4	
	84-134	44.1	38.7	27.3	26.0	1320	<0.02			
Bololedi 2	0- 20	44.4	21.1	9.4	9.4	1370	<0.02	>>70	2.3	>>7.4
	20- 30	41.6	20.6	13.9	11.4	1380	<0.02		0.9	
	30- 60	40.7	25.6	17.2	15.0	1430	<0.02		3.2	
	60-100	37.5	29.1	20.1	19.4	1500	<0.02		1.0	

Soil erosion

Soil erosion was observed everywhere, though not very dramatic. Sheet wash was the main process. As a result of good infiltration, run-off and soil erosion were reduced.

3.5.4 Flat to nearly level and gently undulating, deep, very dark grey clay-loam soils (Map Unit 4.2.1.3)

Profile characteristics

A 'plain' and a 'woodland' site were described (Togoro 1 and 3, respectively). Most profile characteristics of the two sites were rather alike. However, the clay content and the depth of the solum were different. Clay contents were significantly higher and the solum was twice as deep at the plain site.

Colours were usually very dark grey, but locally also reddish-brown colours were observed thoughout the profile. This can be explained only by assuming a better 'rock drainage' influencing the weathering of the overlying volcanic deposits. Where kopjes emerged from the browner soils, they consisted of considerably smaller boulders than those in kopjes emerging from grey soils. This phenomenon was observed frequently in the Northern Extension. The smaller the boulders, the more cracks were present in the bedrock, the better the rock drainage, resulting in browner soils. Unfortunately differences in soil colour could not be mapped properly because of changes in short distances (Section 10.3).

Chemical characteristics

Chemical characteristics were comparable to those of site Bololedi 2 (Appendix D37, D39). Exchangeable K^+ was lower, because the gneisses at Bololedi 2 contained more potassium feldspars.

Physical characteristics

Granular size distribution: The clay content at Togoro 1 increased from 18% in the topsoil to 45% (40-84 cm), below 84 cm it decreased somewhat (32%). The silt content of the subsoil (84-134 cm) was high: 40%, compared to 19% at Bololedi 2 (Appendix C).

Infiltration rates: Infiltration rates of Togoro 1 and 3 were about 4 cm/h, which was less than at the two Bololedi sites, but still favourable (Figure 36).

Depth of penetration: Values of 70 and 80 cm are reached at Togoro 1 and 3, respectively.

Moisture retention and availability: Moisture contents at pF2, 3.4 and 4.2 were somewhat higher at the 'plain' site than at Bololedi 2 (Table 10). Maximum available moisture was high as well (10.4 cm).

Below 40 cm, the bulk density decreased from 1450 to 1320 kg/m^3 (84-134

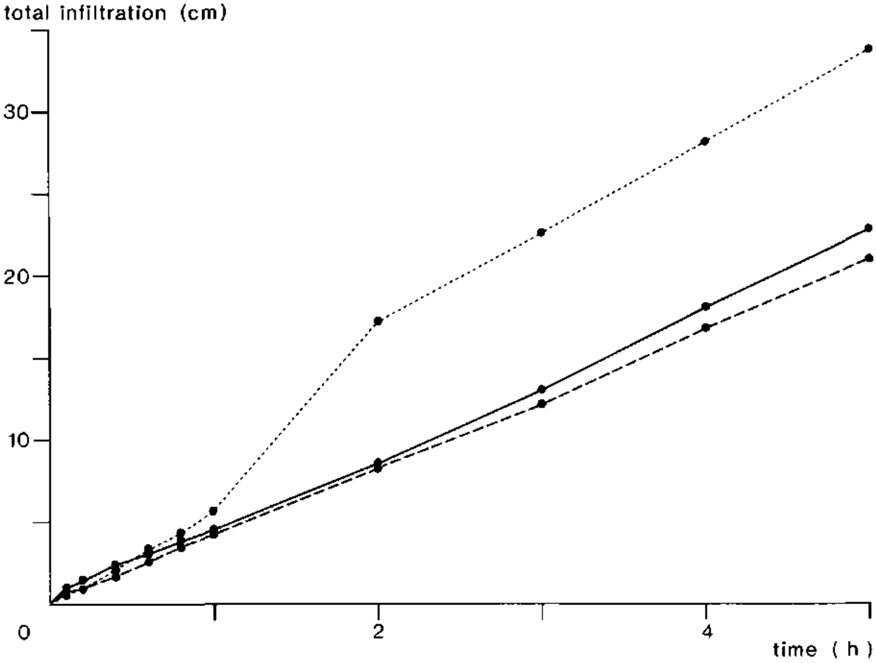


Figure 36. Infiltration characteristics for 3 sites in the Togoro area (older pediplain): Togoro 1 (-----), Togoro 3 (———) and Togoro 4 (--------). Depth of penetration after 5 h was 70, 80 and 80 cm, respectively.

cm). In the well drained reddish-brown soils of the Bololedi area, bulk density increased to a depth of at least 100 cm.

It seems that at site Bololedi 2 weathering had proceeded to greater depths due to high infiltration rates and depths of penetration. A decrease in bulk density indicates a larger amount of less weathered volcanic deposits in the subsoil. The presence of only slightly weathered material in the subsoil of the Togoro sites was confirmed by the high silt contents.

Despite a favourable infiltration rate and depth of penetration, Togoro 1 was under grassland vegetation. This was even more peculiar in relation to Togoro 3, where rather dense woody vegetation was present. The only differences were the depth of the solum and the clay content. Woody vegetation should prevail at the 'plain' site as well (Figure 25), but once the woody vegetation is destroyed it may be hard for tree seeds to establish, because of dense grass roots that soon develop under the favourable moisture conditions at this site (compare Ndoho site, Western Corridor, Section 2.5.3).

Diagnostic horizons

A mollic epipedon and an argillic horizon were present at all sites described. For classification see Chapter 9.

Soil erosion

Sheet wash is the dominant erosion process, as shown by the widespread presence of quartz sand at the surface.

3.5.5 Very gently sloping, deep, black to very dark grey and dark reddish-brown clay-loam soils (Map Unit 4.2.2.1)

Profile characteristics

As can be seen from the profile descriptions (Appendix B44, B40, B41) of the sites Bololedi 3, Togoro 4 and 5, the soils of this unit are rather heterogeneous. Besides 10YR colours also 2.5YR colours were observed, presumably depending primarily on the structure of the underlying bedrock and the soil slope.

The two Togoro sites were about 200 m apart. Togoro 4 was well drained and reddish-brown colours prevailed, Togoro 5 was poorly drained and was very dark grey in the topsoil. At greater depths, brown (7.5YR4/4) colours appeared at both sites. Apart from a slightly gentler slope, only a drastic change in bedrock structure could account for the enormous differences in physical and chemical properties between the two Togoro sites. Soil slopes of the poorly drained Togoro site and the well drained Bololedi site were similar (2%), confirming again that soil slope was not the only factor in soil colour.

Chemical characteristics

The high sodium content of the saturation extract and the high exchangeable Na^+ at the poorly drained site, Togoro 5, stand out (Appendix D40, D41). Weathering proceeds slowly at this site. Thus a high content of relatively fresh ash may still be present, which could contribute to the high cation-exchange capacity.

Bololedi 3, situated in a similar position, did not have the high cation-exchange capacity nor exchangeable Na^+. Apart from the high exchangeable K^+, the chemical characteristics of Togoro 4 were comparable to Bololedi 3. A valley bottom soil in the Bololedi area was also analysed (Appendix D45). Results were similar to Togoro 5. One should bear in mind, however, that at the valley bottom site sedimentation predominates and that for this reason the high cation-exchange capacity and exchangeable Na^+ primarily result from translocation of both the fine fraction and nutrients.

Physical characteristics

Granular size distribution: The topsoil of the poorly drained ridge slope (Togoro 5), had a higher clay content than the well drained sites Togoro 4 and Bololedi 3 (Appendix C). Except for some sedimentation, this was also due to less eluviation as a result of (assumed) low infiltration rates.

Infiltration rates: Infiltration rates at both well drained sites Togoro

4 and Bololedi 3 were about 6 cm/h in the fifth hour (Figure 34 and 36). No infiltration rate was available for Togoro 5, but it would probably not exceed 1 cm/h.

Depth of penetration: Similar values were found for Bololedi 3 and Togoro 4 (about 80 cm).

Moisture retention and availability: Moisture retention was not determined for these sites. For both Togoro 4 and Bololedi 3 they would probably be very favourable in contrast to Togoro 5. Maximum available moisture would exceed 10 cm for the first two sites.

The well drained sites Togoro 4 and Bololedi 3 were both under woody vegetation as expected from their available moisture. Togoro 4 was under *Acacia nilotica* woodland and at Bololedi 3 the dominant tree species were *Acacia clavigera* and *Acacia drepanolobium.* The latter combination was highly unusual, since *Acacia clavigera* was usually found on well drained soils and *Acacia drepanolobium* on poorly drained soils. Thus this was an exception on the general rule that *Acacia drepanolobium* is found exclusively on periodically waterlogged soils.

Herlocker (1976) also encountered *Acacia drepanolobium* on well drained soils in combination with *Acacia senegal* north of the Nyabogati River on a ridge site underlain by Nyanzian rocks. He assumed a relation between the occurrence of *Acacia senegal* and the presence of Nyanzian rocks. At Togoro 5 both long grass (*Pennisetum mezianum*) and *Acacia drepanolobium* trees were observed.

Diagnostic horizons

Topsoils of all sites described, apart from Togoro 4, meet the requirements of a mollic epipedon. Usually an argillic or natric horizon was present. For classification see Chapter 9.

Soil erosion

Coarse quartz sand often covers the surface, indicating that sheet wash has been the dominant process of erosion.

ASH-COVERED YOUNGER PEDIPLAINS

The elevation of the younger pediplain soils ranges from about 1300 m to about 1500 m. Little research was done in the soils overlying the younger pediplains. One site was on a strongly dissected pediplain on Nyanzian rocks, two others on a slightly dissected pediplain underlain by Tertiary volcanics.

3.5.6 Rolling to gently undulating, shallow to moderately deep, reddish-brown loamy soils (Map Unit 5.1.1)

Profile characteristics

The soils are underlain by Nyanzian metamorphic rocks, predominantly schists like chloritoid and carbonated schists (Macfarlane, 1967). Very often a petrocalcic horizon (or kunkar) underlies the solum, directly on the bedrock.

The soil is usually reddish-brown because of favourable 'rock drainage' of the metamorphous rocks and relatively steep slopes.

Soil depth ranges from shallow to moderately deep, depending on slope. Slopes are generally steeper than in the rest of the Northern Extension. Obviously most of the Nyanzian rocks are more prone to erosion as indicated also by the steep banks of the main rivers traversing the area like the Nyabogati and Orangi Rivers.

Chemical characteristics

Chemical characteristics of Banagi 5 (Appendix D36) were much like those of the well drained Bololedi and Togoro sites (Section 3.5.5). Relatively low cation-exchange capacity, exchangeable Na^+ and pH and relatively high exchangeable K^+ are encountered. The subsoil contained nitrate, probably because of past termite activity.

Physical characteristics

Granular size distribution: Below a depth of 10 cm, respective contents of silt and clay increased from 33 and 16% to 36 and 37% (Appendix C). The topsoil had a relatively high silt and clay content (37 and 21%), which made it susceptible to slaking. So run-off can be high. An initial drop in clay and silt content, as observed here, was not noticed at other sites. High silt contents were usually only observed in subsoils where there were large amounts of relatively fresh volcanic material. Redeposition of silt and clay may account for the finer texture of the topsoil.

Infiltration rates: In the fifth hour the infiltration rate at Banagi 5 was about 5 cm/h (Table 11).

Depth of penetration: The maximum depth of moisture fluctuation, 25 cm, was significantly less than the depth of penetration after 5 h of infiltration, 80 cm. The soft surface sealing has been cracked along the edge of the infiltration ring. This explains the high depth of penetration compared to the depth of moisture fluctuation measured with the neutron probe over a one year period. However, frequent measurements with the neutron probe could have enhanced sealing. Such sealing can vary locally, for instance under a tree better physical characteristics are encountered, influencing the infiltration rate and depth. Splash erosion, greatly affecting slaking, will be considerably less underneath trees. So here the maximum depth of moisture fluctuation should be considered a minimum, the depth of penetration a maximum.

Moisture retention and availability: If a depth of moisture fluctuation of 25 cm is taken, maximum available moisture would be 3.9 cm, which is as has been explained above an underestimate (Table 11). A value of about 10 cm would be more realistic.

Bulk densities did not change significantly below 10 cm.

Favourable moisture conditions were responsible for the woody vegetation. If the soils are shallow to very shallow, woody vegetation becomes even more dense. Obviously cracks in the bedrock reach to great depths. Roots follow the cracks, enabling the trees to fulfill their water requirements. Termite mounds were also common (*Macrotermes* spp.) on shallow soils, on which they must therefore be able to satisfy their water needs.

Diagnostic horizons

Usually a mollic epipedon or an argillic horizon were observed. For classification see Chapter 9.

Soil erosion

Slaking enhanced the surface sealing, thus increasing run-off and erosion. Gully erosion was not noticed. Sheet wash was the dominant erosion process.

3.5.7 Slightly dissected pediplains on granitic rocks (Map Unit 5.2.1)

Data on the soils overlying the slightly dissected pediplains on granitic rocks are scarce. No detailed site descriptions are available, since the area occupied by these soils is very small. Ridges usually had gentler slopes than the ridge soils of the older pediplains. Like them, the ridge slope soils had 5YR and 2.5YR colours and loamy textures. We saw many big termite mounds (*Macrotermes* spp.) when we crossed the area. Coarse sand covered the surface. The soils of the slightly dissected pediplains in granitic rocks were under woody vegetation.

3.5.8 Slightly dissected pediplains on Nyanzian rocks (Map Unit 5.2.2)

Soils of the slightly dissected pediplains on Nyanzian rocks were very similar to the soils on granitic rocks. Dark grey colours were found only in the clayey soils; the loamy soils were brown to reddish-brown. Locally the ridge soils were underlain by kunkar. Coarse quartz sand, found in soils underlain by granitic rocks, was absent. The gently undulating soils were shallower and somewhat coarser textured than the nearly level soils. The very gently sloping ridge slope soils will be discussed in more detail (Banagi 3 and 4).

Table 11. Moisture retention, maximum available moisture, bulk density and coefficient of linear extension for a moderately deep younger pediplain soil.

	Depth (cm)	Volume fraction of moisture (%) pF				Bulk density (kg/m^3)	Coefficient of linear extension	Maximum depth of fluctuation in moisture (cm)	V(pF2)-V(pF4.2) (cm)	Maximum available moisture (cm)
		1	2	3.4	4.2					
Banagi 5	0- 10	41.0	29.1	16.9	12.5	1610	<0.02	25	1.7	3.9
	10- 30	44.4	29.8	14.5	13.9	1410	<0.02		2.2	
	30- 60	41.3	28.3	20.1	16.7	1440	<0.02			
	60- 80	45.2	35.9	24.2	19.2	1450	<0.02			

Table 12. Moisture retention, maximum available moisture, bulk density and coefficient of linear extension for two pediplain soils on Nyanzian rocks.

	Depth (cm)	Volume fraction of moisture (%) pF				Bulk density (kg/m^3)	Coefficient of linear extension	Maximum depth of fluctuation in moisture (cm)	V(pF2)-V(pF4.2) (cm)	Maximum available moisture (cm)
		1	2	3.4	4.2					
Banagi 3	0- 15	46.0	38.6	29.0	20.1	1320	<0.02			
	15- 45	47.9	46.0	44.2	34.6	1260	0.06			
	45- 70	50.5	47.3	43.4	34.6	1260	0.06			
	70-100	51.3	48.6	40.8	33.8	1250	0.04			
Banagi 4	2- 15	47.8	43.4	34.5	24.7	1340	0.07	25	2.8	3.8
	15- 50	27.3	44.6	42.6	34.3	1390	0.07		1.0	
	50- 70	48.6	45.0	38.5	31.4	1280	0.10			
	70-100	48.6	45.2	39.9	32.1	1300	0.03			

Profile characteristics

In the topsoil of both Banagi 3 and 4, 10YR colours were encountered. At greater depths (below 50 cm), however, there was a transition to redder hues (Appendix B34, B35), probably caused by the higher organic matter content of the topsoil.

Chemical characteristics

Electrical conductivity, pH and exchangeable Na^+ were relatively high (Appendix D34, D35). At both sites lime was present almost throughout the profile. Volcanic ash deposits are presumably responsible for the high figures.

Physical characteristics

Granular size distribution: Characteristic for the sites on Nyanzian rocks was the high silt content. In the topsoil of Banagi 4, the silt content exceeded 50%; in the B2.1 horizon it was 56% (Appendix C). At greater depths, it was as follows: 15-50 cm, 27%; 50-70 cm, 32%; 70-100 cm, 37% and 100-130 cm, 35%. The clay content was highest in the B2.2 horizon (15-50 cm): 58% and gradually decreased to 47% in the subsoil. A high silt content can be caused by both a large amount of fresh volcanic material and a large contribution of weathering products of Nyanzian schists to the solum. For this reason, the relation between silt content and the presence of volcanic deposits was not valid in this area.

Infiltration rates and depth of penetration: At site Banagi 4 the infiltration rate was 0.8 cm/h. In the fifth hour, the depth of penetration was 45 cm (Figure 37).

Moisture retention and availability: Moisture retention characteristics for the topsoil (0-15 cm) were favourable at both sites. The difference in

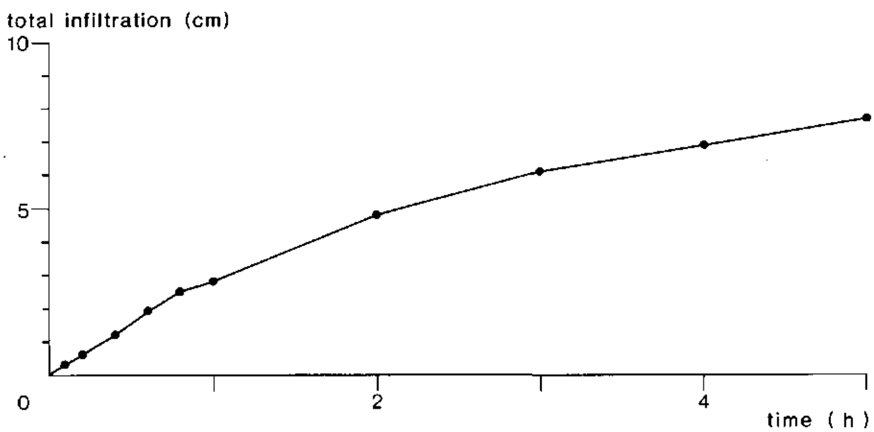


Figure 37. Infiltration characteristics for Banagi 4. Depth of penetration after 5 h was 45 cm.

volume fraction of water between pF2 and pF4.2 was about 18. However, less favourable conditions in the subsoil and a rather shallow depth of moisture fluctuation resulted in a low maximum available moisture figure at Banagi 4 (Table 12).

With correction for swell and shrinkage, bulk density was 1650 (15-50 cm), 1610 (50-70 cm) and 1430 kg/m^3 (70-100 cm). This decrease with depth suggests an increase in relatively fresh volcanic material.

As would be expected from the low available moisture, Banagi 3 and 4 were under grassland; especially long grass species like *Pennisetum mezianum* and *Digitaria macroblephara* are common.

Diagnostic horizons

Usually, soils underlain by slightly dissected pediplains on Nyanzian rocks have a mollic epipedon and a natric horizon. For classification see Chapter 9.

Soil erosion

Clear evidence for soil erosion in this area was not noticed. Certainly, slightly eroded wildlife tracks and some sheet wash were observed, but they did not give rise to serious problems.

3.5.9 Slightly dissected pediplains on Tertiary volcanics (Map Unit 5.2.3)

The Tertiary volcanics cover the early Miocene planation surface on granite rocks. Two sites were described: Lamai 1 and 2, situated on a ridge and ridge slope respectively (Appendix B55, B56).

Hardened plinthite lay under the shallow to moderately deep ridge soils. The hardened plinthite did not contain gravel and was softer than the plinthite over the older pediplains. At the Lamai site, it covered trachytic phonolites. On top of the plinthite, both angular and somewhat rounded gravel was found, probably derived from quartz veins in the surrounding gneisses.

Dense *Rhus natalensis* thickets were found at this site.

The slope soils were heavy-textured, dark grey and very gently sloping. They lay on angular phonolyte gravel. Sodium strongly predominated in the saturation extract and exchangeable Na^+ was rather high (8-14%). Cation-exchange capacity of subsoil reched 440 mmol/kg. Volcanic deposits, apart from the lavas, had probably influenced the soils.

Locally *Balanites aegyptiaca* trees (characteristic for alkaline soils) were found. The grass vegetation was dominated by *Themeda triandra* and *Sporobolus fimbriatus*.

3.6 SOIL AND VEGETATION

3.6.1 Distribution of woodland and grassland

Figure 25 helps to explain distribution of woodland and grassland. Well to moderately well drained soils, having a favourable infiltration rate as well as good depth of penetration were under woody vegetation. Togoro 1 was an exception. Nearly all sites were under woodland, except for a number of ridge slopes that did not meet the criteria (infiltration rate > 2.5 cm/h and depth of penetration > 50 cm). Usually they were finer textured than the ridge soils, which were under long grass.

In the Western Corridor, it was suggested that deposition of volcanic ash had influenced physical conditions, leading to lower available moisture. As a result, potential woodland may have reverted to grassland. These processes were not so important in the Northern Extension. This point is emphasized for the Rhino Mbali Pali area in relation to elephant damage (Section 6.6.2).

For the Northern Extension, there was no evidence that soil conditions had changed. So if trees were pushed down by elephants, it would not be soil conditions that possibly prevented re-establishment of woody vegetation.

Locally, at sites on Nyanzian schists, regeneration of woody vegetation may be hampered by a surface sealing.

3.6.2 Distribution of woodland species

As clear a picture as for the Western Corridor cannot be given for the Northern Extension. There were many similarities, however. *Acacia drepanolobium* was usually found in poorly drained periodically waterlogged soils. *Acacia clavigera* was most numerous in well drained soils, and *Balanites aegyptiaca* was limited to imperfectly drained slightly alkaline soils. The distribution of species like *Acacia senegal*, *Acacia hockii* and *Acacia gerardi* did not seem to be determined by soil conditions only, since they were rather similar for the three species. The boundary between the association of *Combretum molle* and *Terminalia mollis* and that of *Acacia clavigera* (Herlocker, 1976) could not be explained by a change in soil conditions either.

Herlocker states that 'the *Acacia* woodlands have replaced evergreen to semi-deciduous bushland, just as *Combretum molle* and *Terminalia mollis* woodland has replaced evergreen forest, the successional communities being the most fire resistant'.

3.6.3 Distribution of grassland species

Long grasses predominated by far, because of favourable moisture conditions. Short grassland occurred only on the 'termite moundline soils' in the northwestern part of the Serengeti Park (Section 6.10).

Themeda triandra is the common grass in the Northern Extension, especially on the finer textured imperfectly to moderately well drained soils, although also sometimes on well drained soils (Lamai 1, Togoro 4). *Eustachys paspaloïdes* was widest distributed in the Togoro-Bololedi area on well drained soils. On poorly drained soils, *Pennisetum mezianum* and to a smaller extent *Themeda triandra* were present under *Acacia drepanolobium* woodland. *Digitaria macroblephara* was not limited to particular soils. McNaughton (pers. commun.) explained the increase of *Themeda triandra* grassland in the northwest at the expense of *Hyparrhenia* grassland as a result of reduction in tree cover. However, *Themeda triandra* was often limited to the clayey and loamy soils and to a much smaller extent the transition towards sandy soils. On the sandy soils, *Loudetia* and *Hyparrhenia* species were dominant.

3.7 Wildlife distribution in relation to soil and vegetation

Populations of animals were seasonally high on the ridge slopes of the 'Older pediplains', for instance wildebeest migrating to the Masai Mara Game Reserve in Kenya. Contents of P and Ca in dry matter of these *Themeda triandra* grasslands were 2.5 and 5.0 g/kg respectively, resulting in a Ca/P ratio of 2 (average for 11 samples), the minimum calcium content required by wildebeest during maximum milk production being 4.3 g/kg (Section 2.7) and the mass ratio of Ca/P not lower than 1. There was also sufficient in the Bololedi-Togoro area, where P and Ca in *Themeda triandra* were 3.1 and 4.7 and in *Digitaria macroblephara* 5.5 and 5.7 g/kg (Table 9). The supply was also sufficient for other wildlife. Calcium contents were more favourable than in the *Chrysochloa orientalis* grasslands of the Western Corridor. The relatively high calcium content in the grass of the Bololedi-Togoro area was surprising in relation to the low calcium contents of the saturation extracts.

4 Landscape of the Fringe of the Serengeti Plain

4.1 INTRODUCTION

The Fringe of the Serengeti Plain was distinguished from the Northern Extension and the Western Corridor by ash cover and geomorphological features. Volcanic deposits had influenced the soils to a greater extent than in the Northern Extension, so distinction was mainly chemical. The Fringe consists essentially of dissected pediplains resulting in a sequence of ridge, ridge slope and valley bottom, whereas the Western Corridor is a complex of large undissected plains and hill ranges with a much less intricate drainage system, so distinction was physiographic, and based on the analysis of aerial photographs.

4.2 GEOLOGY

Crystalline rocks

The soils of the Fringe lie entirely on granitic and gneissic basement rocks. During the Mozambiquian orogeny, some of the granites were metamorphosed and recrystallized into gneisses with a decreasing intensity towards the west. Granitic rocks range in type from coarse biotite leucogranite to more mafic biotite granite (Macfarlane, 1968).

Superficial deposits

Since the Fringe is relatively close to the volcanoes of the Ngorongoro Highlands, the impact of the ash deposits is more pronounced than in the Northern Extension. The underlying granitic rocks are very resistant to weathering, as indicated by the presence of many kopjes consisting of huge boulders. So 'rock drainage' (Section 10.3) is poor and weathering processes proceed at a slower speed than in the Northern Extension.

With increasing thickness of the ash deposits, the nature of the rock becomes less important. In the Seronera area where outcropping kopjes are common, much coarse sand is found in the profile and on the surface, whereas in the Larale Medungi area the kopjes have been buried by ash and coarse quartz sand is absent. So there are areas within the Fringe where weathering products of bedrock, in particular coarse sand, contribute to the solum. In other areas, the solum exclusively consists of volcanic deposits and its weathering products.

4.3 GEOMORPHOLOGY

The Fringe is a slightly dissected pediplain landscape. In the area south of the Western Corridor, a transition zone towards the older Cretaceous pediplain is represented by the plateau of the Itonjo Hills. The altitude of the 'Fringe pediplain' corresponds with the altitude of the early Miocene bevel (Section 10.1). The pediplain is subdivided into ridges and ridge slopes. Kopjes can be found throughout the area.

4.4 LEGEND

Landscape of the Fringe of the Serengeti Plain

6 Pediplain and pediments covered with ash on granitic rocks
- 6.1 Pediments and strongly dissected pediplain
  - 6.1.1 Gently undulating to gently rolling, shallow to moderately deep and sometimes deep, very dark grey-brown loamy soils with locally kopjes
- 6.2 Slightly dissected pediplain
  - 6.2.1 Ridges
    - 6.2.1.1 Flat to nearly level, deep, very dark grey-brown clay-loam soils
    - 6.2.1.2 Flat to nearly level, very deep, dark grey-brown clay-loam soils
  - 6.2.2 Ridge slopes
    - 6.2.2.1 Gently sloping, deep, very dark grey clay-loam and clay soils.

Features common to all landscapes

7 Stony uplands
- 7.2 Kopjes

8 Bottomlands
- 8.1 Complex deep and very deep, sandy, loamy and clayey river and depression sediments.

4.5 SOIL DESCRIPTION

Soils at five sites were fully described and 7 profiles were analysed. Three sites are situated close to the Institute (SRI-1, 2 and 3), three in the Larale Medungi area east of the Serengeti Research Institute and one in the Simiyu area south of the Corridor.

No additional data are available on the shallow to moderately deep and deep pediment and dissected pediplain soils.

4.5.1 Ridge soils (Map Unit 6.2.1)

A subdivision into deep and very deep ridge soils was made. Very deep ridge soils occurred closest to the Crater Highlands. In contrast to the deep ridge soils, they were covered with short grass (compare de Wit, 1978). Another major difference between the two soils was the presence or absence of coarse quartz sand. In the Fringe, the presence or absence of fair amounts of quartz sand correlated with the presence of kopjes emerging above the surroundings. So the sand most probably largely originates from the emerging kopjes and not from the underlying granitic rocks. Whether or not kopjes were found depended on the thickness of the ash deposits. Thus, the shorter the distance towards the source of the ash deposits, the thicker the ash deposits, the fewer kopjes emerged and the less quartz sand was to be found. Because the quartz sand is a weathering product from the emerging kopjes, one cannot conclude from a high sand content that the contribution from the underlying rock to the solum is considerable. Even a soil in first instance formed in ash deposits can contain quartz sand, as long as kopjes are found in the area. Termites mix the granitic components thoroughly with the solum.

Profile characteristics

Site SRI-1 is an example of a (moderately) deep ridge soil (Map Unit 6.2.2.1). Below 80 cm, small gravel (quartz and small unweathered rock fragments) was encountered. Close by, kopjes emerged, causing the high content of coarse and very coarse sand in the topsoil of this profile. Colour values were higher at Larale 1 (moist subsoil 10YR4/2.5 in contrast to 10YR2/2 at SRI-1), a deep to very deep ridge soil (Map Unit 6.2.2.2). An effervescent carbonate reaction was observed at a depth of 20 cm at Larale 1. In the subsoil carbonate concretions up to 8 cm were present, whereas at the well drained SRI-1 site no free carbonates were observed (Appendix B57). The characteristics of sites Larale 1 and Simiyu were very similar.

Chemical characteristics

Alkalinity of the soils at Larale 1 (Appendix D60) was very high as was exchangeable Na^+ in the subsoil. At the Simiyu site, high exchangeable Na^+ and electrical conductivity of extract were encountered in the subsoil (Appendix D63), and pH was lower than at the Larale site. The latter is probably caused by the high concentration of carbonates and bicarbonates in the saturation extract of the Larale profile. In the Simiyu area, sulphates and chlorides are the dominant anions.

If the cation-exchange capacity of the clay fraction (at pH 8.2) be taken as a criterion for the presence of non-crystalline material, the solum consists largely of this material, especially at Larale where the cation-exchange capacity increased with depth to 2.7 mol/kg. The same was true for the subsoil in the Simiyu area, where values exceeded 1 mol/kg below 85 cm. However, part of the non-clay fraction may consist of non-crystalline aggregates with a high exchange capacity. If so, the values in clay are overestimates.

An incomplete dispersion of the clay fraction during analysis of particle size distribution is not inconceivable for amorphous material and would give the same effect.

Physical characteristics

Granular size distribution: Clay content increased with depth at site SRI-1 (19.7, 28.5 and 41.8%), whereas it dropped sharply after an initial increase at the Larale site below 90 cm (Appendix C), indicating that relatively fresh ash increased at greater depths because of a decrease in weathering. In the Simiyu area, the same tendency was found (Appendix C), only the clay contents were much higher, indicating that the soils were more weathered than in the Larale Medungi area. Present rainfall is higher in the Simiyu area and weathering could have been more intensive.

Infiltration rates and depth of infiltration: Infiltration rate was 6.3 cm/h and depth of penetration 90 cm at SRI-1; values at Larale 1 were 2.4 cm/h and 50 cm (Figure 38 and 39) and at Simiyu 3 cm/h and 50 cm.

Moisture retention and availability: Only for site SRI-1 were sufficient data available for a proper estimate (Table 13). Differences in moisture content between pF2 and pF4.2 were rather small, but because of a favourable depth of moisture fluctuation, the maximum available moisture was relatively high: 7.4 cm. If depths of penetration and infiltration rates were compared it seems conceivable that the moisture availability at Larale 1 would be considerably less. For Simiyu an intermediate value would probably be found.

The vegetation was closely related with the availability of soil moisture. SRI-1 was under woody vegetation (*Acacia clavigera, Albizia harveyi*), at Simiyu a few isolated *Acacia tortilis* trees were present, and Larale 1 was under short grass. At Larale, however, infiltration rate and depth of penetration were such that they would enable woody vegetation to survive (Figure 25). Fire may have destroyed the woody vegetation on the flat ridges, thus increasing the danger of slaking and sealing (silt content of the topsoil was 34%). Such sealing could easily be broken by installing the infiltration rings, so that the values of 2.4 cm/h and 50 cm for infiltration rate and depth of penetration could be on the high side. Also, cattle, before the establishment of the Park, and later wildlife, may, because of a preference for flat ridges, have prevented the regrowth of woody vegetation, once it had been destroyed.

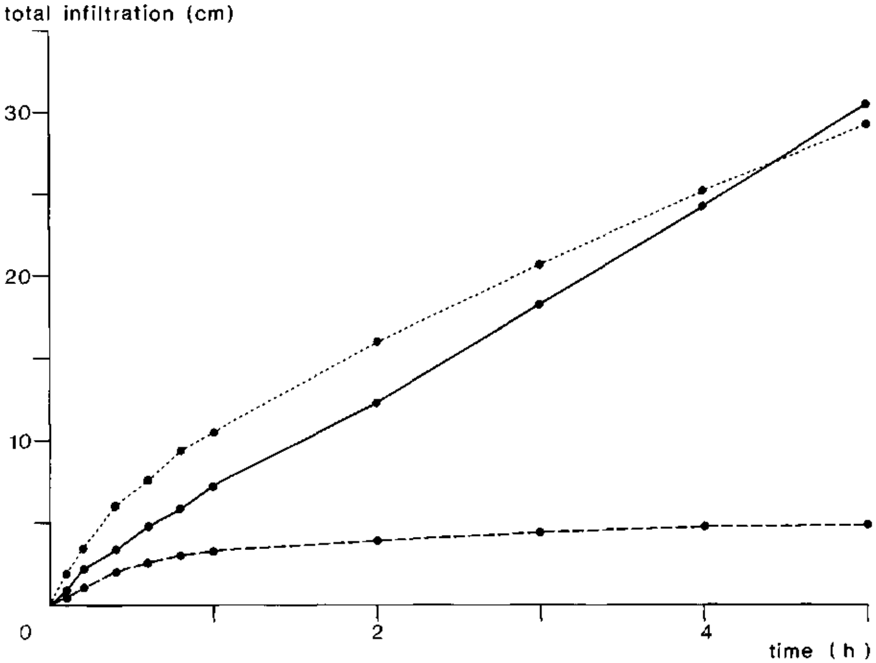


Figure 38. Infiltration characteristics for 3 sites in the area of the Serengeti Research Institute (slightly dissected pediplain): SRI-1 (———), SRI-2 (-----) and SRI-3 (·······). Depth of penetration after 5 h was 90, 25 and 45 cm, respectively.

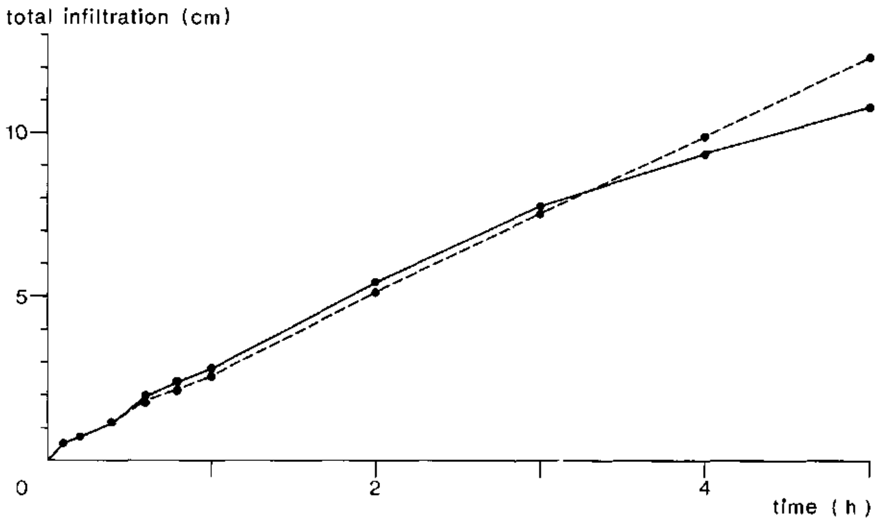


Figure 39. Infiltration characteristics for 2 sites in the Larale Medungi area (slightly dissected pediplain): Larale 1 (-----) and Larale 2 (———). Depth of penetration after 5 h was 50 and 35 cm, respectively.

Table 13. Moisture retention, maximum available moisture, bulk density and coefficient of linear extension for four slightly dissected pediplain soils.

	Depth (cm)	Volume fraction of moisture (%) pF				Bulk density (kg/m^3)	Coefficient of linear extension	Maximum depth of fluctuation in moisture (cm)	V(pF2)-V(pF4.2) (cm)	Maximum available moisture (cm)
		1	2	3.4	4.2					
SRI-1	0- 9	37.1	22.0	20.3	14.3	1530	<0.02	100	0.7	>7.1
	9- 30	44.9	26.5	22.0	16.4	1400	<0.02		2.1	
	30- 80	44.5	27.5	23.9	18.9	1350	<0.02		4.3	
SRI-2	0- 9	39.0	34.4	30.1	15.7	1510	0.03	20	1.7	2.4
	9- 19	42.4	35.9	35.1	28.4	1440	0.04		0.7	
	19- 33	45.2	38.9	27.4	26.0	1300	0.05			
	33- 80	47.2	39.0	32.7	26.0	1250	0.03			
	>80	45.0	35.0	34.5	31.0	1270	0.02			
SRI-3	0- 6	44.4	44.3	24.8	18.2	1320	0.08	50	1.6	6.2
	6- 42	46.2	44.0	41.8	33.0	1310	0.06		3.9	
	42- 67	46.7	43.2	40.8	34.7	1330	0.05		0.7	
	67- 87	48.4	42.6	36.6	28.6	1270	0.05			
	87- 40	46.2	36.8	36.3	29.1	1310	0.02			
Simiyu	0- 12	46.8	36.7	.	18.1	1220	0.03	50	2.2	7.7
	12- 25	47.1	36.2	.	19.9	1250	0.02		2.1	
	25- 55	49.8	47.8	.	34.0	1190	0.09		3.4	
	55- 85	53.1	50.5	.	36.0	1210	0.06			
	85-110	52.0	46.2	.	33.3	1180	0.02			
	110-130	49.7	43.2	.	27.9	1220	<0.02			

Diagnostic horizons

Usually there were a mollic epipedon and an argillic horizon. For classification see Chapter 9.

Soil erosion

On the ridge soils, there was little evidence of erosion. That material had been transported was shown by the high concentrations of coarse sand around kopjes.

4.5.2 Ridge slope soils (Map Unit 6.2.2)

Two sites were described downhill of the ridge sites (SRI-1 and Larale 1): SRI-2 and Larale 2.

Profile characteristics

Prismatic structures were common in the ridge slope soils. Usually free carbonates were found below 20 cm because of poor infiltration. In the Larale Medungi area, the carbonate content of the slope soils had presumably been influenced by the high nutrient content of the run-off water from the ridges.

Chemical characteristics

High exchangeable Na^+, pH and electrical conductivity of extract were characteristic for the ridge slopes of the Fringe of the Serengeti Plain. At site Larale 2, electrical conductivity exceeded 4 mS/cm (saline) and increased to 13 mS/cm below 70 cm. The deeper subsoil was extremely alkaline too, with EC_e exceeding 75 mS/cm. Further west, chemical conditions were more favourable but alkalinity remained very high. Even easily soluble salts like chlorides and sulphates were present in high concentrations in the saturation extract of the Larale samples (Appendix D61).

Physical characteristics

Granular size distribution: Below 9 cm the clay content at the poorly drained site SRI-2 remained uniform, while below 30 cm the silt content increased to 35%. Below 14 cm at Larale 2, the silt content increased and the clay content decreased. As expected, higher silt contents were present in deeper horizons because of slower weathering. The very high silt content of the Larale topsoil (41%) was probably a result of both clay eluviation and a fresh silt supply from on the ridge (Larale 1).

Infiltration rates and depth of penetration: Infiltration characteristics at Larale 2 were more favourable than at SRI-2. The infiltration rate was 1.5 cm/h and depth of penetration 40 cm at Larale 2; values at SRI-2 were 0.1 cm/h and 22 cm (Figure 38 and 39). The higher values at Larale 2 were caused by differences in soil structure.

Moisture retention and availability: Data were available only for SRI-2. Maximum available moisture was low, 3.8 cm (Table 13), so the site was under short grass. Despite the salinity and alkalinity, dense woody vegetation was present around the Larale site (*Commiphora trothae* and *Acacia tortilis*).

Infiltration rate and depth of penetration were not favourable either. However, the water supply was abundant, since run-off would be received from up the ridge.

Herlocker (1976) stated incorrectly that the soils of the *Commiphora* woodland in this area were derived from granite and granitic gneisses. Volcanic ashes have contributed greatly.

Diagnostic horizons

At all sites, there were a mollic epipedon and an argillic or natric horizon. For classification see Chapter 9.

Soil erosion

Material had been redistributed especially on the ridge slopes with a low infiltration rate (SRI-2). The sand cover mainly resulted from supply from the ridges and to a lesser extent from removal of clay, leaving behind the coarser fractions.

4.6 ORIGIN OF QUARTZ SAND

A few short remarks need to be made on the presence of quartz sand in the landscape of the Fringe of the Serengeti Plain. The sand was encountered in fair amounts in areas where kopjes emerged above the surroundings. At the SRI sites at two dates, five months apart, before and after the long rains, the coarse sand (> 1.7 mm) at the surface of two sites, 1 metre square, was removed and weighed.

	1976-01-28	1976-06-25	Mass fraction > 1.7 mm in topsoil (g/kg)
SRI 1	560 g	287 g	133
SRI 2	674 g	617 g	150

Observations revealed that already after a few heavy showers, it was difficult to distinguish the plots where the surface sand had been removed from the surroundings.

The main process responsible for the sand cover was transport downhill. After 5 months, the initial value of 674 g/m^2 was almost reached again at site SRI-2. If removal of the finer fractions caused the establishment of the sand cover, much higher values would have expected initially. During heavy showers (rainfall rates exceeding 100 mm/h have been measured), one can see the sand being carried over the surface. Possibly the values for 1976-06-25 had been reached much earlier.

Other evidence for the hypothesis that the coarse sand had derived from the kopjes and not from the underlying bedrock was the decrease in coarse sand content with depth (Appendix D57 and D58).

Quartz sand and carbonate concretions were not separated in the coarse material fraction. However, by visual observations there was a clear to abrupt change in coarse sand content between top and subsoil in deep soils.

At Larale Medungi, there was much less coarse sand (Appendix D60 and D61) and the coarse material usually consisted of very small to medium-sized carbonate concretions, especially in the subsoil.

In a deep soil such as Simiti 2, in the Kirawira area (Chapter 5), there was much pink quartz sand, decreasing sharply with depth (coarse material values given in Appendix D31 increased with depth, because of the sharp increase in carbonate concretions). Perhaps the same processes were involved as in the Fringe. If the soils were moderately deep to shallow, however, the bedrock could become a major supplier of coarse sand to the solum.

5 The Kirawira area

The Kirawira pilot area is a cross-section through the western part of the Western Corridor around Kirawira (Figure 1, Map A). This area is more diverse in landscapes, soils, vegetation and wildlife than the Rhino Mbali Pali area (Chapter 6).

5.1 CLIMATE

Total annual rainfall was about 950 mm with two prominent peaks, one around December and one around April, resulting in an excess of rainfall above evaporation in December and from March to May (Figure 4; Norton-Griffiths et al., 1975). According to Thornthwaite's climatic classification, this area is called semi-arid (Thornthwaite index -15, Figure 4).

5.2 GEOLOGY

The Kirawira area is intersected by the Simiti Hills, a range consisting mainly of iron-rich meta-cherts and jaspillite of Nyanzian (Precambrian) age, reaching a height of about 1500 m. To the north and south of the range lie extensive plains, predominantly on granites, which are recognizable on the aerial photographs as elliptic shields, derived from the joint pattern, emerging a little above the surroundings and thus influencing the drainage pattern. Areas not showing these typical patterns must lie on Nyanzian rocks, which were found where checks could be made. However, on the lower pediments, the solum proved too deep to check the nature of the bedrock.

The nature of the underlying bedrock was an important criterion in the legend, since soils underlain by jaspillites meta-cherts and other Nyanzian rocks have different chemical and physical properties, resulting in dark reddish-brown colours of the soils in contrast to the dark grey colours on granitic rocks.

The detailed study area had been covered with alkaline volcanic deposits from the volcanoes of the Ngorongoro Highlands, about 200 km south-east of Kirawira. Accumulation of volcanic deposits were found especially on the plains. At the Mbalageti River, ash deposits had a thickness of over 2 m in places. Analysis indicates that the ashes were part of the Upper Ndutu beds (Hay, 1976, and pers. commun.), from an eruption of Oldoinyo Lengai about 40 000 years before present (Chapter 8). This is confirmed by dating of a fossil rhino skull from just below the ash (M.D. Leaky, pers. commun.). The upper layers had supposedly been influenced by the more recent Plain ashes as well (Section 8.4).

5.3 GEOMORPHOLOGY

The greater part of the Kirawira area lies on remnants of the early Miocene erosion bevel (Section 10.1): Dutwa Plain, Kirawira and Nangangwe Plain. Hilltops of the Simiti Hills are reckoned to be remnants of the late Cretaceous erosion surface. At many sites around Kirawira and at Dutwa Plain and Nangangwe Plain, well rounded gravel has been found over the rock surface, indicating that the formation of these plains was influenced by lateral planation by streams. According to Handley (1969) this is one of the two main pedimentation processes, the other being weathering and removal of debris by rill wash and unconcentrated flow.

In the legends of the reconnaissance and detailed soil maps, the remnants of the early Miocene planation surface were called pediplains, since they probably result from backwearing rather than downwearing, as would be expected from the sequence hilltop, hillslope, upper pediment and lower pediment. However, downwearing cannot be fully excluded.

A subdivision of the pediment into an upper and a lower pediment was made, because there were great differences between the soils of the two parts. According to the definition given by Ruhe (1975), pediment slopes are transport slopes and the overlying soils shallow to moderately deep. Often the soils of the upper pediment lie on hardened plinthite, thus obscuring the bedrock. In a few cases, it was observed that the plinthite lay on the bedrock.

In the detailed study area, the pediment soils are underlain by Nyanzian rocks (Figure 40), which are more susceptible to weathering. If the slopes are very gentle (lower pediment and part of the upper pediment) deep to very deep (> 4 m) soils develop; if the slopes are gently sloping to sloping,

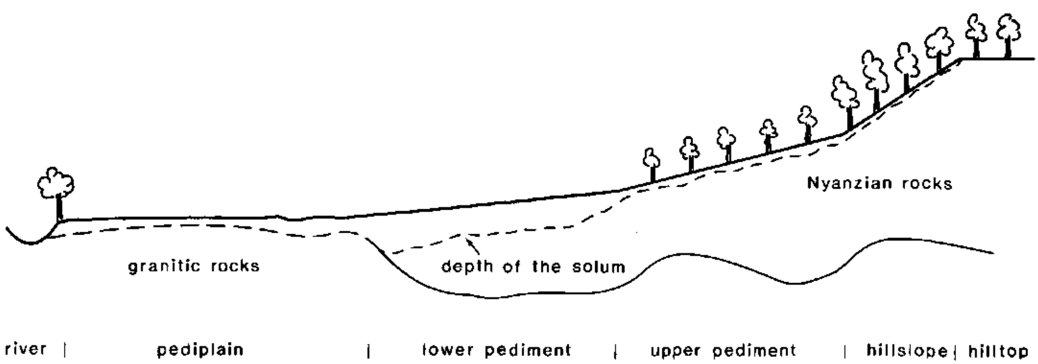


Figure 40. Schematic topsection of the area between Simiti Hills and Grumeti River with the assumed boundary between granitic and Nyanzian rocks.

moderately shallow to shallow soils (upper pediment) develop. Possibly the deep soils are still present because of the quicker weathering and because of relatively favourable physical characteristics (infiltration rate and depth of penetration), so limiting run-off and erosion. The contribution of the volcanic sediments to the solum of the lower pediments was also more substantial.

Further downhill, remnants of the early Miocene erosion bevel were still present, either in granite or in Nyanzian rocks overlain by hardened plinthite. There was, however, one exception (Map Unit 4.2.1), perhaps because the composition of the underlying Nyanzian rock differed from the 'typical' Nyanzian rock.

Due to slow weathering of the bedrock and high run-off, the soils on the early Miocene erosion surface were relatively shallow. Obviously, the greatest part of the early Miocene bevel, originally present in Nyanzian rocks, had been broken down by more recent pedimentation. According to Howard (1942; quoted by King, 1976), a 'pediment should be considered an erosion surface that lies at the foot of a receded slope, with underlying rocks or sediments that also underlie the upland, which is barren or mantled by alluvial sediment', and which normally has a concave upward longitudinal profile. Because the granitic rocks form intrusions in the older Nyanzian rocks, it is possible that after a long period of backwearing, granitic rocks would underlie the solum and pediments would become granitic pediplains (Figure 40).

Despite the presence of considerable ash deposits (implying sedimentation), the terms pediplain and pediment (implying erosion) were maintained.

5.4 SOIL DESCRIPTION

Five different soil groups are distinguished (Map A). Of these the upper and lower pediment soils, and pediplain and pediplain slope soils will be discussed in more detail.

5.4.1 Upper pediment soils

Subdivision:	A 2.1.1	Sloping, shallow, reddish-brown loamy soils with a petroferric contact
	A 2.1.2	Gently sloping, shallow to moderately deep, reddish-brown loamy soils, often with a petroferric contact
	A 2.1.3	Gently sloping, deep, reddish-brown loamy soils without a petroferric contact.

The shallow and shallow to moderately shallow soils were brown to reddish-brown and lay on hardened plinthite, in turn underlain by iron-rich

Nyanzian rocks. The hardened plinthite includes many angular jaspillite and phyllite fragments.

The deep (at least several metres) very gentle sloping upper pediment soils were also brown to reddish-brown (7.5 YR 4/4 to 5 YR 4/6) and lay on iron-rich Nyanzian rocks as well. Hardened plinthite was absent. The soils were loamy and usually moderately well drained. Here and there on the surface was coarse reddish sand containing ferruginous phyllite and jaspillite, which suggests periodic high run-off that had transported the coarse sand over the compact surface. The sand veneer is attributed to transport of sand more than to removal of fine fractions.

5.4.2 Lower pediment soils

Subdivision:	A 2.2.1	Nearly level, very deep, brown clay soils (Kirawira 4 and 5)
	A 2.2.1	Nearly level, very deep, black to dark brown swelling clay soils (Simiti 1).

Profile characteristics

Lower pediment soils were deep and clayey, and in this area lie entirely on Nyanzian rocks. One augering at Kirawira 5 reached a depth of over 5 metres. Because of the presence of hard purple carbonate concretions the auger went no deeper. Slopes of the lower pediment soils were about 1%, or even less. The B horizon was prismatic or columnar. Differences in colour and texture of the topsoil related to differences in soil slope, which was somewhat gentler for the black to dark brown swelling clay soils (Simiti 1). The subsoil of the two types was similar in colour. Section 10.3 gives possible explanations for the difference in colour between topsoil and subsoil. Carbonate concretions were present in the subsoil of both soil types.

Chemical characteristics

Profile Kirawira 5 had higher pH (extract), higher exchangeable Na^+ and lower cation-exchange capacity than profile Simiti 1. Electrical conductivity of extract was higher in Simiti 1, especially in the subsoil, because of a large supply of nutrients (standing water after heavy showers). At Kirawira 4 (wooded depression with an outlet in Map Unit A 2.2.1) conductivity, pH (extract) and exchangeable Na^+ were significantly lower than for Kirawira 5, because of differences in physical characteristics. In all soils traces of nitrate were found, indicating the presence of termites, as confirmed by the profile descriptions.

Physical characteristics

Granular size distribution: For the reddish-brown lower pediment soil (Kirawira 5), clay content was almost uniform throughout the profile (56 to

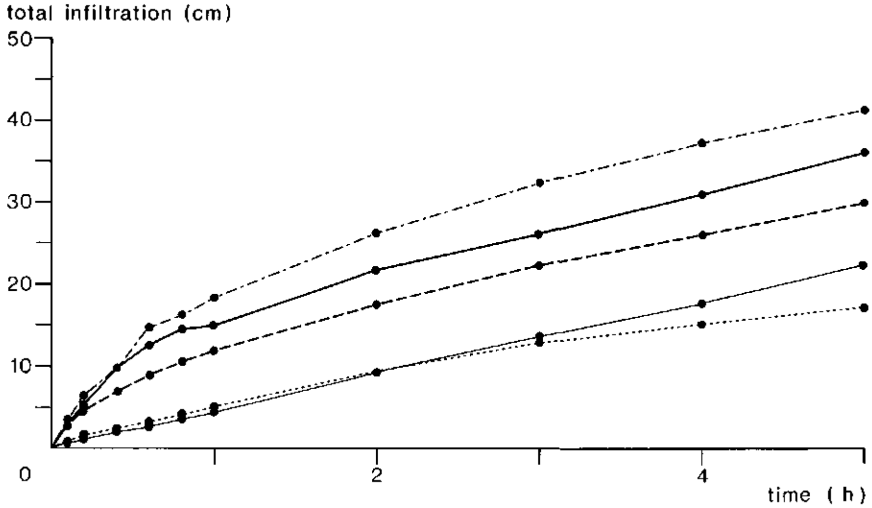


Figure 41. Infiltration characteristics for 2 lower pediment sites: Kirawira 4 (———) and Kirawira 5 (---------); and 3 pediplain slope sites: Kirawira 3 (– – – –), Kirawira 7 (–·–·–·) and Kirawira 8 (———). Depth of penetration after 5 h was 60, 35, 45, 50 and 90 cm, respectively.

59%), except for the thin A1 horizon (sandy loam).

Infiltration rates: Unfortunately no infiltration rates are available from Simiti 1, but they seemed greater than at Simiti 2. At the time of excavation of the pit, however, after a rainy period, the top 50 cm was moist, compared to 10 cm at Simiti 2 in the granitic pediplain, excavated at the same time. The depth of infiltration at Kirawira 5 was 35 cm in 5 hours. At Kirawira 4 (woodland) and 5 (grassland) the infiltration rate in the fifth hour was 4.7 cm and 2.2 cm, the depth of penetration being 60 and 35 cm (Figure 41), respectively.

Many nodules (round iron-maganese concretions, with a diameter of about 3 mm) at Kirawira 5 also suggested a periodic excess of water due to the hardly permeable columnar B horizon and a high iron and manganese supply from the hinterland.

The deep black clay soils were flooded periodically in the wet season by back-ponding, so the soils were poorly drained despite a reasonable infiltration rate. Moisture content at different moisture tension was not determined for the lower pediment soils.

5.4.3 Pediplain soils

Subdivision: Pediplain on granitic rocks

A 3.1.1 Moderately deep to deep, dark grey clay-loam soils (Kirawira 1, 6; Dutwa 1 and Simiti 2)

Pediplain on Nyanzian rocks

A 3.2.1 Shallow, reddish-brown loamy soils with a petroferric contact (Kirawira 2)

A 3.2.2 Moderately deep to deep, reddish-brown clay-loam soils.

Profile characteristics

Pediplain soils on granite extended over most of the sample area. In the centre of the granitic shields, soils were shallow and rock even outcropped; towards the edges, the soils became gradually deeper (Simiti 2). All these soils had 10 YR 2/2 to 5/3 colours, a more (Kirawira 1) or less (Dutwa 1) developed natric horizon, and carbonate concretions in the subsoil. They contained fair amounts of 'granitic' sand (a mixture of purple and clear quartz), usually decreasing with depth, by vertical transport of clay and surface wash (Section 4.6).

Profile characteristics of pediplain soils on Nyanzian rocks are much like those on granite, except for colours (7.5 YR 3/2 to 3.5/4), which was due to by a difference in 'drainage' through the underlying rock (Section 10.3). Near Kirawira, a petrocalcic horizon (kunkar) was exposed here and there. This horizon resulted from soil genesis in the solum derived from carbonate-rich metamorphous rocks. Petrocalcic horizons were never encountered on granitic rocks.

The pediplain soils on granitic or Nyanzian rocks must have been partly derived from the same parent material, since there were relatively high amounts of coarse quartz sand at both sites.

Both the soils lay on very well rounded quartz gravel (relict flood plain). However, Kirawira 1 contained somewhat more coarse sand, so the original topsoil (alluvium and volcanic deposits) must have been mixed with weathering products of the bedrock.

Chemical characteristics

Pediplain soils on granite were highly alkaline and in the saturation extract had high electrical conductivity and pH, especially Dutwa 1 (Appendix D27). Yet trees were still found (*Balanites aegyptiaca*) at that site.

Pediplain soils on Nyanzian rocks were less alkaline and saline, because of better internal drainage.

Physical characteristics

Granular size distribution: At Kirawira 1 on granite and 2 on Nyanzian rock, clay content increased with depth. However, on Nyanzian rocks, clay content was much higher and ranged from 38% in the topsoil to 53% in the bottom horizon (35-68 cm). At comparable depths, clay content at Kirawira 1 was 10 and 27%, respectively. The silt contents were similar and almost uniform with depth, so that subsequently the sand content in the granitic pediplain soil is higher. This is explained by the high quartz content of the granitic rocks. In the deeper granitic pediplain soil (Dutwa 1) clay content increased from 17 to 47% (at *100* cm). The *silt* content *of* the subsoil was much higher than in the topsoil (Appendix C), suggesting the presence of more volcanic deposits than at the shallow Kirawira 1 site.

Infiltration rates and depth of penetration: Infiltration rates were very low for the soils on granite: from 0.2 cm/h at Kirawira 1 to 0.4 cm/h at Dutwa 1 (Figure 42). On Nyanzian rocks, a much better rate was found: about 2.6 cm/h in the fifth hour (Figure 42). The same is true for the depth of penetration after 5 h of infiltration, which was about 35 cm on granite and more than 70 cm on Nyanzian rocks. The low infiltration rates were caused by the weak prismatic to columnar structure of the B2 horizon. After swelling of these elements, the subsoil almost completely sealed off.

Moisture retention and availability: 'Granitic' pediplain soils retained little moisture and had low maximum available moisture (Table 14). Since the depth of moisture fluctuation was not known, depth of penetration was used for calculating the maximum available moisture (Chapter 7). Kirawira 2 ('Nyanzian pediplain soil') undoubtedly had a more favourable moisture regime.

Bulk density showed the same trend as in the rest of the Western Corridor: values decreased with depth. The same explanation, a decrease in weathering with depth, would apply here too.

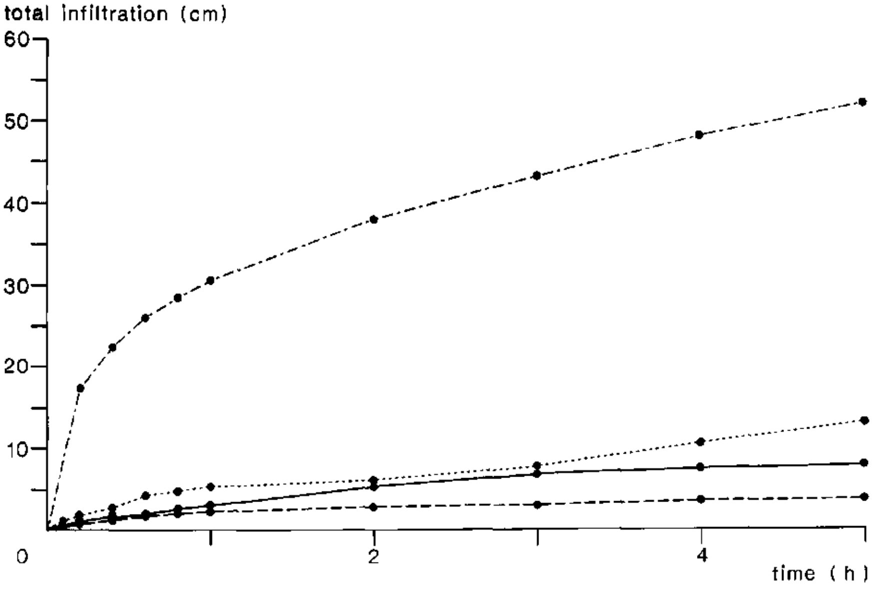


Figure 42. Infiltration characteristics for 3 pediplain sites: Kirawira 1 (– – – – –), Kirawira 2 (·········) and Dutwa 1 (————); and 1 bottomland site: Dutwa 3 (–·–·–). Depth of penetration after 5 h was 34, >70, 40 and 70 cm, respectively.

Table 14. Moisture retention, maximum available moisture, bulk density and coefficient of linear extension for two pediplain soils (Kirawira 1, Dutwa 1), one pediplain slope soil (Kirawira 3) and one bottomland soil (Dutwa 3).

	Depth (cm)	Volume fraction of moisture (%) pF				Bulk density (kg/m^3)	Coefficient of linear extension	Maximum depth of fluctuation in moisture (cm)	V(pF2)-V(pF4.2) (cm)	Maximum available moisture (cm)
		1	2	3.4	4.2					
Kirawira 1	0- 5	29.5	23.2	11.6	10.4	1690	<0.02	35	0.6	4.1
	5- 29	34.6	29.0	19.7	17.8	1700	<0.02		2.7	
	29- 55	38.3	38.0	32.7	23.8	1620	<0.02		0.8	
Kirawira 3	0- 30	36.0	31.9	22.1	11.2	1630	<0.02	45	6.2	9.6
	30- 50	37.2	34.8	23.2	11.7	1550	0.03		3.4	
	50-100	41.7	38.6	24.0	14.6	1460	0.03			
	>100	40.7	38.0	31.6	18.3	1420	0.04			
Dutwa 1	0- 20	31.3	21.6	17.1	17.0	1730	<0.02	40	0.9	3.1
	20- 40	39.8	38.4	34.0	27.6	1520	<0.02		2.2	
	40- 60	42.0	38.9	38.8	28.8	1470	<0.02			
Dutwa 3	0- 10	49.5	43.4	38.4	29.9	1350	0.04	70	1.3	12.7
	10- 75	51.4	48.7	37.7	29.7	1270	0.08		11.4	

5.4.4 Pediplain slope soils

Subdivision:	A 4.1	Gently sloping, moderately deep, grey clay-loam soils with erosion steps
	A 4.2	Very gently sloping, deep to very deep, grey clay-loam soils (Kirawira 3, 7 and 8)

Pediplain slope soils occupy the area between the pediplains and the drainage lines. Erosion is more important than sedimentation, leading to very sandy topsoils. Sometimes even outcropping gravel, elsewhere underlying the pediplain soils, is transported downhill. On the reconnaissance-scale soil map, the pediplain slope soils are marked as pediplain soils (Mapping Unit 2.1.3 and 2.1.4, depending on the depth of the solum).

Profile characteristics

Only profile descriptions of the very deep pediplain slope soils are available. In general these soils are comparable with the pediplain soils underlain by granite, except that they are much deeper. At Kirawira 3 at a depth of 460 cm, the augering was severely hindered by the presence of much dry coarse quartz sand, making further progress impossible. Prismatic B horizons are widespread (Figure 43).

Chemical characteristics

There was much similarity between the chemical characteristics of the 'granitic' pediplain soils and the pediplain slope soils. Only the characteristics of Kirawira 8 differed because of past termite activity. Here exchangeable Na^+ was significantly lower (Appendix D21, D25 and D26), while the nitrate content was considerably higher. Traces of nitrate were detected at all depths.

Physical characteristics

Granular size distribution: No accurate mechanical analysis was carried out on pediplain slope samples.

Infiltration rates: Infiltration rates were higher than in pediplain soils: about 4 cm/h and on an old termite mound about 6.5 cm/h. This difference was due to a clearly developed prismatic B horizon in the soil not influenced by termites. Depth of penetration ranged from about 50 cm at Kirawira 3 and 7 to 90 cm at Kirawira 8 (Figure 41).

Moisture retention and availability: Kirawira 3 had a much higher maximum availability of moisture than the pediplain soils underlain by granites (Table 14). Both the depth of penetration and the difference in moisture content between pF2 and pF4.2 were higher. Moisture availability was most likely overestimated, since moistening of the prisms was very slow and therefore available soil moisture in the topsoil would be less than expected.

Figure 43. Strong, very coarse prismatic structures in the topsoil of pediplain slope soils.

Characteristic for the pediplain slope soils is the presence of a continuous coarse sand (sometimes even gravel) veneer on the surface as a result of the high run-off.

After heavy showers, the run-off from the surrounding pediplains was enormous. Despite it and the reasonable infiltration, the whole area was occasionally flooded, hampering tree growth (shortage of oxygen) and favouring (long) grassland. At somewhat higher locations *Balanites aegyptiaca* trees were present (Figure 44). Soil alkalinity and perhaps burning could also have played a role in establishing the present distribution of vegetation. However, periodic flooding was considered to be most important.

5.4.5 Bottomland soils

Subdivision:	River and depression sediments	
	A 5.1.1	Dark grey loamy soils
	A 5.1.2	Black clayey soils
	A 5.1.3	Dark grey to black loamy and clayey soils
	Flood plain sediments	
	A 5.2.1	Black clayey soils
	A 5.2.2	Grey to black loamy and clayey soils

Figure 44. Balanites aegyptiaca browsed by giraffe on a flooded pediplain slope.

Figure 45. Bottomland under *Acacia drepanolobium* near Kirawira.

Loamy river sediments are present as river levees around present or former rivers, mostly under riverine forest. The clayey sediments (Map Unit A 5.1.2) occur in depressions and backswamps. If distinction was difficult, loamy and clayey soils were taken together in a complex unit.

Flood plain alluvium is widespread in the northwestern part of the sample area; this area is often flooded in the wet season. It consists of an intricate system of creeks. For simplicity, most of it has been named as one complex unit, although clayey soils are by far dominant. In Section 2.5.5 2 profiles from the Ndabaka Flood Plain are discussed.

The bottomlands were usually under *Acacia seyal* and *Acacia drepanolobium* and long grasses (Figure 45). Cracking clays may locally hamper establishment of trees.

5.5 DIAGNOSTIC HORIZONS

Lower pediment soils have a mollic epipedon and an argillic (black to dark brown swelling clay soils) or a natric horizon (reddish-brown clay soils).

Pediplain soils underlain by granites usually met the mollic requirements (Dutwa 1, Simiti 2), but locally the colour contrast between topsoil and subsoil was not sufficient (Kirawira 1). A natric horizon was common. Only at Dutwa 1 no prismatic or columnar horizon was observed, despite high exchangeable Na^{+}. Pediplain slope soils had either a natric or an argillic horizon and a mollic epipedon.

For classification see Chapter 9.

5.6 BIOLOGICAL ACTIVITY

Termites were ubiquitous in the Kirawira area. High termite mounds (Figure 52) built by *Macrotermes* spp. were found on the moderately well to well drained slope, upper pediment and pediplain soils (underlain by Nyanzian rocks or hardened plinthite).

Small mounds with many small chimneys built by *Odontotermes* spp. (Figure 53) are frequently observed on the moderately to poorly drained alkaline soils. *Odontotermes* mounds were found even on soils flooded for short periods (pediplain slope soils). The distribution of *Macrotermes* species and *Odontotermes* species suggests a relation with soil drainage.

One pit was excavated in an old termite mound (Kirawira 8). Results of chemical analysis and infiltration experiments were compared with those of a soil not influenced by termites (Kirawira 7). The following differences were noticed in the degraded termite mound:

- the clay content of the topsoil was significantly higher
- no clear prismatic structures could be detected
- the horizon cemented (by silica?) was at a greater depth than at Kirawira 7

- electrical conductivity of extract was much lower in the subsoil
- nitrate content was higher
- exchangeable Na^+ was lower
- infiltration rate in the 5th hour and depth of infiltration were slightly higher (Figure 41).

In summary: termite activity had destroyed the prismatic structure and increased infiltration, lowering electrical conductivity and exchangeable Na^+ in the subsoil of the old mound. The chemical composition of the topsoils was difficult to compare because of the great difference in texture. So, termites have had a favourable influence on the physical and chemical soil properties. In the Rhino Mbali Pali area (Section 6.6.1), reverse effects of termites had been encountered and the topsoil had become almost impermeable, infiltration rate 0.1 cm/h.

On ridge transects in the intermediate grasslands of the Serengeti Plain, de Wit (1978) noticed higher salt contents in fresh and old termite mounds than in their surroundings. He attributed the high salt content of the fresh mounds to biological processes in turn attributable to termites and the even higher contents of the older mounds are explained by pedogenetic processes. Strong prismatic structures such as those in the Kirawira area were absent on the ridges of the intermediate grasslands.

Thus the effects of termites depend greatly on the soil properties.

5.7 VEGETATION

Hilltops and hillslopes were covered with woodland and long grass. Since they were well drained, the most common tree was *Acacia clavigera*. The vegetation of the upper pediment was similar.

Lower pediment soils were generally entirely under grassland, the length depending mainly on available moisture, which was determined by infiltration rate and depth of infiltration. The swelling clay soils were covered with long grasses (Simiti 1) like *Pennisetum mezianum* and *Themeda triandra*, the deep reddish-brown clay soils were under medium long grassland (Kirawira 4): *Chrysochloa orientalis*.

Pediplain soils were under short grass (*Chrysochloa orientalis*), if underlain by granites (low infiltration rates), or under woodland (*Acacia senegal* and *Acacia clavigera*) if underlain by Nyanzian rocks or hardened plinthite. *Acacia mellifera* was also common on soils underlain by hardened plinthite. *Acacia mellifera* has proved to be a colonizer of disturbed soils in Uganda where it often grows after extensive overuse of land and indicates a regression from a more mesic community (Langdale-Brown et al., 1964; quoted by Herlocker, 1976). Around Kirawira on the more sandy centres of the granitic shields and also on the other pediplain soils, patches of *Sansevieria* sp. and *Acacia mellifera* were found around old termite mounds. Locally dense thickets of *Dichrostachys cinerea* were found, indicating overgrazing (Dale & Greenway, 1961).

The pediplain slopes were covered with long and medium long grass (*Digitaria scalarum, Sporobolus marginatus*). Scattered trees (*Balanites aegyptiaca*) were also present but hardly any regeneration was observed. At Simiti 1, where the soils were poorly drained despite a reasonable infiltration rate, *Acacia drepanolobium* was common.

Bottomlands were under *Acacia seyal* and *Acacia drepanolobium* and long grasses.

5.8 EROSION

Many erosive features were observed in the Kirawira area:

- Shallowness of soils on hilltops and slopes.
- Exposure of hardened plinthite on the upper pediment. Other features in this area include gullies and exposed tree roots. Overgrazing might be partly responsible for this process. The grass cover in this woodland area (*Acacia clavigera*) was locally very sparse, thus failing to hold soil particles together.
- Coarse quartz sand on the surface of granitic soils. Locally gravel, outcropping below the pediplain soils, was transported downhill the pediplain slope soils. The pediplain slopes also showed small erosional steps, possibly by soil creep and enhanced by animals (Section 6.8).
- Deep channels in the riverbanks by hippos, crocodiles and wildebeest.

Erosion depended strongly upon soil slope and the amount of water that could be stored in the soils on the upper slope. Upper pediment soils underlain by hardened plinthite could only store small amounts of water because of their shallowness. So run-off was high and the topsoil had been removed locally. Gullies had formed in the deeper upper pediment soils further downhill. The same relation existed between the pediplain and pediplain slopes. The high run-off from the pediplains has to be removed by the pediplain slopes, resulting in a surface veneer of coarse sand. It seemed easier to transport the coarse sand than to loosen the clay particles from the compact surface. Gully erosion was not common here because of the very gentle slopes.

6 The Rhino Mbali Pali area

The Rhino Mbali Pali area forms a cross-section through the northwestern part of the Northern Extension, from the Mara River southwards (Figure 1, Map B).

6.1 CLIMATE

There is a rainfall gradient from south-east to north-west (Norton-Griffiths et al., 1975). Along the Fringe of the Serengeti Plain, annual rainfall is about 600 mm, exceeding 1100 mm in the extreme northwestern part of the Northern Extension. Norton-Griffiths classified the area as dry subhumid according to the Thornthwaite index (about -15). The rainfall shows a single peak, with an excess of rainfall over evaporation from March to June.

6.2 GEOLOGY

The soils are underlain by Precambrian granitic gneisses, essentially consisting of quartz, microcline, albite-oligoclase and biotite.

Probably the area has been covered from time to time with alkaline volcanic deposits. This may account for a decrease in pH with depth at the ridge site (Rhino 1) and for the relatively high pH (generally above 7) at other sites. The influence of volcanic deposits was less than in the Western Corridor, presumably because of its geographical position, if the deposits originate from the volcanoes in the Ngorongoro Highlands and if the prevailing wind has always been to the west.

From the ridges most of the deposits had been removed by termites, weathering and water.

6.3 GEOMORPHOLOGY

The aerial photographs show a very clear pattern of ridges, ridge slopes and valley bottoms (Figure 46). The ridges are better developed in the centre of the area than near the edges. In all directions, the width of the convex ridges decreases. Altitude is maximal in the centre of the sample area. The ridges are believed to represent the remnants of an old erosion surface, probably the early Miocene surface (Pulfrey, 1960; Saggerson, 1966; Mc Farlane, 1976).

Closer to the Mara River in the north and the Grumeti River in the south,

Figure 46. Aerial photograph of the centre of the Rhino Mbali Pali area taken in February 1956.

the remnants of the old surface are more dissected, resulting in narrower ridges. Finally the ridges disappear and only kopjes remain between the drainage lines.

The distribution of erosion surfaces will be discussed in detail in Section 10.1.

On the ridges, slightly rounded gravel is present, usually cemented by hardened plinthite. The fact that the gravel is not completely angular may suggest local transport.

Below the ridge is a seepage line (Herlocker, 1976), where water that has infiltrated into the sandy ridges and travelled over the hardpan reaches the outcrop of hardened plinthite at the transition from the convex ridge to a linear slope (Figure 47).

The banks of drainage lines are steep, indicating that incision is still active.

Figure 47. Seepage line around a ridge in the Rhino Mbali Pali area.

6.4 SOIL DESCRIPTION

There was a clear relation between soils, vegetation and topography in this undulating landscape (Figure 48). Three soil groups were distinguished: ridge soils; ridge slope soils; and valley bottom soils. Only ridges and ridge slopes will be discussed in more detail.

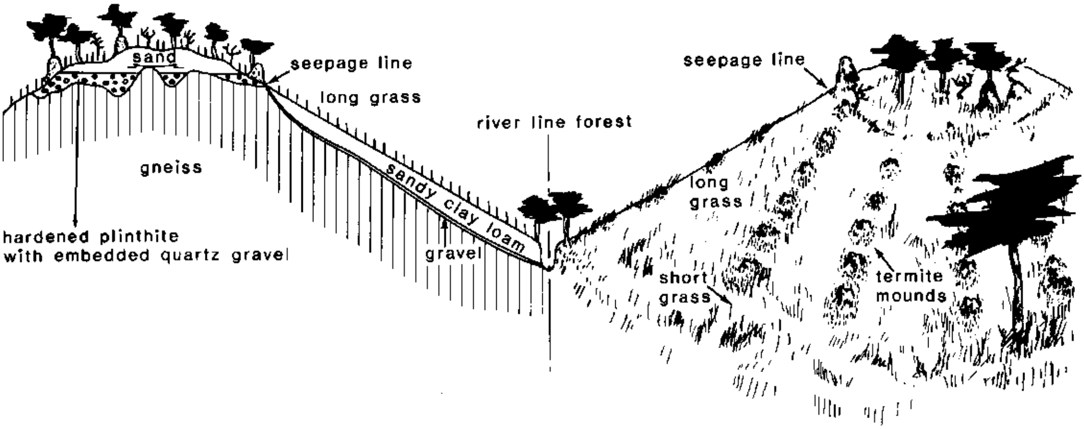


Figure 48. Relation between topography, soils and vegetation in the Rhino Mbali Pali area.

6.4.1 Ridge soils

Subdivision: B 2.1.1 Undulating topography with shallow to moderately deep, very dark grey-brown sandy soils with a petroferric contact

B 2.1.2 Gently undulating topography with moderately deep to deep, dark brown sandy soils with a petroferric contact

At higher sites soils were moderately deep, whereas at somewhat lower altitudes shallow soils were commonly found (Map B).

Ridge soils were very sandy (sand to sandy loam), had woody vegetation and lay on hardened plinthite or angular and somewhat rounded gravel. Hardened plinthite could have originated in another era where it represented the top of an erosion surface. In more recent times, the weathering products of volcanic sediments may have contributed to the formation of the hardened plinthite (Wielemaker & van Dijk, 1981; Mc Farlane, 1976). Large chunks of this 'bevel' had been eroded away especially near the Mara and Grumeti Rivers. So the hardened plinthite was absent on the ridge slopes.

The sandy texture may result from a combination of weathering and biological activity. Relatively easily weatherable minerals like feldspars fall apart and are, after being brought to the surface by termites, transported downhill, resulting in a relative enrichment with quartz in the ridge soils. Termites prefer particles smaller than 2 mm for building their mounds (Nye, 1955; Miedema & van Vuure, 1977). In the course of time, erosion destroys the mounds and the finer particles are transported downhill and the sand fractions remain behind. The presence of gravel on the bedrock surface can be explained the same way as a result of 'undermining' and subsequent removal of the finer fractions (Section 6.11).

Profile characteristics

Soil depth varies from shallow to moderately deep (20-100 cm) with local outcrops (kopjes). At Rhino 5, the colour changes with depth from 10 YR to 5 YR with a decrease in organic matter. The texture does not change significantly with depth.

Chemical characteristics

Electrical conductivity decreased with depth from 0.4 to 0.2 mS/cm and pH decreased from 7.8 in the topsoil to 5.7 in the subsoil (Appendix D49), suggesting enrichment with soda-rich volcanic deposits. The potassium content in the saturation extract of the topsoil was relatively high too (1.2 mmol/kg).

Physical characteristics

Infiltration rate: The ridge soils had relatively high infiltration rates. After 5 h, 20 cm of water was taken up by the soil, and infiltration in the fifth hour was 3.4 cm/h (Figure 50). Almost all the infiltrated water was available for vegetation: at pF 4.2, the volume fraction of moisture was 4.2. The moisture front reached to a depth of 80 cm (Rhino 5) during the experiment, the depth of the hardened plinthite, so that the whole profile had been moistened in 5 h with 5 cm head of water. This also happens in reality, because medium and small roots were common in the bottom horizon.

Moisture retention and availability: The depth of penetration partly governed maximum available moisture. At site Rhino 5, maximum available moisture was 8.6 cm (Table 15). Not all the rainfall was stored in the soil. Some water was transported over the bedrock or hardened plinthite (compare Herlocker, 1976) and reached the surface at the outcrop.

6.4.2 Ridge slope soils

Ridge slope soils occur on the slopes between ridges and valley bottoms. They are clayey and usually covered with grass vegetation only. A distinct line pattern was visible on the slopes from the air; parallel lines of termite mounds (*Odontotermes* sp.) perpendicular on the contours between the seepage line and the valley bottom (Figure 46).

It could result from termite activity, since there is no underlying erosion pattern of the bedrock (Section 6.10). Glover et al. (1964) described the same phenomenon for the Loita Plains in Kenya near the northern part of the Serengeti National Park.

Between the lines of termite mounds the topsoil (about 30 cm deep, at Mbali Pali 2) consisted of loamy sand, whereas the topsoil of the termite mounds was clayey (sandy clay).

After destruction of the termite mounds the finer particles would be transported downhill, whereas the coarser particles would finish up inbetween the mounds, hence the sandy texture of topsoil between the mounds.

The described pattern was very important because it had strongly influenced the vegetation through a drastic change in soil conditions, especially physical characteristics that determined the available moisture.

The lines of termite mounds occupied about a quarter of the ridge slope. Further downhill, soils became somewhat more clayey (Mbali Pali 2 and 4). In Section 6.10 the origin of termite mound lines is discussed.

The sequence from the ridge down the slope represents a catena, since the soils are directly related to one another.

Creep (Figure 51) was considered to be of importance for the profile differentiation on a slope, especially for clay transport. Nye (1954, 1955) and Hallsworth (1965) distinguished a creep and a sedentary horizon. Soil fauna transports particles and nutrients upwards into the creep horizon, which is then transported downhill (Figure 49).

Table 15. Moisture retention, maximum available moisture, bulk density and coefficient of linear extension for one ridge (Rhino 5) and four ridge slope soils.

	Depth (cm)	Volume fraction of moisture (%) pF				Bulk density (kg/m³)	Coefficient of linear extension	Maximum depth of fluctuation in moisture (cm)	V(pF2)-V(pF4.2) (cm)	Maximum available moisture (cm)
		1	2	3.4	4.2					
Rhino 5	0- 18	40.4	16.2	9.1	4.8	1470	<0.02	80	2.1	8.6
	18- 50	39.3	14.7	7.0	4.8	1450	<0.02		3.2	
	50- 80	37.5	15.8	8.8	4.8	1500	<0.02		3.3	
Rhino 7	0- 10	40.3	32.2	15.7	11.3	1510	<0.02			
	10- 55	38.2	37.0	28.0	24.9	1600	<0.02			
	55- 75	42.9	41.7	31.6	20.1	1470	<0.02			
	75-100	43.4	39.4	31.7	23.7	1280	<0.02			
	100-140	44.0	40.0	38.4	29.7	1390	<0.02			
Mbali Pali 3	0- 15	42.0	36.2	.	19.4	1450	0.04	20	2.5	3.0
	15- 45	34.6	31.5	.	21.9	1500	0.02		0.5	
	35- 70	39.8	39.5	32.9	24.1	1430	0.04			
	70-130	40.3	39.5	37.4	25.4	1440	0.05			
Mbali Pali 2	0- 30	20.7	19.9	.	9.5	1540	<0.02	60	3.1	7.0
	30- 60	36.9	35.9	.	22.8	1500	0.03		3.9	
	60-100	41.4	40.3	.	25.1	1440	0.05			
Mbali Pali 4	0- 25	36.5	30.6	25.4	15.6	1460	0.02	60	3.8	8.0
	25- 45	40.4	40.3	37.1	26.9	1460	0.07		2.7	
	45- 85	38.5	37.9	34.2	27.8	1520	0.04		1.5	
	85-110	38.0	36.4	31.5	25.2	1470	0.03			

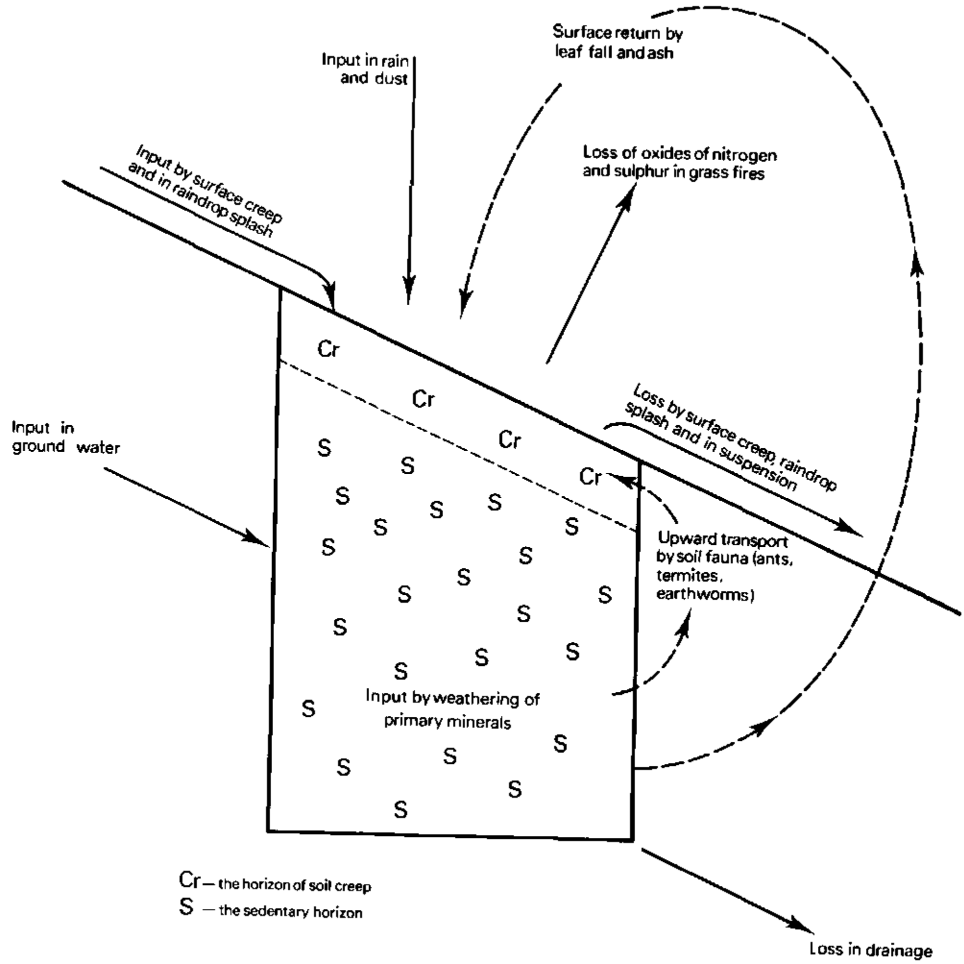


Figure 49. Dynamics of profile differentiation of a soil on a slope (from Hallsworth, 1965).

Subdivision:	B 2.2.1	Gently sloping, shallow, very dark grey-brown sandy soils with a petroferric contact
	B 2.2.2	Gently sloping, shallow to moderately deep, very dark grey loamy soils, here and there with a petroferric contact
	B 2.2.3	Gently sloping, moderately deep, dark grey clay-loam soils
	B 2.2.4	Gently sloping, moderately deep to deep, dark grey clay-loam soils with erosion steps
	B 2.2.5	Very gently sloping, deep to very deep, very dark grey clayey soils

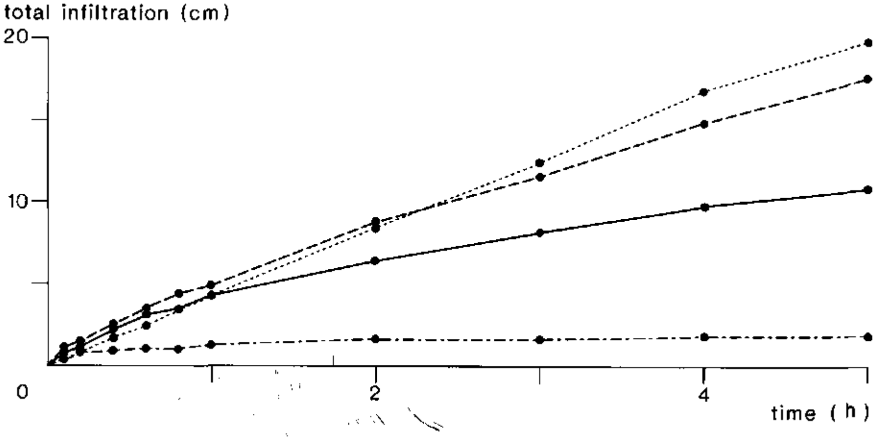


Figure 50. Infiltration characteristics for 4 sites in the Rhino Mbali Pali area: Rhino 5 (·········), Mbali Pali 2 (– – – – –), Mbali Pali 3 (–·–·–) and Mbali Pali 4 (———). Depth of penetration after 5 h was >80, 60, 20 and 60 cm, respectively.

Map Unit B 2.2.1: was still above the seepage line with soils comparable to ridge soils. It represented the first phase of ridge slope development. Because there were small depressions in the terrain sloping towards the drainage line, run-off collected there, and tree cover was relatively dense. In the detailed study area, these soils were found only close to the Grumeti River in the southern part.

Map Units B 2.2.2 + B 2.2.3: were below the seepage line on the slope towards the drainage lines. Both were under woodland: the shallow phase (Map Unit B 2.2.2) was more sandy and more densely covered with woody vegetation than the moderately deep phase (Map Unit B 2.2.3), where almost all the trees were on termite mounds. Soil depth classes are given in Appendix A. The soils described form the next phases in slope development towards less favourable physical conditions (lower infiltration rates and deeper soils). In both units, lines of termite mounds were observed.

Map Unit B 2.2.4: was studied in more detail. Results are discussed below.

Map Unit B 2.2.5: had gentler slopes and the soils became more clayey. Long grass (*Themeda triandra*) was the dominant vegetation (Mbali Pali 4).

Profile characteristics

The difference in thickness and/or texture between the A and B horizon of the ridge slope at Rhino 4 and 3, and especially Mbali Pali 2 and 3 was obvious.

At the bottom of the Rhino pits was gravel, probably on bedrock. At Mbali Pali 4 many concretions were observed at about 85 cm, presumably also on

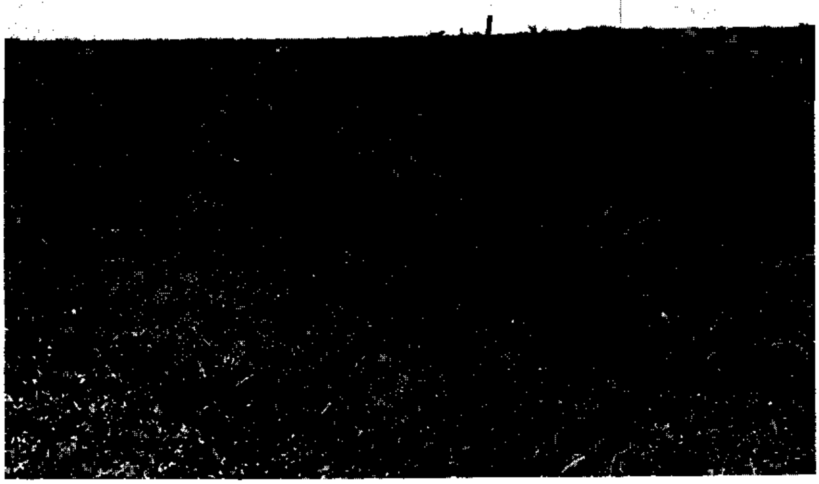


Figure 51. Soil creep on a ridge slope in the Rhino Mbali Pali area.

bedrock. At Mbali Pali 4, the subsoil looked yellowish-grey and yellow, indicating wet conditions during the rainy season as a result of high supply of run-off or a locally high watertable.

Chemical characteristics

Electrical conductivity, pH(paste), cation-exchange capacity and alkalinity were slightly higher in the soils influenced by termites. In the saturation extract, pH was not significantly different. Lapperre (1971) and Hesse (1952, 1955) also found that pH of the mounds and surrounding subsoils was similar.

The presence of nitrates is directly related to termite activity (de Wit, 1978; Lapperre, 1971). The differences are particularly clear between Mbali Pali 2 and 3 (Appendix D52, D53). Thus termitaria were somewhat richer in nutrients, partly because of enrichment by termites (e.g. gathering of organic matter for their fungus gardens), partly by a decrease in leaching of the salts, as will be explained under physical characteristics. Also the amount of exchangeable Na^+ was consistently higher in the soil influenced by termites at all depths. Glover et al.(1964), found a high content of exchangeable Na^+ only in the topsoil of a termite mound.

Physical characteristics

Infiltration rates: Differences in infiltration rate between the soils on and between the lines of termite mounds were striking. In 5 h, 18 cm water infiltrated the soil between the termite mounds (similarly to the ridge soils), and about 2 cm in the line of mounds. Depth of infiltration was 60 and 20 cm at the respective Mbali Pali sites (Figure 50). Lateral flow may have influenced the infiltration rate between the lines. The differences were mainly attributable to the texture and structure of the topsoil.

Moisture retention and availability: Despite unfavourable moisture retention at Mbali Pali 2 (compare the topsoil of Mbali Pali 2 and 3), maximum available moisture was 7.0 cm in contrast to 3.0 cm at Mbali Pali 3 (Table 15). There too depth of penetration rather than retention characteristics determined the maximum available moisture.

Bulk density: Bulk density of oven-dry soil did not decrease with depth as clearly as in the Western Corridor and the Fringe of the Serengeti Plain. Neither did the clay content decrease significantly below the B2.2 horizon. If weathering was the main factor in bulk density and clay content, weathering in the Northern Extension had proceeded to greater depths than in the Western Corridor and the Fringe of the Serengeti Plain. The data confirm that differences in soils of the Northern Extension and from those of the Western Corridor and the Fringe were primarily caused by:
- differences in removal or weathering of volcanic deposits
- deposition of different amounts of volcanic ash
- differences in degree of eluviation.

6.5 DIAGNOSTIC HORIZONS

Ridge soils commonly have a mollic epipedon but no argillic horizon. Ridge slope soils are characterized by dark topsoils and clay illuviation and met the requirements for a mollic epipedon and an argillic horizon.

6.6 BIOLOGICAL ACTIVITY

6.6.1 Termites

Termites (*Macrotermes* spp.) may have played a major role in the formation of the sandy ridge soils and the gravel pavement on the rock surface. Termite mounds were not frequent around the seepage line. They could reach a height of about 3 m (Figure 52). There was a relation between the presence and perhaps the height of termitaria and the presence of water, that after moving over the laterite hardpan reached the surface there. The termites present on the ridge slopes belong to the *Odontotermes* family. It is often found that *Odontotermes* species are present on poorly drained soils, while the *Macrotermes* species are limited mainly to well drained soils. Characteristic for the *Odontotermes* species are the low mounds (30-40 cm) and the presence of many small chimneys (Figure 53).

Figure 52. Termite mound built by *Macrotermes* sp. on a well drained ridge.

Figure 53. Termite mound built by *Odontotermes* sp. on a poorly drained ridge slope.

6.6.2 Elephants

Several people have suggested that on the ridge tops elephant cause severe damage, by pushing down mature trees (Norton-Griffiths, 1979). The damage was assessed with aerial photographs; and decreases in woody cover of about 2.6% per year over 10 years were calculated. Herlocker (1976) and Sinclair (1979b) stated that at one time forest presumably covered the *Themeda* grasslands. Judging from the results of the infiltration experiments (Figure 25) this is not very likely. The number of trees and not the area under trees decreased, since woody vegetation was restricted to the sandy ridge tops.

Despite the impact of elephants, the chemical and physical soil characteristics were such, that seedling establishment would not be hampered by deterioration of the soil conditions, as was suggested in the Western Corridor.

6.7 VEGETATION

The woodland of the ridges was mapped by Herlocker (1976) as *Combretum molle* and *Terminalia mollis* in the central and western part of the area and as *Acacia clavigera* woodland in the eastern part.

According to Herlocker the *Combretum molle* and *Terminalia mollis* had replaced the evergreen forest as a plant community adapted to fire, like the *Acacia* woodland that had replaced the evergreen to semi-deciduous bushland. Woody vegetation in the eastern part consisted mainly of *Acacia clavigera* (a species often found on well drained soils), *Terminalia mollis* and *Kigelia africana*. In the central and western part, *Terminalia mollis*, *Combretum molle*, *Boscia angustifolia*, *Lannea stuhlmanii*, *Fiscus sonderi*, *Euphorbia candelabrum* and *Strichnos* sp. were common.

Most of the trees grew on termite mounds except *Terminalia mollis* and *Combretum molle*, as observed also by Herlocker.

Bush and shrub vegetation included *Rhus natalensis* (especially on termite mounds), *Acacia hockii* and *Heeria reticulata*.

The following long grasses were present: *Loudetia kagerensis*, *Hyparrhenia filipendula*, *Setaria* sp., in the eastern part also *Themeda triandra*.

The ridge slopes were predominantly under grassland (Figure 54). Often the shrub *Rhus natalensis* grew on termite mounds. As a result of the low infiltration rates and the clayey topsoil, less water was available for the vegetation in the lines of termite mounds than between the lines. So grass around the termite mounds was sparser and shorter: *Cynodon dactylon*, *Sporobolus fimbriatus* and *Harpachne schimperi*. Between the mounds was long grass: *Themeda triandra* and to a small extent *Sporobolus staphianus* and *Sporobolus fimbriatus* (Figure 55). The herb *Mariscus mollipes* was rather common in the lines of termite mounds.

Glover et al. (1964) gave a self-explanatory diagram of the vegetation

Figure 54. Herd of wildebeest grazing on a ridge slope in the Rhino Mbali Pali area.

Figure 55. Long grass, predominantly *Themeda triandra* and *Sporobolus* spp., between the lines of termite mounds.

on a termite mound and its surroundings (Figure 56). Often the zone of tall grass is present only between the mounds.

6.8 EROSION

Step erosion is a widespread phenomenon on ridge slopes, especially when the slope exceeds 5% (Figure 57). Locally the topsoil was removed and the slightly prismatic B horizon was exposed.

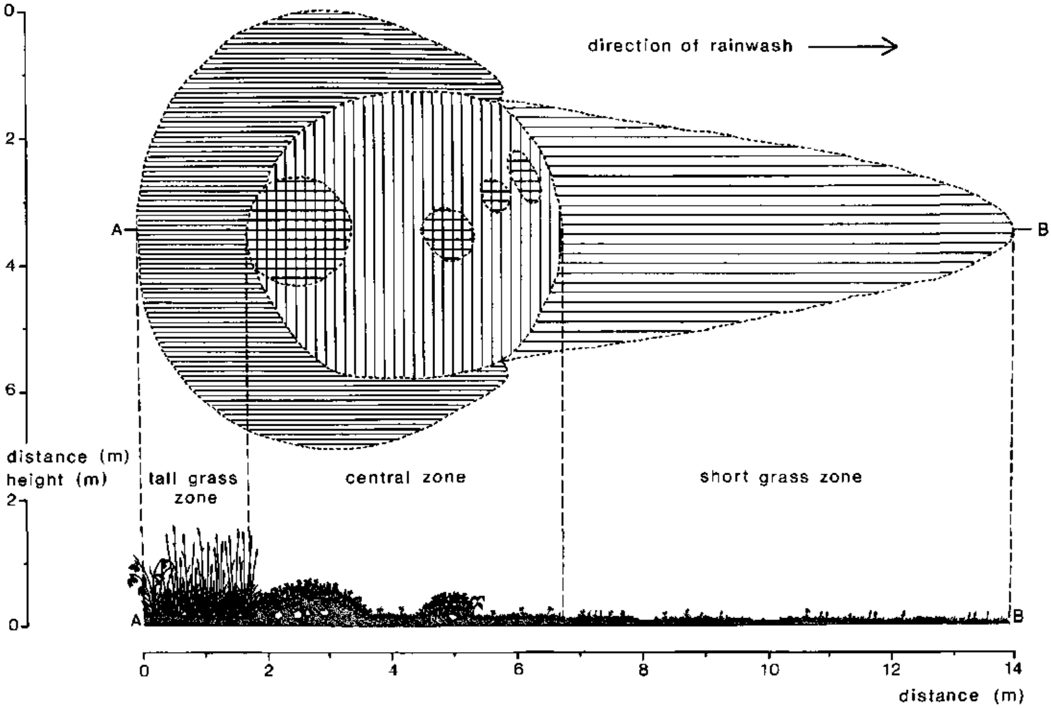


Figure 56. Vegetation on a low termite mound and its surroundings on a ridge slope. The mound was built by *Odontotermes* sp. (from Glover et al., 1964).

The B horizon was more resistant to erosion. After heavy rain, the topsoil became saturated with water because of the high supply of run-off. At a later stage, the B horizon is also attacked and the erosion steps expand (regressive erosion).

De Wit (1978) concluded that erosion steps on the Serengeti Plain were due to stability of the topsoil rather than of the subsoil. The subsoil of the Plain soils seemed to disperse more easily than that of the Rhino Mbali Pali area where the soils were more mature and considerably less alkaline.

Step formation was also described by Glover & Wateridge (1968) for the Loita-Aitong area just north of the Serengeti National Park. They emphasize trampling and overgrazing by cattle and game. According to their illustrations, slopes there were more gentle than in the Rhino Mbali Pali area. Game animals could have enlarged the steps, for instance by carrying away soil material. Especially buffaloes, of which there are large herds in the Rhino Mbali Pali area, like to wallow on the steps, since standing water is present much longer because of low infiltration rates of the B horizon.

In the Rhino Mbali Pali area, step formation was primarly due to stability of the subsoil rather than of the topsoil. The topsoil was removed by transport of soil and water over the B2 horizon.

Figure 57. Step erosion on ridge slopes, usually exceeding 5%.

6.9 FIRE

Fire plays an important role in the Rhino Mbali Pali area. At least once a year extensive grassfires sweep through the area. Its impact at the beginning of the dry season seems more pronounced on the slopes than on the ridges.

Because of the more favourable retention characteristics of the ridge soils, vegetation stays green longer (drying out of the vegetation starts on the lower end of the ridge slopes), so that fires from the ridge slopes die out when they reach the ridge. However, if fires start at the end of the dry season, when much of the vegetation is tinderdry, hot fires can severely harm the ridge vegetation. So 'cool burning' in the beginning of the dry season is arranged between wardens of the Tanzania National Parks and staff of the Serengeti Research Institute.

Grazing limits the harmful effects of burning, it reduces the amount of litter (Figure 54). This was particularly obvious during the previous five years, during which animal populations especially of wildebeest had increased at a rate of about 15% per year (Sinclair, 1979c).

6.10 ORIGIN OF LINES OF TERMITE MOUNDS

Glover et al. (1964) reported the presence of oriented termite mounds on the Loita Plains in Kenya. There the soils were composed of volcanic deposits, forming 'brown calcareous loams and grey compacted loamy sands', often on hardened plinthite. The Loita Plains were under open grassland dissected by wooded water courses of the Mara River. Slopes in that region are generally more gentle than in the Rhino Mbali Pali area. The orientation of the patches influenced by termites was the same (perpendicular on the contours), though in the Rhino Mbali Pali area termite mounds (built by *Odontotermes* species) were found in lines, which was apparently not always true on the Loita Plains. Presumably the lines develop more clearly in areas with steeper slopes. The line pattern is more clearly developed in the western than in the eastern part of the Rhino Mbali Pali area where slopes are slightly steeper.

Termites may prefer to build new mounds at the foot of former mounds because they are drier than the "lowland" further away from the mound. Finally termites may have a preference for the more alkaline clays of the 'foot slopes', for sealing off certain sections inside the mound. If so, it is understandable that the lines become more prominent on steeper slopes. The termites (*Odontotermes*) seemed to have started their activity around the seepage line.

Another possibility would be that the pattern had been superimposed on an already existent soil pattern. Since the pattern was very regular and widespread this is not very likely.

6.11 ORIGIN OF STONELINES

The soils in the Northern Extension and occasionally in the Western Corridor are underlain by a 'stoneline', which covers either the bedrock or the rotten rock. Stonelines consist of slightly rounded to angular gravel (an average 2-8 cm). Close to a flood plain or main rivers like the Grumeti, Mbalageti and Mara well rounded gravel was found.

Slightly rounded gravel suggests local transport by soil creep or regressive erosion. Soil creep could also contribute by detaching rock fragments from quartz veins. Ruhe (1959; 1976) described rounded gravel on rotten rock as an erosion pavement on an erosion surface. Coarse particles remain as a lag concentrate. According to him, the stoneline was an erosion pavement formed by running water.

Although the stoneline often covered an erosion surface, running water obviously could not have played an important role because the gravel was angular.

Termites may have played a major role in the formation of the stonelines by causing gravel to sink down to the rock surface (Nye, 1955).

Probably the gravel originated by regressive erosion or by soil creep, thus detaching fragments from quartz veins, while the concentration of gravel as a pavement on the bedrock was a result of biological activity.

Sometimes pieces of very well rounded gravel were found amidst angular gravel (Togoro Plain). Perhaps part of the gravel was older and may have covered an older pediplain, while the greater part was younger and had been transported only locally.

7 Soil moisture regime

7.1 INTRODUCTION

Early in the survey, the significance was recognized of physical properties of the soil, such as infiltration rate and depth of infiltration, for the vegetation.

By means of the infiltration experiments and tests on moisture content at different moisture tension, an estimate could be made of the maximum amount of available moisture from the soil to the plant.

Actual availability was calculated from the moisture readings in the field (Section 7.4.4). Evapotranspiration was calculated too.

The neutron probe made it possible to estimate run-off, since water did not percolate through many of the soils.

Soil moisture was studied in detail at 9 sites near the Serengeti Research Institute. Measurements were made each month at another 19 sites in cooperation with the African Wildlife Leadership Foundation monitoring programme during flights to check the rain-gauges. The usefulness of the neutron meter in research on soil moisture was well illustrated by the detailed studies of Schrale (1976) and Vachaud et al. (1980). The latter group studied infiltration and redistribution of water, and their effect on the hydrodynamical properties of each soil layer.

7.2 METHODS

The moisture measuring equipment consisted of a Wallingford soil moisture probe model M 225 that was connected with a rate scaler model 604A, manufactured by Pitman, U.K. (Figure 58).

At all sites, an aluminium pipe of diameter slightly larger than the probe was inserted after augering a hole slightly smaller than the pipe to insure a tight fit between pipe and soil.

The neutron source was americium-beryllium. Source and detector were lowered into access tubes and a fast neutron flux was established in the soil. The fast neutrons were slowed down by collisions with hydrogen nuclei, mainly of molecules of soil water. The ratio of emitted fast neutrons to back-scattered slow neutrons is a measure of content of moisture. Measurements usually started a few weeks after the pipes had been inserted.

To check the accuracy of the topsoil readings (5-10 cm), containers filled with water were placed around the pipe (Eeles, 1969). The results

Figure 58. Wallingford soil moisture probe and rate scaler.

were influenced at counts less than 100. If readings exceeded 100, the extra water caused no significant changes.

7.3 CALIBRATION OF THE NEUTRON PROBE

For almost every moisture monitoring site, a calibration curve, giving the relation between neutron flux and volume fraction of moisture was established. The procedure is outlined below.

Around each tube 4 to 6 vertical holes were made with an auger. In samples taken every 10 cm moisture contents were determined gravimetrically. By multiplying the contents by bulk density, volume fractions of moisture were obtained. This procedure was repeated in the wet and dry season. Samples were taken for gravimetric determination of moisture also when the pipe was inserted. So the calibration curves reflected practically the whole range of moisture contents.

Later only two calibration curves proved necessary for all soils.

Neutron transport characteristics are discussed in detail by Schrale

(1976), Greacen & Schrale (1976) and Visvalingam & Tandy (1972). The major soil factors influencing neutron flux are as follows:

- water irreversibly bound to the mineral fraction
- hydrogen in humus
- presence of neutron-absorbing elements like magnesium, potassium, boron and chlorine
- bulk density
- soil texture
- soil temperature

For the Serengeti Woodlands, the following two regression equations were derived (Figure 59):

$$Y = a + bX \qquad (1a)$$
$r^2 = 0.97$; $P < 0.005$ $n = 52$ $a = 0.36$ $b = 0.48$

$$Y = a + bX \qquad (1b)$$
$r^2 = 0.96$; $P < 0.005$ $n = 52$ $a = -2.45$ $b = 0.067$

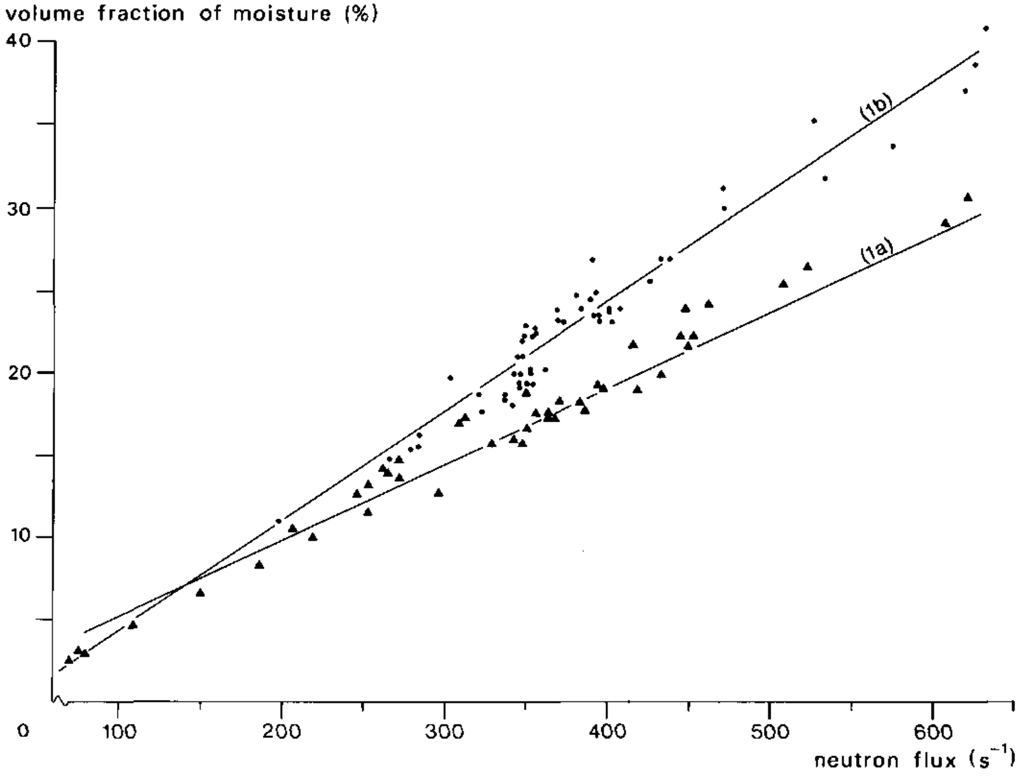


Figure 59. Calibration curves of the neutron probe for neutral and mildly alkaline soils (1a), and for alkaline and strongly alkaline soils (1b).

in which Y is the volume fraction of moisture in soil and X the number flux of neutrons.

In general, Equation (1a) decribed the relationship for the neutral to mildly alkaline soils, and Equation (1b) for the alkaline and strongly alkaline soils near the Serengeti Plain. Sometimes Equation (1a) applied to topsoil and Equation (1b) to subsoil.

If only Equation (1a) were used, moisture in alkaline soils would be grossly underestimated. The amount of recent volcanic ash determined which of the two equations applied. Soils with recent volcanic ash most likely contained more neutron-absorbing elements (like boron) than soils derived from older volcanic material. If a soil with recent volcanic ash were well drained, it would be weathered and leached faster, so that Equation (1a) would apply to the topsoil and Equation (1b) to the subsoil.

The two equations were adopted for calculating the moisture contents because the result did not differ significantly from that with the individual calibration curves.

The influence of the other soil factors on the neutron flux was taken to be negligible, although soil texture may play a role. Results indicated that there was no interaction between other soil factors and moisture content on neutron flux, so the method was reliable.

No significant changes in the neutron source itself were registered when the probe was lowered regularly into a drum filled with water.

7.4 RESULTS

7.4.1 Introduction

Once the aluminium tubes were installed, measurements with a neutron probe could be made indefinitely. At the 9 sites in the Seronera area, readings were taken each week or even more frequently; the other sites were visited once a month. Rain-gauges were present or were installed at all sites. A rainfall-intensity recorder was placed at site SRI-2.

Water did not percolate through the majority of soils. Only on the very sandy ridges in the Northern Extension did the moisture front reach the bedrock frequently. So loss of moisture could generally be attributed only to evapotranspiration and run-off. Evapotranspiration in relation to moisture content was estimated by recording moisture contents in a dry period after heavy rains. Maximum and minimum moisture content of the profiles was calculated over the measuring period of about one year.

The accuracy of the infiltration experiments was checked with double-ring infiltrations around the moisture-access tubes.

Moisture contents of the topsoil were estimated gravimetrically and required new samples each time, so data were more scattered than with the neutron probe. This is unfortunate, since fluctuations in moisture in the topsoil were often critical because of the low infiltration.

7.4.2 Detailed study of soil moisture

Soil moisture was studied in detail in the Seronera area. Two of the sites (SRI-1 and 2) were situated on a sequence of ridge and ridge slope in the Fringe of the Serengeti Plain (Map Units 6.2.1.1 and 6.2.2.1), two on upper pediments (Mukoma 1 and Nyara Swiga 2; Map Unit 1.1.1), three on lower pediments in the Western Corridor (Mukoma 2 and 3, Nyara Swiga 3; Map Unit 1.2.1) and two on a sequence of ridge and ridge slope in the Northern Extension (Banagi 4 and 5; Map Units 5.1.1 and 5.2.2.2.2). Results are summarized in Appendix E.

Moisture contents at Banagi 5 were influenced by frequent treading during

Table 16. Comparison of maximum moisture storage and maximum depth of fluctuation in moisture, calculated from measurements with the neutron probe, and infiltration characteristics.

Site	Maximum moisture storage (mm)	Infiltration rate in the 5th hour (mm/h)	Maximum depth of fluctuation in moisture (cm)	Depth of penetration after 5 h of infiltration (cm)
Mbalageti 1	95	33	95	100
Mbalageti 2	35	2	35	30
Simiyu	55	30	55	50
Ndoho	>115	38	105	95
Banagi 4	30	8	25	45
Banagi 5	15*	49	25*	80
Sigiria 1	>60	.	>65	.
Sigiria 2	35	.	.	.
Bololedi 2	>60	87	>75	90
Mbali Pali 1	>60	33	>95	80
Mbali Pali 2	65	27	65	60
Mbali Pali 3	45	1	50	20
Mbali Pali 4	75	12	65	60
Rhino 1	>60	33	85	80
Rhino 2	65	29	65	60
Rhino 3	45	11	55	45
SRI 1	60	63	105	100
SRI 2	30	1	35	20
Nyara Swiga 2	65	28	65	75
Nyara Swiga 3	25	10	25	20
Mukoma 1	65	6	35	40
Mukoma 2	55	6	35	40
Mukoma 3	55	8	45	40
Togoro	30	44	60	70
Kirawira 7	65	40	50	50

* These low values are thought to be caused by slaking due to frequently treading the silty topsoil.

the measurements. The results show what happens when a surface seal develops. Infiltration experiments nearby where there was no seal gave an infiltration rate of 49 mm/h and a favourable depth of penetration (80 cm); depth of fluctuation in moisture and moisture storage as estimated with the neutron probe were very low (Table 16).

7.4.3 Maximum moisture storage and depth of fluctuation

Maximum moisture storage was calculated from the difference between maximum and minimum moisture content during the measuring cycle (about 14 months).

It ranged from 15 mm at the site where a seal had developed (Banagi 5) to over 60 mm or even 115 mm in the Ndoho Plain. Usually 5-15 mm more than the minimum moisture content was required before a green flush developed.

Depth of fluctuation in moisture was taken as the depth below which no fluctuation in moisture was observed. It ranged from 25 to over 105 cm, and coincided closely with depth of penetration after 5 h of infiltration with a double-ring infiltrometer (Table 16). Only at Mbali Pali 3 did they inexplicably differ greatly.

7.4.4 Available moisture

Available moisture is usually defined as the difference in moisture content at field capacity and at permanent wilting point.

The amount of water retained by the soil against gravity after heavy rains is called the moisture content at field capacity. Binding force (moisture tension) is usually considered to be 10-33 kPa (FAO, UNESCO, 1973). In Kenya, a value of 20 kPa, equivalent to pF 2.3 was used (Kenya Soil Survey, 1978).

For this study pF 2.0 was used for reasons of simplicity, since facilities present did not allow for extraction of undisturbed samples at higher pF values. Usually the moisture content at the permanent wilting point is defined as the amount of water bound by the soil at pF 4.2 (equivalent of a binding force of 1600 kPa).

In Figures 60 and 61, the moisture variations in the topsoil, and over the total depth of observation, for roughly one year are given for Mukoma 3, an imperfectly drained clay soil, and Nyara Swiga 2, a moderately well drained clay-loam soil.

At Mukoma 3, the moisture content at the permanent wilting point was reached or exceeded in the topsoil only for short periods. In reality, green grass was observed for much longer periods.

At Nyara Swiga 2, the moisture content at pF 4.2 was often exceeded in the topsoil. If the total measured depth were considered, the moisture content exceeded that at the permanent wilting point for short periods only.

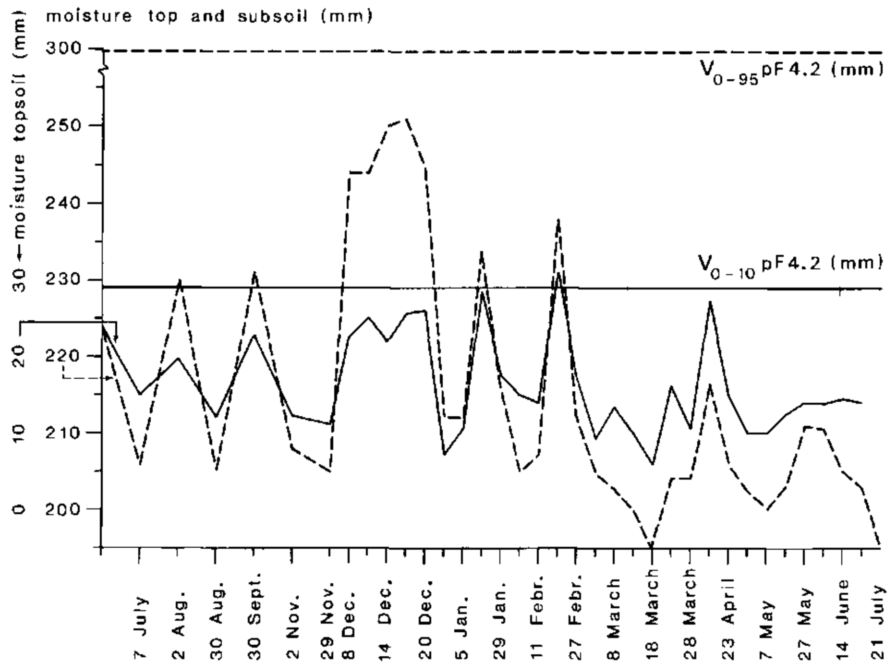


Figure 60. Moisture variation over the depth of observation (0-95 cm) and for the topsoil (0-10 cm) at Mukoma 3. Moisture content at pF 4.2 for both depths is also given.

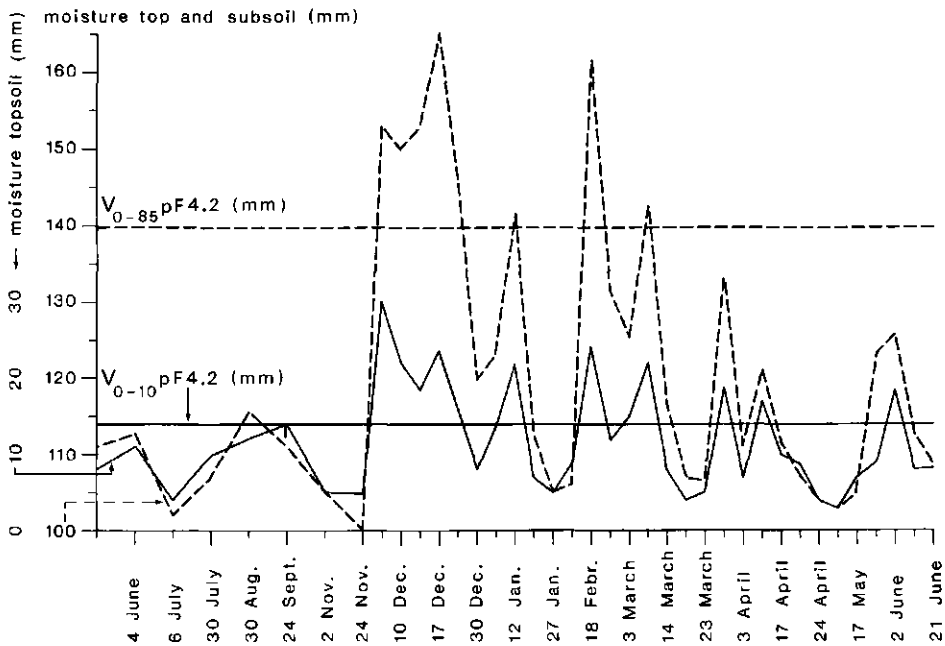


Figure 61. Moisture variation over the depth of observation (0-85 cm) and for the topsoil (0-10 cm) at Nyara Swiga 2. Moisture content at pF 4.2 for both depths is also given.

The duration of actual 'green grass' corresponded to the time during which the moisture content of the topsoil exceeded pF 4.2.

There are many reasons for a presence of green grass at moisture contents below the permanent wilting point, as was observed at Mukoma 3 and other clayey sites.

- A green flush was observed if only the upper 5 cm were moistened. Especially where low infiltration rates prevailed (e.g. Mukoma 3), one cannot assume a homogeneous distribution of moisture in the top 10 cm.
- Soil moisture may become available at tensions exceeding 1600 kPa
- The methods applied may not give satisfactory results on soils containing large amounts of X-ray amorphous material. A longer equilibration time at pF 4.2 may have given different results. In this study, the samples were equilibrated for 3 to 4 days, depending on the soil texture. The results obtained in the soils laboratory in the Serengeti were checked against those at the Agricultural University, Department of Soils and Fertilizers (equilibration time 72 h). Results proved very similar.

Actual maximum available moisture was calculated by subtracting 5-15 mm, the amount required on the dry soil for a green flush, from the maximum moisture storage (Table 16).

These values are lower than maximum available moisture calculated from the difference in the moisture contents at pF 2 and pF 4.2 over the depth of fluctuation in moisture, given under the soil descriptions.

Actual maximum available moisture seemed a fair measure of availability.

7.4.5 Evapotranspiration

Evapotranspiration could be measured from the soil moisture profiles in the drying period after heavy rains. This is only possible if no percolation occurs.

Depending on the moisture content, values at SRI-1 ranged from less than 1 to 5 mm/d and at SRI-2 up to 3 mm/d (Appendix E1). Because of physical properties, available moisture, green biomass and evapotranspiration were less at SRI-2 than at SRI-1.

Data in Appendix E also show that evapotranspiration was 1-2 mm/d at the point of green flush, so to sustain a green flush situation 1 mm of water should infiltrate the root zone daily.

7.4.6 Accuracy of infiltration experiments

At six sites, infiltration was measured around the tube used for the neutron probe as a check on the accuracy of the experiments (Table 17). About half the infiltrated water was recovered with the neutron probe. At SRI-1, the moisture front reached the gravelly subsoil in 2 h, after which lateral flow would increase. So recovery decreased sharply during the second half

Table 17. Infiltration measured by double-ring and simultaneous neutron probe scanning.

Site		Time in minutes											Depth of moisture front (cm)
	0	6	12	24	36	48	60	90	120	180	240	300	
SRI-1	A	12	17	26	.	35	42	56	67*	85	97	108	100
	B	9	22	34	.	48	59	73	123*	183	242	305	
SRI-2	A	6	7	10	11	11	12	.	17	20	26	27	20
	B	7	10	12	13	15	17	.	22	27	31	34	
Nyara Swiga 2	A	7	9	14	19	24	28	40	53	71	91	105	80
	B	11	19	29	38	47	56	76	97	140	178	217	
Nyara Swiga 3	A	3	3	4	6	9	12	19	39	45	55	62	50
	B	5	7	12	18	24	30	44	58	85	108	131	
Mukoma 1	A	5	8	14	22	27	30	34	35	37	40	40	30
	B	3	7	15	24	33	43	58	68	83	91	97	
Mukoma 3	A	4	4	5	6	7	8	11	15	21	26	31	40
	B	8	9	13	16	21	24	31	37	49	57	67	

A Increase in moisture during infiltration (mm).

B Water infiltrated (mm).

* Moisture front reached gravelly subsoil.

of the experiment. The infiltration experiments with the double-ring method thus overestimated the infiltration as a result of lateral flow.

Moisture contents of the topsoil could not be included in the calculations. Undoubtedly part of the difference between the results of double-ring infiltration and neutron probe scanning was caused by an increase in moisture content of the topsoil. However, the topsoil was moist before the first measurement.

Only at site SRI-2 was recovery almost complete. The rings there fitted well into the prismatic B horizon, thus preventing lateral flow.

7.4.7 Run-off

Run-off was estimated from the neutron probe data for sites studied in detail, by substracting loss of moisture from the soil and estimated evapotranspiration (Appendix E).

On 21-22 June, loss of moisture was 9 and 35 mm for SRI-1 and 2, respectively. Consequently run-off was at least 4 and 32 mm out of a total of 47 mm precipitation (maximum rate of rainfall 35 mm/h).

For 4-8 March, run-off was at least 19 and 36 mm for the two sites. Run-off at SRI-1 was considerably higher in June because the short-term rainfall rate was more than twice as much (96 mm/h). At SRI-2, run-off was noticed even at a rainfall rate of 10 mm/h; at SRI-1, not below 30 mm/h.

7.5 CLASSIFICATION OF THE SOIL MOISTURE REGIME

The moisture control section was discussed in Section 1.1.5. Soil Taxonomy (1975) gives the following rough guides for the limits of the control section: 10-30 cm for fine loamy, coarse silty, fine silty and clayey soils, 20-60 cm for coarse loamy soils, and 30-90 cm for sandy soils.

According to Soil Taxonomy, about 200 mm is stored at field capacity and some part of the control section is dry after 75 mm of evapotranspiration and all parts are dry after 175 mm of evapotransporation in absence of precipitation.

In the Serengeti Woodlands, actual maximum available moisture ranged from about 30 mm to over 100 mm. If an average evapotranspiration rate be taken as 2 mm/d for soils with low availability of moisture and 4 mm/d for soils with high availability, starting from maximum moisture content, the control section would be dry after 10-20 d without precipitation.

In the first and third quarter of 1975, the number of days with rain exceeded 20, whereas in the second and fourth quarter there were 16 and 17 days, respectively (Table 1). So during 1975, part of the moisture control section was moist for more than 180 cumulative days (Ustic moisture regime).

During 1976, the number of days with rain exceeded 30 in the first and second quarters, suggesting that some part of the control section was moist for 90 consecutive days (Table 2). Maximum available moisture of less than 30 mm was observed as well, especially in the pediplain and locally on ridge slopes. Upper and lower limits of the moisture control section were almost the same there. Depth of infiltration of 2.5 cm of water after 24 h was almost identical to the depth of infiltration of 7.5 cm after 48 h, usually about 20 cm. Consequently run-off figures are very high at these locations.

In the dry part of the Serengeti Woodlands, near the Serengeti Plain, the requirements for an Ustic moisture regime were presumably not met. In the Serengeti Plain, where precipitation figures were considerably lower but infiltration rates significantly higher, de Wit (1978) concluded that Ustic moisture regimes prevailed.

7.6 CONCLUSIONS

Available moisture is the crucial factor for plant growth in the Serengeti Park.

The nutrient status of the soils would not limit plant production, in view of the chemical data (Appendix D). In the Western Corridor infiltration was low and run-off was high on the lower pediment and pediplain soils. Such soils occupy about half the area.

Slightly less than half the rainfall infiltrates in the solum, and the other half represents run-off. Thus for the areas heavily occupied by herbivores (pediplains and lower pediments), the effective precipitation is less than half the actual rainfall. Since swelling of the prismatic and columnar structure elements prevents deep penetration, the topsoil is saturated easily, so that even light showers hardly contribute to available moisture.

Despite a high rainfall of 900 mm per year at Kirawira, not more than 400 mm is available for the vegetation covering the pediplain and lower pediment soils. The run-off to the lower pediment soils from the upper pediment soils where more moisture infiltrates was ignored since it is difficult to estimate. For the ridge slopes of the Fringe of the Serengeti Plain and Northern Extension effective rainfall would be low as well.

Much less moisture was available in the heavily occupied areas than would be expected from rainfall. A more uniform distribution of rainfall throughout the year would drastically increase the production of the grasslands. Such an increase in productivity plus the fact that nutrients are abundant is one of the reasons of the recent growth in game numbers, especially of wildebeest and buffalo (Sinclair, 1979a, b, c).

8 Mineralogy

8.1 INTRODUCTION

From early in the Project, evidence came to light that volcanic ash might have covered both the Serengeti Plain and the Serengeti Woodlands. Mineralogical studies of the Serengeti Woodlands soils in the Department of Soils and Geology of the Agricultural University at Wageningen confirmed suspicions. Some samples from the Serengeti Plain, collected by de Wit, were included.

8.2 METHODS

The barium-saturated clay fraction (smaller than 2 µm) and the fine earth fraction (smaller than 2 mm) were analysed chemically. Clay was separated after a pre-treatment with H_2O_2 in a buffered medium of sodium acetate and acetic acid (pH 5). Iron compounds were not removed before clay separation. After destruction of the sample with HF, Fe_2O_3 and FeO were determined colorimetrically (Begheijn, 1979) and Na^+ and Mg^{2+} spectrophotometrically. The other components given in Appendix F were determined by X-ray fluorescence spectroscopy. The results were used, for instance in petrochemical calculations, alongside data on particle size distribution.

Granulometric analysis of soil samples (Appendix C) influenced by recent volcanic ash deposits and by cementation of iron oxides would not reflect the initial granulometric composition. Samples for granulometric analysis were treated H_2O_2 and sodium acetate as for chemical analysis. Granulometric analysis with HCl pre-treatment instead in the Laboratory for Soil and Crop Testing at Oosterbeek, the Netherlands, did not give significantly different results.

De Wit (1978) also observed that the results of the particle size distribution analysis were independent of the pre-treatment of the samples. He concluded that amorphous materials soluble in HCl were evenly distributed over the fractions.

The outcome of the petrochemical calculations was compared with the results obtained by:
- X-ray diffraction and electron microscopy of the clay fraction
- X-ray diffraction and petrographical microscopy of the sand fraction.

For the X-ray diffraction, the clay fraction was saturated with Mg^{2+} and K^+.

When results obtained by X-ray diffraction proved discordant with the petrochemical calculations, a few samples were studied with a transmission electron microscope in order to study the nature of this X-ray amorphous material.

The presence of swelling clay minerals was confirmed with the magnesium-saturated samples treated with glycerol. Light and heavy minerals were studied in a few samples. An attempt was made to separate potassium-feldspars from plagioclases and quartz by using a bromoform-dicaline mixture (Doeglas et al., 1965).

8.3 RESULTS

8.3.1 Chemical composition

The chemical composition was studied of 64 samples, both clay (< 2 µm) and fine earth fractions (< 2 mm). The non-clay data were calculated from the clay and fine earth fractions. Results are given in Appendix F.

Table 18 shows the SiO_2/Al_2O_3, SiO_2/Fe_2O_3 and Al_2O_3/Fe_2O_3 mole ratios of the clay fraction for 51 samples collected in the Serengeti Woodlands. Some of de Wit's (1978) data for the Serengeti Plain were used as well.

The content of Fe_2O_3 in clay, non-clay and total fine earth fractions is separately shown in Table 19.

The molar SiO_2/Al_2O_3 ratio of the clay fraction, often used as a weathering index, ranged from 2.8 to 5.0. The lowest ratios occurred in the well drained soils (Bololedi 2 and SRI-1) with high infiltration and great depths of penetration. At those sites, the composition of the clay minerals was presumably a bit different because of more intense weathering. Probably the X-ray amorphous material was slightly more crystalline here, though diffraction patterns showed no difference.

No significant differences in crystallinity could be detected between the Serengeti Plain and Woodlands.

The content of Fe_2O_3 in the fine earth fraction decreased gradually from the south-east to the north-west of the Serengeti Park.

Weathering and leaching of part of the liberated iron have presumably greatly affected the Fe_2O_3 content. Site Nyara Swiga 2 was exceptional because its iron-rich metamorphous rocks (banded ironstone) had influenced the iron content of the soil.

The content of Fe_2O_3 in clay and non-clay fractions differed significantly between the Serengeti Plain and Woodlands. In the southeastern part of the Serengeti Plain the Fe_2O_3 content of the two fractions was almost equal (9-10%). In the Woodlands, the content of Fe_2O_3 of the clay fraction was slightly higher, and of the non-clay fraction considerably lower than in the Plain soils.

Thus weathering intensity, in line with the rainfall gradient, had in-

Table 18. SiO_2/Al_2O_3, SiO_2/Fe_2O_3 and Al_2O_3/Fe_2O_3 mole ratios of the clay fraction for some sites in the Serengeti Woodlands and Plain. Data on Plain soils (GS-3, NANO-A, NANO-B, SEK-NE) were derived from de Wit (1978).

	Depth (cm)	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	Al_2O_3/Fe_2O_3
SRI-1	0- 9	3.6	11.5	3.8
	9- 30	2.9	11.0	3.8
	30- 80	2.9	11.7	3.9
SRI-2	0- 9	3.4	11.6	3.4
	9- 19	3.4	11.8	3.4
	19- 33	3.1	12.0	3.8
	>80	4.0	13.5	3.3
SRI-3	0- 6	3.8	12.4	3.2
	6- 32	3.7	12.1	3.2
	32- 42	3.9	12.4	3.1
	42- 67	4.0	13.0	3.2
	67- 87	4.1	13.0	3.1
	>87	4.2	13.6	3.2
Mukoma 1	0- 15	3.5	10.5	3.0
	15- 30	3.5	11.1	3.1
	30- 45	3.9	12.6	3.2
	45- 60	4.0	13.0	3.2
	60- 90	4.0	13.4	3.3
	90-120	4.1	13.3	3.2
	120-150	4.2	13.7	3.2
Mukoma 3	0- 10	3.8	11.6	3.0
	10- 30	3.9	11.3	2.8
	30- 60	4.0	12.4	3.1
	60- 80	4.1	11.6	2.8
	80-100	4.2	12.5	2.9
	100-120	4.4	12.3	2.7
	150-160	4.2	13.4	3.1
Mbalageti 1	0- 14	3.4	12.4	3.6
	14- 40	3.2	11.4	3.4
	40- 70	3.3	11.7	3.4
	70-100	3.4	12.3	3.5
	100-115	3.7	13.8	3.6
Mbalageti 2	0- 6	3.6	11.7	3.2
	6- 20	3.4	11.5	3.4
	20- 60	3.6	12.5	3.4
	60- 77	3.7	13.4	3.6
	77- 92	3.7	13.0	3.4
	92-117	3.8	13.5	3.5
Togoro 1	0- 20	3.8	11.5	3.0
	20- 40	3.5	10.8	3.0
	40- 84	3.5	10.8	3.0
	84-135	4.1	12.6	3.0
Rhino 7	0- 10	4.5	15.1	3.3
	10- 55	4.2	13.3	3.1
	55- 75	4.0	13.7	3.4
	75-100	4.7	15.1	3.1
	>100	5.0	15.5	3.0
Bololedi 2	0- 20	3.0	9.3	3.1
	20- 30	2.8	9.4	3.2
	30- 60	2.8	10.1	3.6
	60-100	2.8	10.1	3.5
Mbalageti ash		4.6	15.8	3.4
SRI-3*	0- 15	3.2	9.9	3.1
	15- 32	2.9	10.6	3.7
	32- 45	3.2	11.6	3.6
	67- 80	3.4	12.0	3.5
	92-105	3.5	12.5	3.5

Table 18. Continued.

	Depth (cm)	SiO_2/Al_2O_3	SiO_2/Fe_2O_3	Al_2O_3/Fe_2O_3
GS-3	0- 9	4.3	11.8	2.7
	9- 20	3.8	11.1	2.9
	20- 30	3.8	11.3	2.9
	40- 50	3.7	11.8	3.1
	80- 90	3.9	12.1	3.1
	110-120	3.9	12.6	3.2
	140-150	4.0	13.1	3.3
NANO-A	0- 25	4.2	15.3	3.6
	25- 45	3.7	13.7	3.7
	45- 57	3.6	13.8	3.8
	70- 95	4.1	16.2	3.9
	120-140	4.5	20.0	4.4
NANO-B	0- 20	4.2	15.0	3.6
	20- 40	3.7	13.6	3.7
	50- 60	3.6	13.4	3.7
	80-100	3.8	15.1	3.9
	120-140	3.7	19.8	5.3
SEK-NE	0- 16	4.0	15.8	3.9
	30- 40	3.8	14.9	3.9
	55- 70	3.7	14.4	3.8
	90-110	3.6	13.8	3.8
	130-150	3.9	14.2	3.7
	190-210	4.4	14.2	3.2

fluenced the Fe_2O_3 content of fine earth and non-clay fractions. The changes in Fe_2O_3 content of the non-clay fraction was more abrupt in the Serengeti Plain-Woodlands transitional area than the change in Fe_2O_3 content of the fine earth fraction (compare iron contents of SRI-2 and GS-3, located in the Woodlands and Plain, respectively).

The Fe_2O_3 content of all three fractions of the Mbalageti ash sample, collected some 75 km west of the Plain-Woodlands boundary at a depth of about 3 m, was somewhat lower than at a Plain site near the Ngorongoro Highlands.

The age of the Mbalageti ash was estimated at about 40 000 B.P. (Section 2.2.2), whereas the Plain ashes were of more recent date (22 000-1500 B.P.). Probably the ash cover of the Serengeti Woodlands consists of a mixture of the older Mbalageti ash (Upper Ndutu beds; Hay, 1976) and recent Plain ashes (Naisiusiu and Namorod beds). The influence of the Plain ashes decreases westward and northward of the Plain.

The highest TiO_2 content of the fine earth fraction of the subsoil samples (about 1.5%) was encountered in the area near the Serengeti Plain. The TiO_2 content of the fine earth fraction of the Mbalageti ash was 2.2%. If the soils of the Western Corridor had formed predominantly in the Mbalageti ash, one would expect more TiO_2. So the Corridor soils must have been influenced by recent Plain ashes too. Outside the Western Corridor, the Plain ashes probably covered part of the Northern Extension.

Table 19. Mass fractions of Fe_2O_3 in total fine earth, non-clay and clay fractions for some sites in the Serengeti Woodlands and Plain. Data on Plain soils were derived from de Wit (1978).

	Depth (cm)	Mass fraction (%)		
		Total fine earth	Non-clay	Clay
SRI-1	0- 9	3.7	2.2	10.0
	9- 30	4.4	2.2	10.3
	30- 80	5.6	2.3	10.3
SRI-2	0- 9	4.6	1.7	10.6
	9- 19	4.9	1.2	10.6
	19- 33	4.7	1.0	10.5
	>80	6.2	3.7	9.8
Mukoma 1	0- 15	3.2	1.6	11.1
	15- 30	5.4	1.3	10.9
	30- 45	5.0	1.0	10.2
	45- 60	6.0	1.9	10.0
	60- 90	5.5	3.7	9.9
	90-120	6.0	4.2	10.1
	120-150	6.3	5.6	9.8
Mukoma 3	0- 10	6.6	2.0	10.9
	10- 30	6.8	1.2	11.2
	30- 60	7.1	2.7	10.5
	60- 80	7.4	2.7	10.9
	80-100	7.5	4.2	10.6
	100-120	8.0	4.9	11.0
	150-160	8.0	7.1	10.1
Mbalageti 1	0- 14	6.2	4.5	10.1
	14- 40	6.8	4.0	10.7
	40- 70	8.2	5.3	10.5
	70-100	7.8	4.8	10.2
	100-115	7.4	6.4	9.5
Mbalageti 2	0- 6	5.7	4.5	10.4
	6- 20	7.9	6.0	10.7
	20- 60	7.7	4.4	10.1
	60- 77	7.6	6.7	9.6
	77- 92	7.7	6.5	9.8
	92-117	7.8	6.8	9.7
Togoro 1	0- 20	3.4	1.7	11.1
	20- 40	4.2	1.7	11.7
	40- 84	6.1	1.3	12.0
	84-135	6.9	5.0	10.8
Rhino 7	0- 10	1.3	-	9.2
	10- 55	2.8	-	10.1
	55- 75	3.1	-	9.9
	75-100	3.6	-	9.5
	>100	3.7	-	9.5
Bololedi 2	0- 20	3.3	1.0	12.4
	20- 30	3.4	-	12.4
	30- 60	4.0	-	11.4
	60-100	5.4	1.2	11.7
Nyara Swiga 2	0- 19	7.2	5.0	15.0
	19- 62	9.1	5.6	15.2
	62- 95	10.1	6.3	15.9
	95-150	10.5	6.9	15.1
Mbalageti ash		8.5	8.5	8.4
GS-3	0- 9	7.7	6.6	10.1
	9- 20	9.1	6.9	10.4
	20- 30	8.9	6.8	10.2
	40- 50	9.5	9.4	9.5
	80- 90	9.2	8.9	9.5
	110-120	9.0	8.9	9.2
	140-150	8.6	8.6	8.0

Table 19. Continued.

	Depth (cm)	Total fine earth	Non-clay	Clay
NANO-A	0- 25	8.5	8.8	7.8
	25- 45	9.2	9.5	8.5
	45- 57	9.3	9.7	8.5
	70- 95	7.2	7.2	7.3
	100-140	7.6	7.8	5.8
NANO-B	0- 20	8.5	8.3	8.0
	20- 40	9.1	9.5	8.3
	50- 60	8.9	9.0	8.5
	80-100	7.4	7.4	7.2
	120-140	7.2	7.4	4.3
SEK-NE	0- 16	9.2	9.9	7.6
	30- 40	9.5	7.8	10.2
	55- 70	9.2	9.6	7.9
	90-110	8.9	9.1	8.4
	130-150	9.0	9.3	8.2
	190-200	10.0	10.3	8.5

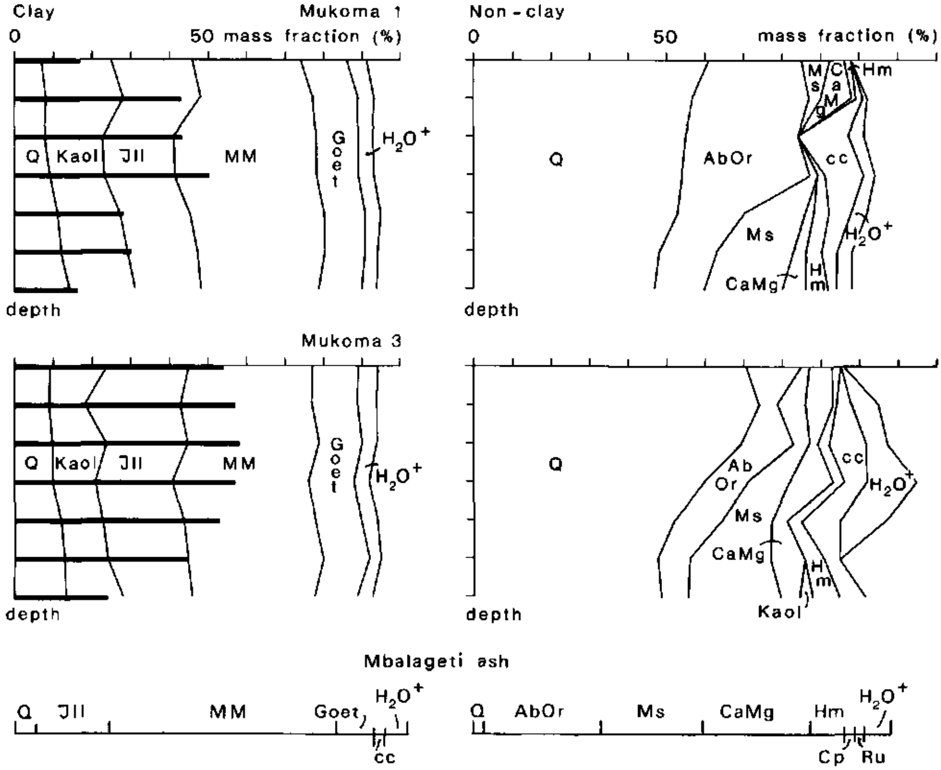
8.3.2 Petrochemical calculations

Possible mineralogical composition of clay (< 2 μm) and non-clay fractions was derived by both conventional and thermodynamic calculations.

Goethite norm calculation

Conventional goethite norm calculations were based on the chemical composition of the clay and non-clay fraction, according to methods developed by Burri & Niggli (1945) and Burri (1959), modified by van der Plas and van Schuylenborgh (1970). The thermodynamic norm calculations were based on Brown & Skinner (1974) and Meijer (in prep.). Results of the conventional calculations for the clay fraction are graphically represented in Figure 62, 63 and 64. Gradual changes in the six normative components, quartz, kaolinite, illite, montmorillonite, goethite and water suggest that either the weathering products of the different ash deposits were similar in composition, or that the soils had been formed in a thick homogeneous ash (uniform parent material). Calculations for soils from the Serengeti Plain and Woodlands gave similar results. Depth of clay accumulation and clay content depend on the degree of weathering and position in the terrain.

Results of the conventional goethite norm calculation did not agree with the results of X-ray analysis of the clay fraction (Section 8.3.3), indicating that weathering was not complete. Results of the thermodynamical goethite norm calculation (298.15 °K, 101.5 kPa, H_2O available, CO_2 available) differed from both the conventional calculation and from the mineralogical analysis. The thermodynamical calculation assumes that the most stable mineral assemblage is present. For the clay fraction of the Serengeti soils, this is certainly not true.



Q : quartz	Goet: goethite	Hm: hematite
Kaol: kaolonite	AbOr: albite and orthoclase	Ru: rutile
Ill : illite	Ms : muscovite	Cp: calcium phosphate
MM : montmorillonite	CaMg: calcium-magnesium minerals	cc: calcium carbonate

Figure 62. Mineral composition of clay and non-clay fractions of the horizons of profile Mukoma 1, Mukoma 3 and Mbalageti ash, according to goethite and epinorm calculations, respectively. Bars indicate clay content.

Epinorm calculation

Conventional epinorm calculations were based on the chemical composition data of the non-clay fractions (< 2 mm). Results are given in Figure 62, 63 and 64. One notices differences between Serengeti Plain and Woodlands soils. SEK-NE, a short grassland site on the Serengeti Plain, had low contents of normative quartz and relatively high contents of normative musvovite and calcium-magnesium minerals, whereas sodium and potassium feldspars (albite and orthoclase) were absent. At a typical Serengeti Woodlands site like Boloedi 2 (in the Northern Extension), normative quartz and feldspars were present in large amounts, whereas muscovite and calcium-magnesium minerals were almost absent, showing the influence of the underlying rock. In between the two sites one finds intermediate compositions. The Mbalageti ash (Figure 62) hardly contained any normative quartz, but was rich in normative sodium-potassium feldspars, muscovite and calcium-magnesium minerals.

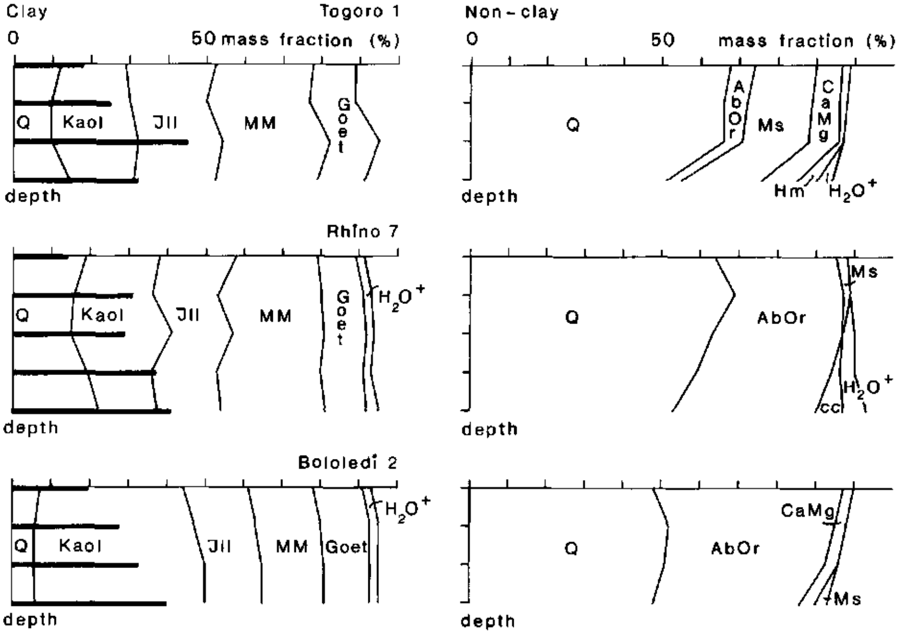


Figure 63. Mineral composition of clay and non-clay fractions of the horizons of profile Togoro 1, Rhino 7 and Bololedi 2, according to goethite and epinorm calculations, respectively. Bars indicate clay content. For key see Figure 62.

Conclusions

The mineral composition of the recent Plain ashes and the Woodlands ashes differs slightly. The Woodlands ashes, a mixture of 'Mbalageti ash' and recent Plain ash, contain, according to the petrochemical calculations, normative feldspars in contrast to the Plain ashes that are richer in normative muscovite and calcium-magnesium minerals, at least in the non-clay fraction.

The results of the conventional epinorm and thermodynamic goethite norm calculation on the non-clay fraction agree fairly well with results from optical analysis and from X-ray diffraction. Part of the non-clay fraction may consist of non-crystalline aggregates with a very high cation-exchange capacity (Section 8.3.8).

8.3.3 X-ray diffraction patterns

X-ray diffraction patterns were analysed for the clay fraction (< 2 μm) from the Serengeti Woodlands and for the sand fraction of the Mbalageti ash sample. Except in samples from the Rhino Mbali Pali area, where montmorillonite and kaolinite were observed, hardly any crystalline material was detected.

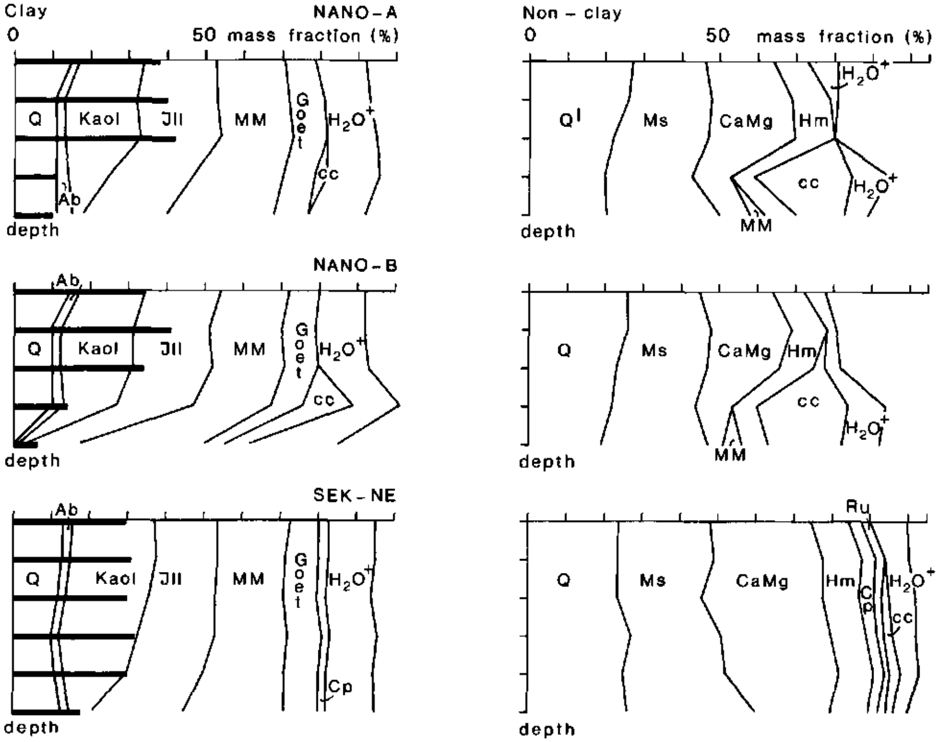


Figure 64. Mineral composition of clay and non-clay fractions of the horizons of profile NANO-A, NANO-B and SEK-NE, according to goethite and epinorm calculations, respectively. For the calculations, data were used from de Wit (1978). For key see Figure 62. Bars indicate clay content.

The X-ray amorphous material, 'behaved' like allophane (amorphous aluminosilicates) as described in the literature (Jackson, 1956; Fey & le Roux, 1975; Wada & Harward, 1974). Clay fractions of a Mukoma 3 subsoil (lower pediment soil in the Western Corridor) and a Togoro 1 topsoil (ridge soil in the Northern Extension) were treated with NaOH (Hashimoto & Jackson, 1960). The loss of weight of both samples after this treatment was negligible and the diffraction pattern of the residue was similar to that of the original material. Treatment with ammonium oxalate (Fey & le Roux, 1975) gave the same results. Both treatments were repeated after a dithionite treatment to remove iron coatings that would have protected any allophanes. Again there was no change in the diffraction pattern.

The X-ray diffraction patterns before and after treatments with NaOH and ammoniumoxalate showed that the clay fraction of the Serengeti Woodlands soils consisted almost entirely of X-ray amorphous material. Some properties of the fraction were similar to those of stable allophanes (Jackson, 1969; Table 21). However, SiO_2/Al_2O_3 mole ratios and cation-exchange capacity of

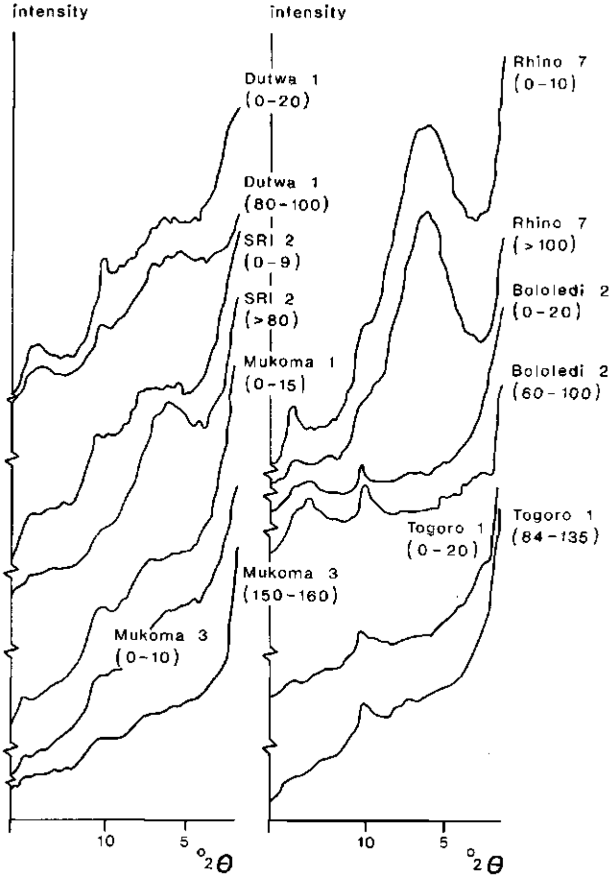


Figure 65. X-ray diffraction patterns for some soils of the Western Corridor (Mukoma 1, Mukoma 3, SRI-2 and Dutwa 1) and for some soils of the Northern Extension (Togoro 1, Bololedi 2 and Rhino 7).

stable allophanes are much lower than for the material from the Serengeti soils.

Here and there in the Serengeti Plain, de Wit (1978) found high contents of amorphous material soluble in HCl as well as zeolites. This again shows the different nature of ash in the Serengeti Plain and Woodlands.

A summary of X-ray diffraction patterns (Figure 65) shows that to the west and north of the Serengeti Plain there are more crystalline clay minerals. The diffractograms showed peaks at wavelengths around 1.0 nm (characteristic for mica type clay minerals) and 1.5 nm (characteristic for swelling clay minerals). After a treatment with glycerol, the peak at 1.5 nm in the Rhino samples shifted to 1.8 nm, indicating that the swelling clay mineral in the Rhino Mbali Pali area was montmorillonite. Samples from the Serengeti Plain showed the same phenomena. Sites SEK-NE, NANO-B, GS-3 and

GT-3 are representative for short, intermediate and long grassland, respectively.

The gradual increase in crystalline clay minerals in a northerly and easterly direction can be a combined result of increased weathering intensity, because of higher rainfall, age and composition of the volcanic deposits. Increased weathering is assumed to be the major factor.

Ashes from eruptions of the volcanoes in the Ngorongoro Highlands would not always cover the same area. Some eruptions may have influenced only the immediate surroundings of the volcanoes; others would have covered the entire area.

8.3.4 Electron microscopy

Since the diffraction patterns are not in line with the petrochemical calculations, electron microscopy was the next step in analysis.

Clay fractions of four samples were studied by transmission electron microscopy after removal of iron coatings. Two of the photographs are shown here (Figure 66 and 67). Electron diffraction showed very little crystalline material. Crystallinity was not altogether absent, as seen from the presence of hexagonal particles.

8.3.5 Thermal analysis

Van Doesburg (1980) found a small loss of weight between 100 and 200 °C for two Plain topsoil samples. Allophanes lose much more weight (Figure 68). In two Serengeti Woodlands soils, losses were a few per cent only. Jackson (1969) found a comparable negligible loss on heating stable allophanes (Table 21).

8.3.6 Cation-exchange capacity delta value

Cation-exchange capacity delta (Aomine & Jackson, 1959) was calculated for some samples. Increases in cation-exchange capacity of the clay fraction between pH 3.5 and pH 10.5 in soils of the Serengeti Woodlands ranged from 200 to 500 mmol/kg. By contrast, allophanes showed a very marked increase, usually exceeding 1 mol/kg.

8.3.7 pH(NaF)

Fieldes & Perrot (1966) developed a field test for allophanes. Two minutes after shaking 1 g of soil with 50 ml NaF (concentration 1 mol/l), the pH exceeds 9.4, or after 1 h, pH 10.8, if allophanes are present. In the Serengeti Woodlands samples, pH was determined after 1 h but no values exceeded 10.8. Only in the Serengeti Plain did pH locally exceed 10.0.

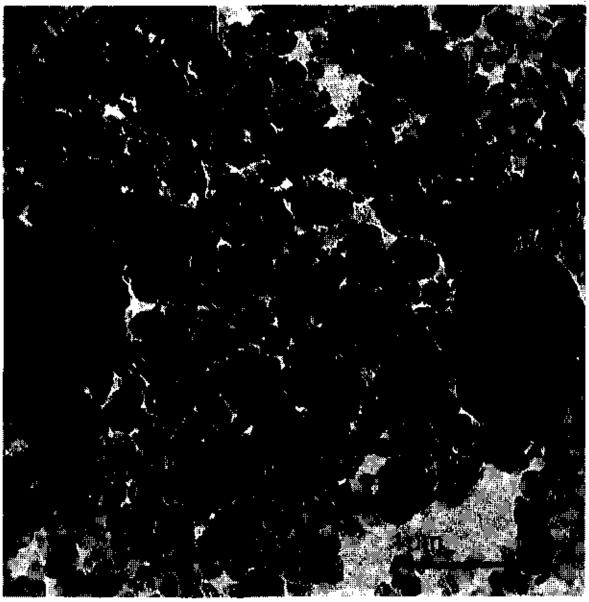


Figure 66. Electron micrograph of clay fraction of subsoil (20-30 cm) at Bololedi 2 (photograph by Technical and Physical Engineering Research Service, Wageningen).

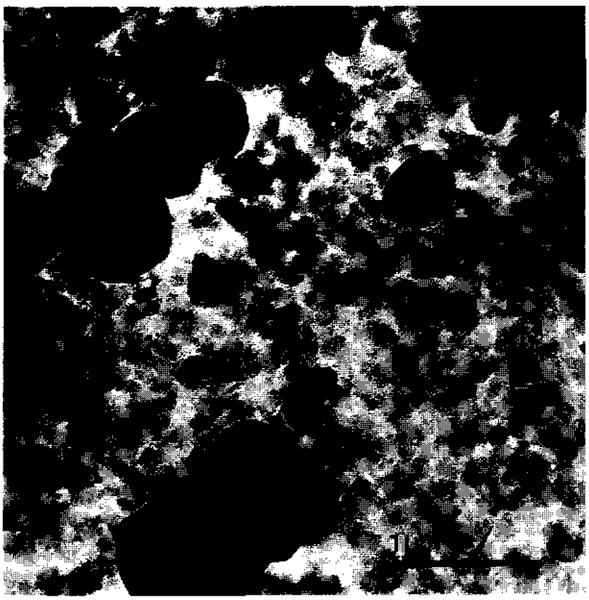


Figure 67. Electron micrograph of clay fraction of subsoil (19-33 cm) at SRI-2 (photograph by Technical and Physical Engineering Research Service, Wageningen).

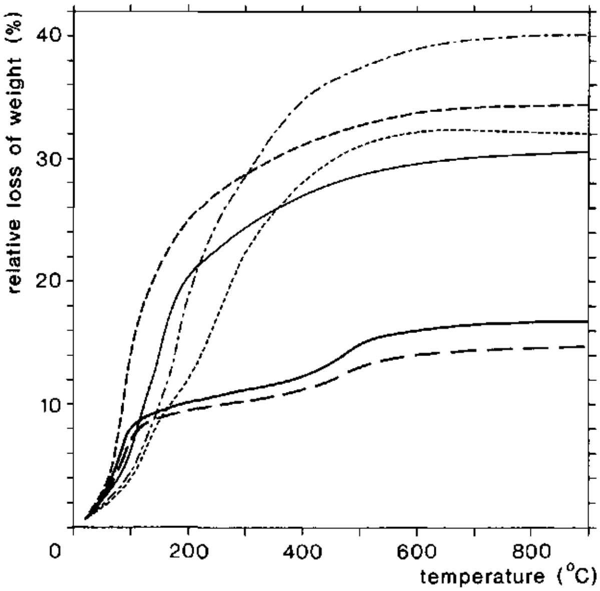


Figure 68. Relative loss of weight after heating 4 allophanes and 2 topsoil samples from the Serengeti Plain: NANO-B (———) and GT-3 (— — —) (from van Doesburg, 1980).

8.3.8 Surface area

Surface area determined by H_2O adsorption for clay fractions of three samples only (Table 20) was high but similar. Surface area for the non-clay fraction of the three samples was extremely high. Especially at Mukoma 3, near the Serengeti Plain, the silt, fine and medium sand fractions must consist almost entirely of stable aggregates of clay particles to explain the high surface area.

8.4 MINERAL COMPOSITION

8.4.1 X-ray amorphous component of the clay fraction

Properties of the X-ray amorphous material in the clay fraction of soils of the Serengeti Woodlands were very similar to those of the 2:1 layer silicate relics described by Jackson (Table 21).

- small loss of weight on heating to 100 °C
- relatively high SiO_2/Al_2O_3 mole ratio: 3-4
- low solubility in acid and alkali
- cation-exchange capacity of clay fraction between 600 and 1000 mmol/kg.

The relics described by Jackson, however, still exhibited much of the morphology of the parent material but were X-ray amorphous. The material

Table 20. Surface area estimated by H_2O adsorption for three soils of the Serengeti Woodlands and for selected clay minerals (Dixon & Weed, 1977).

	Surface area (10^3 m^2/kg)		
	soil	clay	non-clay
Mukoma 3	294	346	236
Togoro 1	94	312	96
Mbalageti ash	165	348	155
montmorillonite		800	
kaolinite		12	
illite		65	
smectite		750	
allophane		500	

Table 21. Diagnostic properties of amorphous mineral colloids of soils (Jackson, 1965).

Type of amorphous material	Weight loss at 100 °C (%)	SiO_2/Al_2O_3 mole ratio	Solubility in dilute acid and alkali	Refractive index	Cation-exchange capacity (mmol/kg)			
					natural	loss on heating (%)		
						100°C	400°C	500°C
Allophane								
unstable	30	0.3-2.0	high	1.48	500-3500	varies	50	-
stable	-	2.0	low	-	100	-	10	80
Silica	10	-	high	1.50	300	-	little change	-
Alumina	20	-	high	-	1000-4000	40	70	-
Iron oxides	10-20	-	high	-	100- 400	varies	100	-
Titanium oxides	20	-	low	-	1000-4000	varies	50	80
2:1 layer silicate relics	10	3-4	low	-	600-1000	-	-	-

studied with the electron microscope did not show mica relics. Jackson (1969) states: 'Thus the amorphous silica derived by the weathering of biotite or muscovite particles retain the sheen and flaky appearance of mica but the atomic spacings in such silica relics are repeated too few times to give diffraction evidence of crystallinity'. Since the Mbalageti ash sample contains much biotite (Section 8.4.3), this process may have contributed to properties, especially of the Serengeti Woodlands soils.

8.4.2 Sand fraction

In eleven samples light and heavy minerals were separated and studied optically and by X-ray diffraction. The mass fraction of heavy minerals (Table 22) ranged from 0.5 (Togoro 1) to 20.6% (Larale 1). Larale 1 was transitional to the Serengeti Plain. Its properties were similar to those of the Plain soils, but the site was surrounded by densely wooded valley slopes and so was included in the Serengeti Woodlands. At sites near the Plain, diopside was the major heavy mineral. Some augite was usually present too, though not in such large amounts as on the Serengeti Plain (de Wit, 1978). Further north and west, epidote, garnets (here and there if underlain by metamorphic rocks), zircon and much opaque material were encountered. Petrochemical calculations suggested the presence of muscovite but it was not detected optically or by X-ray diffraction analysis.

Soils close to the Ngorongoro Highlands contained about 10 times as much heavy minerals as further away in the Serengeti Woodlands (Table 22). At the boundary of Plain and Woodlands, a sharp discontinuity was noticed, suggesting that the Woodlands had been less covered by recent deposits. The rainfall gradient almost coincided with the decrease in volcanic deposits, so it is difficult to distinguish the factors weathering and composition of the parent material.

In the light mineral fraction, both hydrothermal and 'granitic' quartz predominate. Near the Plain, large amounts of plagioclase and some potassium feldspar (sanidine) were observed.

At Bololedi 2 in the Northern Extension, large amounts of potassium feldspar (microcline) were present, because the underlying gneiss contained much potassium feldspar.

Of the light mineral fraction, 8.5, 22.9 and 28.6% consisted of potassium feldspar at sites Togoro 1, Mbalageti 2 and Bololedi 2, respectively. Albite was present locally in smaller amounts.

Thus in the Woodlands 'proper', variations in the light and heavy miner-

Table 22. Mass fraction of heavy minerals in the sand fraction (50-420 nm) of six Serengeti Woodlands and three Serengeti Plain soils.

	Depth (cm)	Mass fraction (%)
SEK-NE	0- 16	39.7
NANO-A	0- 25	57.2
GT-3	0- 10	32.1
Larale 1	90-100	20.6
Mbalageti 2	60- 77	5.4
Mukoma 3	100-120	2.6
SRI-2	33- 80	6.1
Togoro 1	40- 80	0.5
Bololedi 2	30- 60	1.7

al fractions depended mainly on the composition of the underlying rock. So the greater part of the sand fraction is of residual origin.

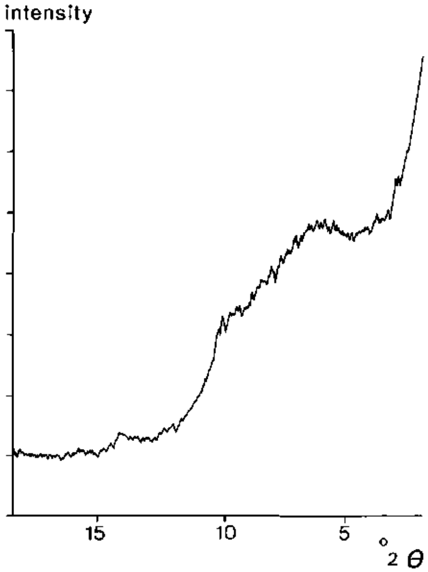
8.4.3 The Mbalageti ash

Chemical composition and the results of petrochemical calculations have been discussed in Section 8.3. Results of X-ray diffraction analysis of the fine clay, clay and fine sand fractions are given below.

Fine clay fraction (< 0.5 μm): The X-ray diffraction pattern showed that there was much interstratified poorly crystalline material (Figure 69). Glycerol treatment caused a shift of the 'composite peak' towards wider spacings, suggesting the presence of swelling clays (Figure 70).

Clay fraction (< 2 μm): The X-ray diffractogram revealed a peak at 1.2 nm, suggesting the presence of vermiculitic clays (Figure 71).

Fine sand fraction (50-250 μm): There was a clear peak in the diffractogram at 1.2 nm (Figure 72). Glycerol treatment caused no shift (Figure 73). Heating to 600 °C caused a shift to 1.0 nm (Figure 74), as did saturating



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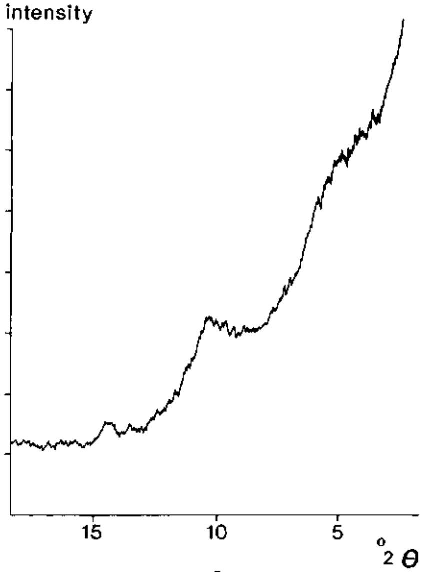

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Figure 69. X-ray diffraction pattern of fine clay fraction from Mbalageti ash after magnesium saturation.

Figure 70. X-ray diffraction pattern of fine clay fraction from Mbalageti ash after glycerol treatment.

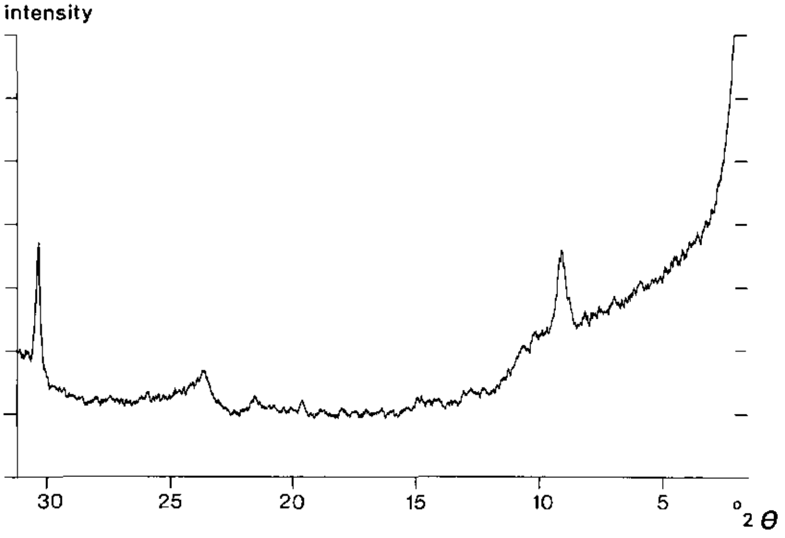


Figure 71. X-ray diffraction pattern of clay fraction from Mbalageti ash.

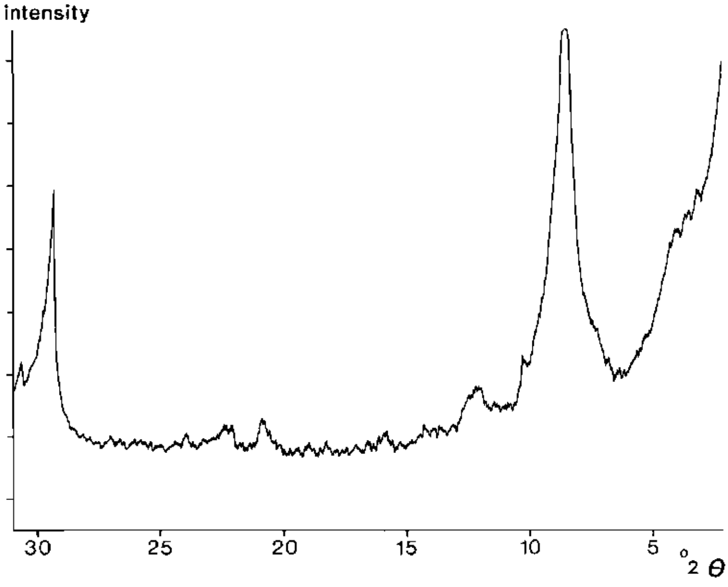
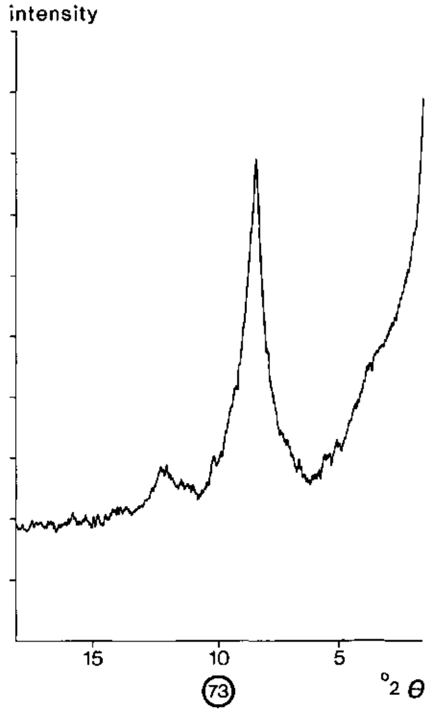


Figure 72. X-ray diffraction pattern of fine sand fraction from Mbalageti ash.



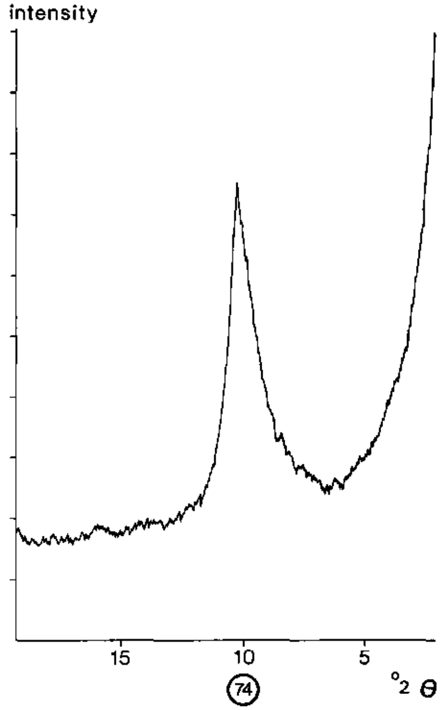


Figure 73. X-ray diffraction pattern of fine sand fraction from Mbalageti ash after glycerol treatment.

Figure 74. X-ray diffraction pattern of fine sand fraction from Mbalageti ash after heating to 600 °C.

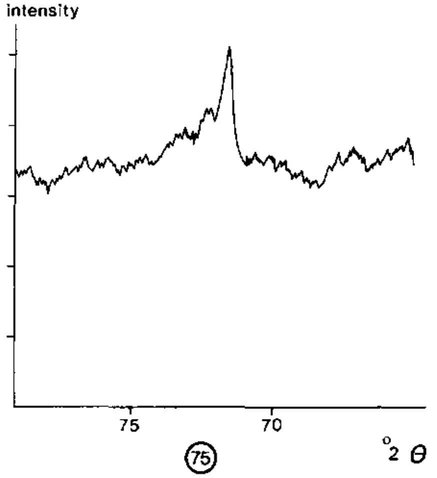


Figure 75. X-ray (060) diffraction pattern of fine sand fraction from Mbalageti ash.

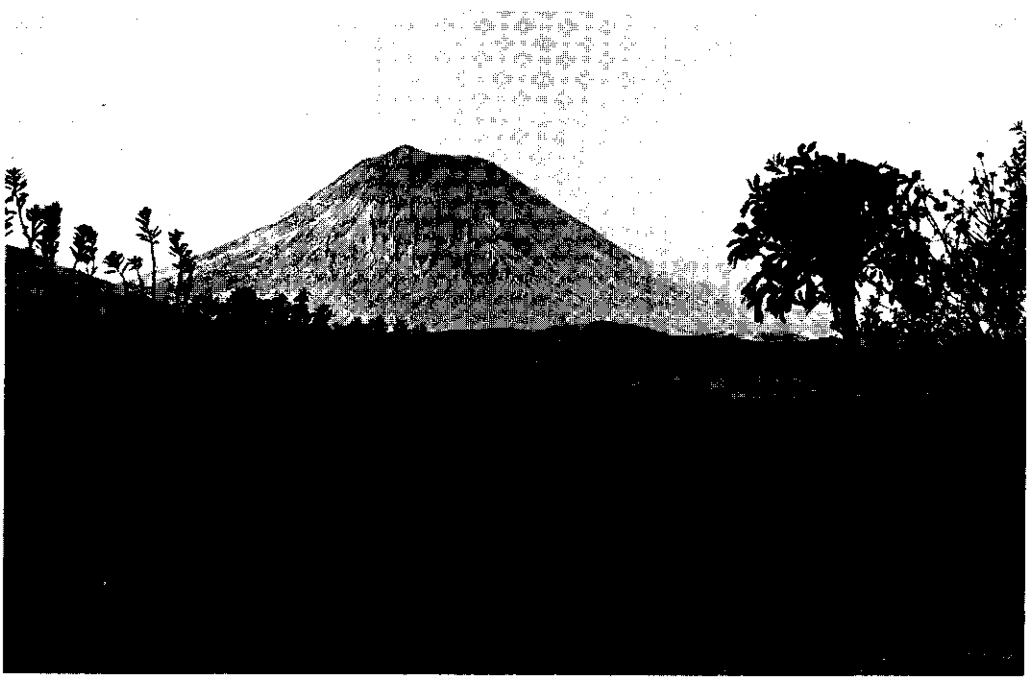


Figure 76. Oldoinyo Lengai, the volcano from which the majority of ash originated, covering the Serengeti National Park.

the soil with K instead of Mg. This is typical for non-swelling vermiculite. The (060) peak at 0.153 nm, diagnostic for the trioctahedral character of the vermiculite, was obvious (Figure 75). So the fine sand fraction must contain a significant quantity of regular interstratified vermiculite (Veniale & van der Marel, 1969). Quartz was present in the fine sand fraction as well. Optical investigation of the sand fraction showed an abundance of biotite. Point counting gave 30% of biotite. The biotite flakes were rather weathered. Conoscopial observation showed a poorly developed crystal, because optically normal interference was not very clear. The pleiochroism was, however, still visible.

Petrochemical calculations indicated muscovite, but biotite has now proved to be a major component. Hay (1976) mentions several 'tuffs' rich in biotite that had erupted from Oldoinyo Lengai (Figure 76) about 40 000 B.P. (Upper Ndutu beds). Leaky (pers. commun.) estimated the date of a rhino skull found in the Mbalageti ash as the same. The ashes of the Serengeti Plain are of much more recent times (de Wit, 1978).

8.5 DISCUSSION

There are two types of ashes in the Serengeti National Park. The Serengeti Plain is covered by young ashes, deposited between 22 000-1500 years ago. In the Woodlands, the recent ash did not reach the same thickness, so the older Upper Ndutu beds have influenced the soil properties and composition too.

The X-ray amorphous character of the clay fraction of soils in the Serengeti Woodlands can be explained partly by weathering of the biotite component towards 2:1 layer silicate relics. However, one would expect that large amounts of volcanic glass would have been deposited too, which would also lead to an X-ray amorphous clay fraction. Fragments of weathered glass may also lead to an X-ray amorphous material, especially if the type of weathering created a permutite-like substance. This substance may break up into clay-sized fragments and may even resemble smectite in swelling properties. Although unweathered glass was not observed, it could have been present. If so, the soils of the Serengeti Woodlands are largely a result of weathering of volcanic glass and biotite.

9 Soil classification

9.1 INTRODUCTION

Tables 23-27 enumerate to family level the classification of the soils described in the Serengeti Woodlands. Soil series are listed in Tables 28 and 29, which mention only the soil series encountered at more than one site. Since topographic names have been used for the sites, soil series are named after people (who contributed to the project), animals (in Swahili) and the presence of hardened plinthite (locally called murram) at shallow depths.

By far the greater part of the soils were classified as Mollisols. Since the colour of the topsoil and contrast between the topsoil and IC horizon are conclusive for the colour requirements of a mollic epipedon, deep boring was sometimes necessary to establish the colour of subsoil or underlying (rotten) rock. The soil pits hardly ever reached the IC horizon. The colour contrast requirement is waved, however, if the surface horizon meets all other criteria for a mollic epipedon and has in addition at least 6% more organic carbon than the IC or IIC horizon or if the epipedon extends to rock. Criteria for base saturation (50% or more) and organic carbon content (at least 0.6%) were always met.

Almost all the Mollisols had an argillic (or natric) horizon.

According to Soil Taxonomy, one should be able to observe clay skins if an argillic or natric horizon is present or if the illuvial horizon has 2:1 lattice clays, there are uncoated grains of sand or silt in the overlying horizon and evidence of pressure caused by swelling (Soil Taxonomy, 1978). Evidence of swelling was often observed. The clay fraction consisted largely of X-ray amorphous materials. So the presence of 2:1 lattice clays was not taken as a prerequisite. An additional requirement is that the argillic horizon should contain at least 3 and 8% more clay if the eluvial horizon has less than 15%, and more than 40% total clay, respectively, or the mass ratio between clay in the argillic horizon to that in the eluvial horizon should be 1.2 or more if the eluvial horizon contains 15-40% clay. Where a horizon was called argillic the last criterion was always met. Clay skins were not always observed, partly because of biological activity.

At the subgroup level, the prefix Udic was often used for the Argiustolls, since soft powdery lime was not detected within 1.25, 0.90 and 0.70 m, if the weighted average particle size class of the upper 50 cm of the argillic horizon was sandy, loamy or clayey, respectively.

The moisture regime in relation to soil classification was discussed in Section 7.5.

9.2 SOILS OF THE WESTERN CORRIDOR

Soils of the Western Corridor and the Kirawira area are listed in Tables 23 and 24. For a subdivision into soil series, soil colours were used (Tables 28 and 29).

All the soils except three were Mollisols. Two valley bottom soils were classified as Vertisols and one granitic pediplain soil as an Alfisol. Two other valley bottom soils (Mukoma 4 and Musabi 2) were classified as Alfisols too, even though all but one criteria for a mollic epipedon were met. If an isomesic or warmer iso-temperature regime prevails, cracks 1 cm wide at a depth of 50 cm, high coefficient of linear extension (> 0.07 when the moisture regime is ustic), high potential extensibility (> 6 cm for the upper 1.25 m) and clay content exceeding 35% are not allowed for a mollic epipedon.

Site Kirawira 3 was classified as an Aquoll, since it was periodically flooded and since the lower part of the mollic epipedon had a chroma 1 and distinct mottles.

There were also shallow and very shallow soils on hardened plinthite or a petrocalcic horizon. They were classified as Petroferric Haplustolls and Petrocalcic Paleustolls. Especially Petrocalcic Paleustolls had a limited distribution.

9.3 SOILS OF THE NORTHERN EXTENSION

All sites in the Northern Extension were classified as Mollisols (Tables 25 and 26). If an argillic or natric horizon was absent, they met criteria for Haplustoll; otherwise they were classified as Argiustolls and Natrustolls. The greater part of the soils were Argiustolls, while in the Western Corridor Natrustolls predominated. In most soils soft powdery lime was not found within the required depths (Section 9.1), so that most Argiustolls were designated Udic.

Some soils in the Northern Extension had a petrocalcic horizon (Petrocalcic Paleustolls).

9.4 SOILS OF THE FRINGE OF THE SERENGETI PLAIN

Sites described in the Fringe fell under Argiustolls or Natrustolls, the latter predominating (Table 27). The soil moisture regime was classified as aridic at SRI-2 and Larale 1, since it was assumed that the soil moisture control section was not moist for 90 consecutive days or more. Larale 1 did not meet the natric requirements, since prims or tongues were not observed despite high exchangeable sodium percentage.

Table 23. Classification of soils of the Western Corridor to family level.

	Mollic epipedon	Argillic horizon	Ustic moisture regime	Natric horizon	Udic	Vertic	Particle size class	Mineralogy	Calcareous	Soil temp. regime	Classification
Mukoma 1	x	x	x	x			fine	amorphic	-	iht	Typic Natrustoll
Mukoma 2	x	x	x	x			fine	amorphic	+	iht	Typic Natrustoll
Mukoma 3	x	x	x	x			fine	amorphic	+	iht	Typic Natrustoll
Mukoma 4	x	x	x			(x)	fine	amorphic	-	iht	Vertic Haplustalf
Mukoma 5	x	x	x	x			fine	amorphic	+	iht	Typic Natrustoll
Mbalageti 1	x	x	x		x		fine	amorphic	-	iht	Udic Argiustoll
Mbalageti 2	x	x	x	x			fine	amorphic	+	iht	Typic Natrustoll
Nyara Swiga 2	x	x	x		x		fine	amorphic	-	iht	Udic Argiustoll
Nyara Swiga 3	x	x	x	x			fine	amorphic	-	iht	Typic Natrustoll
Ndabaka 1	x	x	x				fine	amorphic	-	iht	Typic Pellustert
Ndabaka 2	x	x	x	x			very fine	amorphic	-	iht	Typic Natrustoll
Kamarishe 1	x	x	x		x		loamy skeletal	amorphic	-	iht	Udic Argiustoll
Kamarishe 2	x	x	x	x			fine	amorphic	-	iht	Typic Natrustoll
Kamarishe 3	x	x	x	x			fine	amorphic	+	iht	Typic Natrustoll
Ndoho	x	x	x		x		fine	amorphic	-	iht	Udic Argiustoll
Musabi 1	x	x	x		x		loamy fine	amorphic	-	iht	Udic Argiustoll
Musabi 2	x	x	x			(x)	fine	amorphic	-	iht	Vertic Haplustalf
Musabi 3	x	x	x		x		fine	amorphic	-	iht	Udic Argiustoll

Table 24. Classification of soils of the Kirawira area to family level.

	Ochric epipedon	Mollic epipedon	Argillic horizon	Ustic moisture regime	Aquic moisture regime	Natric horizon	Udic	Particle size class	Mineralogy	Calcareous	Soil temp. regime	Classification
Kirawira 1	x		x	x		x		fine loamy	amorphic	-	iht	Typic Natrustoll
Kirawira 2		x	x	x		x		fine	amorphic	-	iht	Typic Natrustoll
Kirawira 3		x	x		x	x		fine	amorphic	-	iht	Typic Natraquoll
Kirawira 4		x	x	x		x		fine	amorphic	-	iht	Typic Natrustoll
Kirawira 5		x	x	x		x		fine	amorphic	-	iht	Typic Natrustoll
Kirawira 7		x	x	x		x		fine	amorphic	-	iht	Typic Natrustoll
Kirawira 8		x	x	x			x	fine	amorphic	-	iht	Udic Haplustoll
Dutwa 1		x	x	x		x		fine	amorphic	-	iht	Typic Natrustoll
Dutwa 2		x	x	x		x		fine	amorphic	-	iht	Typic Natrustoll
Dutwa 3		x	x	x				fine	amorphic	-	iht	Entic Pellustert
Simiti 1		x	x	x			x	fine	amorphic	-	iht	Udic Argiustoll
Simiti 2		x	x	x		x		fine	amorphic	-	iht	Typic Natrustoll

Table 25. Classification of soils of the Northern Extension to family level.

	Mollic epipedon	Argillic horizon	Ustic moisture regime	Natric horizon	Lithic	Udic	Particle size class	Mineralogy	Calcareous	Soil temp. regime	Depth	Classification
Bololedi 1	x		x		x		fine loamy	amorphic	-	iht		Lithic Haplustoll
Bololedi 2	x	x	x			x	fine loamy	amorphic	-	iht		Udic Argiustoll
Bololedi 3	x	x	x			x	fine loamy	amorphic	-	iht		Udic Argiustoll
Togoro 1	x	x	x			x	fine loamy	amorphic	-	iht		Udic Argiustoll
Togoro 3	x	x	x			x	fine loamy	amorphic	-	iht		Udic Argiustoll
Togoro 4	x	x	x			x	fine loamy	amorphic	-	iht		Udic Argiustoll
Togoro 5	x	x	x	x			fine	amorphic	-	iht		Typic Natrustoll
Banagi 3	x	x	x	x			fine	amorphic	-	iht		Typic Natrustoll
Banagi 4	x	x	x	x			fine	amorphic	+	iht		Typic Natrustoll
Banagi 5	x	x	x			x	fine silty	amorphic	-	iht		Udic Argiustoll
Lamai 1	x		x		x		coarse loamy	amorphic	-	iht	shallow	Petroferric Haplustoll
Lamai 2	x	x	x			x	fine	amorphic	-	iht		Udic Argiustoll

Table 26. Classification of soils of the Rhino Mbali Pali area to family level.

	Mollic epipedon	Argillic horizon	Ustic moisture regime	Lithic	Aquic	Udic	Particle size class	Mineralogy	Calca-reous	Soil temp. regime	Depth	Classification
Mbali Pali 2	x	x	x			x	fine loamy	vermiculitic	-	iht		Udic Argiustoll
Mbali Pali 3	x	x	x			x	fine loamy	vermiculitic	-	iht		Udic Argiustoll
Mbali Pali 4	x	x	x		x		fine	amorphic	-	iht		Aquic Argiustoll
Rhino 2	x	x	x	x			fine loamy	amorphic	-	iht	shallow	Petroferric Argiustoll
Rhino 3	x	x	x				fine loamy	vermicultic	-	iht		Typic Argiustoll
Rhino 4	x		x			x	fine loamy	vermiculitic	-	iht		Udic Argiustoll
Rhino 5	x		x			x	sandy	siliceous	-	iht		Udic Haplustoll
Rhino 6	x		x	x			coarse loamy	amorphic	-	iht	shallow	Petroferric Haplustoll
Rhino 7	x	x	x				fine loamy	vermiculitic	-	iht		Typic Argiustoll

Table 27. Classification of soils of the Fringe of the Serengeti Plain to family level.

	Mollic epipedon	Argillic horizon	Aridic moisture regime	Ustic moisture regime	Natric horizon	Udic	Aridic	Vertic	Particle size class	Mineralogy	Calca-reous	Soil temp. regime	Classification
SRI-1	x	x		x		x			fine	amorphic	-	iht	Udic Argiustoll
SRI-2	x	x	x		x				fine	amorphic	+	iht	Typic Natrustoll
SRI-3	x	x		x				(x)	fine	amorphic	-	iht	Vertic Haplustoll
Larale 1	x	x		x			x		fine silty	amorphic	+	iht	Aridic Argiustoll
Larale 2	x	x		x	x				fine	amorphic	+	iht	Typic Natrustoll

Table 28. Classification of common soils to series level.

(Very) dark grey to black fine amorphic non-calcareous (Mcharo series)	Typic Natrustoll:	Mukoma 1, Kamarishe 2, Kirawira 7, Dutwa 1 and 2, Simiti 2, Togoro 5, Banagi 3
Dark (reddish) brown fine amorphic non-calcareous (Masingiri series)	Typic Natrustoll:	Nyara Swiga 3, Kirawira 2, 4 and 5
(Very) dark grey to black fine amorphic calcareous (Asenga series)	Typic Natrustoll:	Mukoma 2, 3 and 5, Mbalageti 2, Kamarishe 3, Larale 2, Banagi 4
(Very) dark grey to black fine amorphic non-calcareous (Twiga series)	Udic Argiustoll:	Mbalageti 1, Musabi 1 and 3, SRI-1, Simiti 1, Lamai 2
Dark (reddish) brown fine loamy amorphic non-calcareous (Simba series)	Udic Argiustoll:	Bololedi 2 and 3, Togoro 4
(Very) dark grey to black fine loamy amorphic non-calcareous (Duma series)	Udic Argiustoll:	Ndoho, Togoro 1 and 3
(Very) dark grey fine loamy vermiculitic non-calcareous (Chui series)	Typic Argiustoll:	Rhino 3 and 7
(Very dark) grey fine loamy vermiculitic non-calcareous (Tembo series)	Udic Argiustoll:	Mbali Pali 2 and 3
Very dark grey to black fine amorphic non-calcareous (Mbogo series)	Vertic Argiustoll:	Musabi 2, SRI-3, Mukoma 4
(Very) dark brown coarse loamy mixed non-calcareous shallow (Murram series)	Petroferric Haplustoll:	Lamai 1, Rhino 6

Table 29. Classification of soils of limited distribution to series level.

Very dark grey very fine amorphic non-calcareous	Typic Natrustoll:	Ndabaka 2
Very dark greyish-brown fine amorphic calcareous	Aridic Natrustoll:	SRI-2
Very dark grey fine loamy vermiculitic non-calcareous	Udic Argiustoll:	Rhino 4
Dark (reddish) brown fine amorphic non-calcareous	Typic Argiustoll:	Nyara Swiga 2
Very dark grey loamy skeletal siliceous non-calcareous	Udic Argiustoll:	Kamarishe 1
Very dark grey fine silty amorphic calcareous	Aridic Argiustoll:	Larale 1
Very dark grey fine silty amorphic non-calcareous	Udic Argiustoll:	Banagi 5
Very dark grey fine loamy amorphic non-calcareous shallow	Petroferric Argiustoll:	Rhino 2
Very dark grey to black fine loamy amorphic non-calcareous	Aquic Argiustoll:	Mbali Pali 4
Dark reddish-brown fine loamy amorphic non-calcareous	Lithic Haplustoll:	Bololedi 1
Dark grey fine amorphic non-calcareous	Udic Haplustoll:	Kirawira 8
Dark brown sandy siliceous non-calcareous	Udic Haplustoll:	Rhino 5
Very dark grey fine amorphic non-calcareous	Typic Aquoll:	Kirawira 3
Very dark grey to black fine amorphic non-calcareous	Typic Pellustert:	Ndabaka 1
Very dark grey to black fine amorphic non-calcareous	Entic Pellustert:	Dutwa 3

9.5 DESCRIPTION OF THE AMORPHIC MINERALOGY CLASS

Except for four sites, all the sites received the 'unofficial' prefix amorphic at family level, in order to stress the unique character of the clay fraction of the Serengeti soils. Volcanic influence is considerable throughout the Serengeti. However, the properties of the deposits and derived soils cannot be described adequately by the United States Department of Agriculture classification. That the greater part of the clay fraction is X-ray amorphous was shown by the X-ray diffraction characteristics. The X-ray amorphous material did not have the properties of allophanes (Section 8.3.3) and so cannot be called amorphous material as defined by Soil Taxonomy, according to which the following criteria must be met if amorphous material dominates the exchange complex:

- The exchange capacity of the clay at pH 8.2 is more than 1.5 mol/kg and is commonly higher than 5 mol/kg. The high value is in part due to poor dispersion.
- If there is enough clay to have a mass fraction of water of 20% or more at a moisture tension of 1500 kPa, the pH of a suspension of 1 g soil in 50 ml of NaF (concentration 1 mol/l) exceeds 9.4 after 2 min
- The mass ratio of moisture at a tension of 1500 kPa to clay is more than 1.0
- The mass fraction of organic carbon exceeds 0.6%
- Differential thermal analysis shows a low temperature endotherm
- The bulk density of the fine earth fraction is less than 850 kg/m^3 at a moisture tension of 33 kPa.

Occasionally the first and more often the second criterion was met. Especially at the Mukoma and Larale sites, as well as at SRI-2 and Togoro 5 (poorly drained ridge slope) high pH (NaF) was measured (Section 8.3.7). The organic carbon content of the 'amorphic' subsoils was usually less than 0.6%. Loss of weight between 100 and 200 °C was almost negligible and bulk density exceeded 850 kg/m^3.

The prefix amorphic at family level was therefore applied to soils with a bulk density exceeding 1000 kg/m^3 and an exchange complex consisting mainly of X-ray amorphous material.

Besides, differential thermal analysis does not show a characteristic low temperature endotherm.

Cation-exchange capacity of the clay fraction did not usually exceed 1.5 mol/kg and the mass fraction of organic carbon may be less than 0.6%.

De Wit (1978) suggested the introduction of Andeptic subgroups to include Serengeti Plain soils with a bulk density greater than 950 kg/m^3. I do not share his view that the Andeptic subgroups do not apply to the majority of the Serengeti Woodlands soils 'because they only contain small quantities of ash'.

Perhaps the characteristics of the Woodlands soils justify the introduction of a new subgroup. I prefer here to introduce a new mineralogy class.

10 Special subjects

10.1 EROSION SURFACES

10.1.1 Introduction

Much has been published about the presence of erosion surfaces in Africa, especially in the southern part of the continent.

Dixey (1956) distinguished a Jurassic, Miocene and late Tertiary peneplain, King (1948, 1976) recognized six planations.
- The Gondwana planation, equivalent to the Jurassic peneplain mentioned by Dixey
- The Kretacic planation, of early-mid Cretaceous age
- The Moorland planation, comparable to the late Cretaceous or Kisii Highlands peneplain described by Shackleton (1946), Williams (1964) and others working in Kenya
- The Rolling land surface, of Miocene age, has also been called African surface (King, 1948; Handley, 1952) or early Miocene peneplain (Shackleton, 1946; Pulfrey, 1960)
- The 'Widespread' landscape and the Younger Cycle are younger phenomena of Pliocene and Quarternary age, respectively.

The nomenclature suggests that the erosion surfaces have been properly dated. This is locally true for the early Miocene bevel. However, dating of the levels has not often been possible. Also the levels are still forming. If the late Cretaceous pediplain has recently worn back to the early Miocene surface, the resulting plain is called an early Miocene instead of Quarternary level.

Despite objections, the Kenyan nomenclature will be used.

The distribution of the early Miocene bevel in Kenya has been mapped by Pulfrey (1960). Williams (1964) and Saggerson (1966) describe the distribution of erosion surfaces in the area of the Mara River and Sianna and the Loita Hills area near the Serengeti National Park.

So far few data have been published on erosion surfaces in northwestern Tanzania (Handley, 1952; Butzer, 1976).

Williams recognized three erosion surfaces in the area of the Mara River and Sianna:
- The late Cretaceous peneplain
- The Intermediate peneplain
- The early Miocene peneplain.

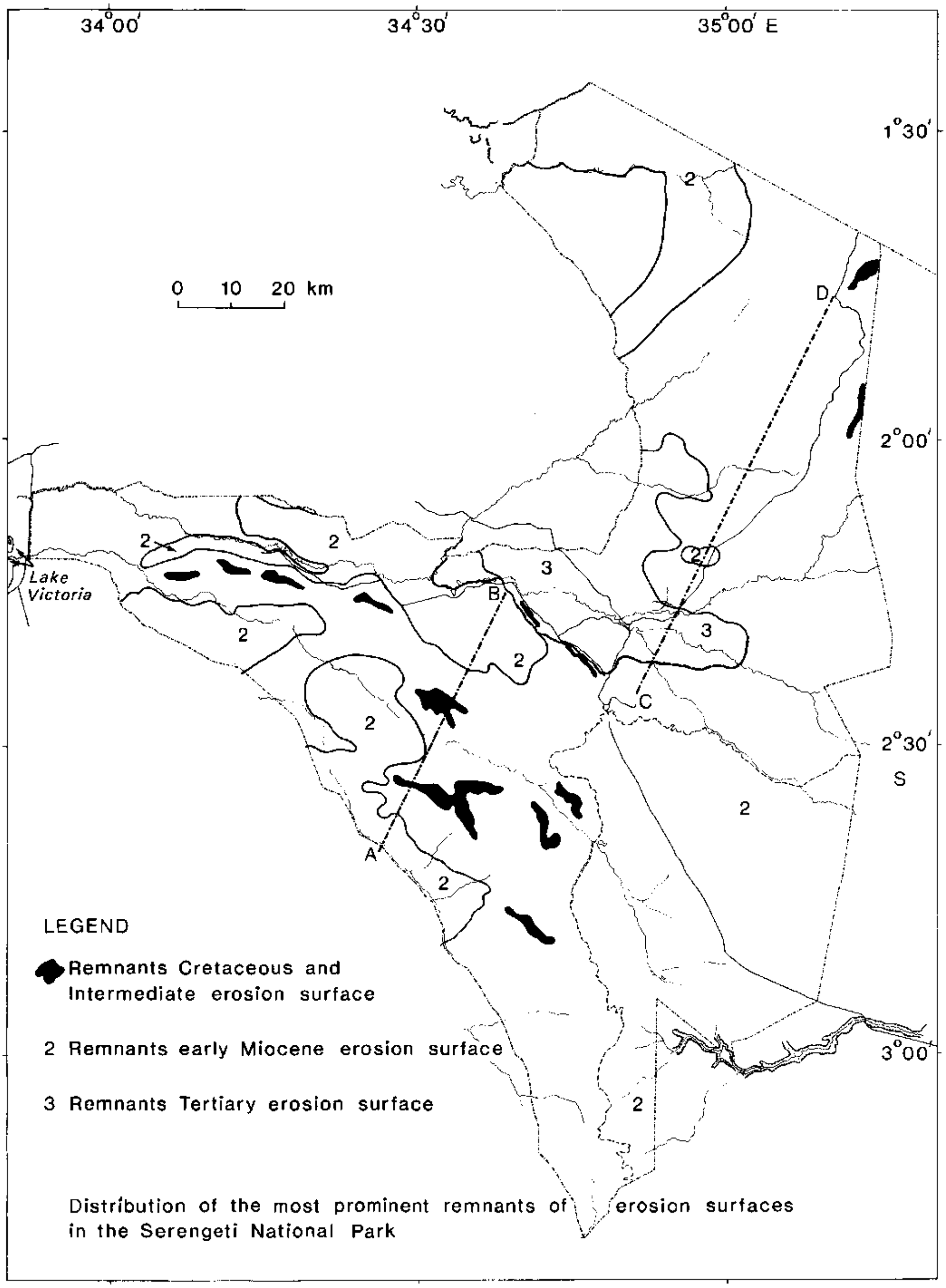


Figure 77. Generalized distribution of erosion surfaces in the Serengeti National Park and location of toposections given in Figures 80 and 81.

Saggerson also mentions a younger planation surface:

- The late Tertiary peneplain.

The erosion surfaces in the Serengeti National Park (Figure 77) will be compared with those recognized by Pulfrey, Williams and Saggerson.

The term peneplain will not be maintained since it implies that the planation has resulted from downwearing rather than backwearing. Recognition of the process is more guess work than the recognition of the surface, since as King (1972) remarks: 'one does not require a passport to identify an old friend'.

Downwearing could well play a role. One would expect a very deep solum covering the old surfaces if backwearing were the only process.

The Cretaceous planation surface has a very shallow soil cover. Locally all soil material has been removed, including the ash that covered the surface in more recent times.

On the early Miocene bevel, most of the residual material has been removed too. On the basis of type and thickness of the soil cover, one could distinguish planation surfaces that are

- bare or covered with a very shallow solum consisting of a mixture of residual material and volcanic deposits (late Cretaceous pediplain),
- covered with a moderately deep to deep or very deep solum consisting of a mixture of both residual materials and volcanic deposits (early Miocene pediplain),
- covered with very thick ash deposits (Serengeti Plain).

10.1.2 The late Cretaceous erosion surface

Williams (1946) suggests that in the area of the Mara River and Sianna remnants of this surface are represented by peaks reaching an altitude of about 7000 ft (about 2100 m). This surface slopes downward from ENE towards WSW. The hilltops consist of quartzite of the Precambrian basement system.

The same situation is found in the northeastern part of the Serengeti Park, in the Kuka Hills area. Peaks there also reach a height of about 2100 m. Further to the east even higher peaks are present (Munderosi Hills, about 2280 m), corresponding to the east-west slope of the surface, from the Great Rift Valley towards Lake Victoria.

In the Western Corridor, relicts of the same bevel are found at a height of about 2000 m (Itonjo Hills). This plain is tilted strongly towards the west. The height of the Nyaroboro Hills (Figure 78) ranges from 2000 to 1720 m towards Lake Victoria. Nyamuma Hills (Figure 79) also reach a height of about 1720 m. Extensive plateaux have developed in the quartzite capping on the granitic rocks.

Further west the highest peaks reach a height of about 1500 m. The Nyanzian rocks seem slightly more easily weatherable than the quartzite cappings, so that the original planation surface must have been present here

Figure 78. Plateau of Nyaroboro Hills, a relict of the late Cretaceous erosion surface.

Figure 79. Plateau of Nyamuma Hills, a relict of the late Cretaceous erosion surface with wildebeest grazing in the foreground on a relict of the early Miocene eroson surface (Ndoho Plain). The tall tree is a palm, *Borassus aethiopum*.

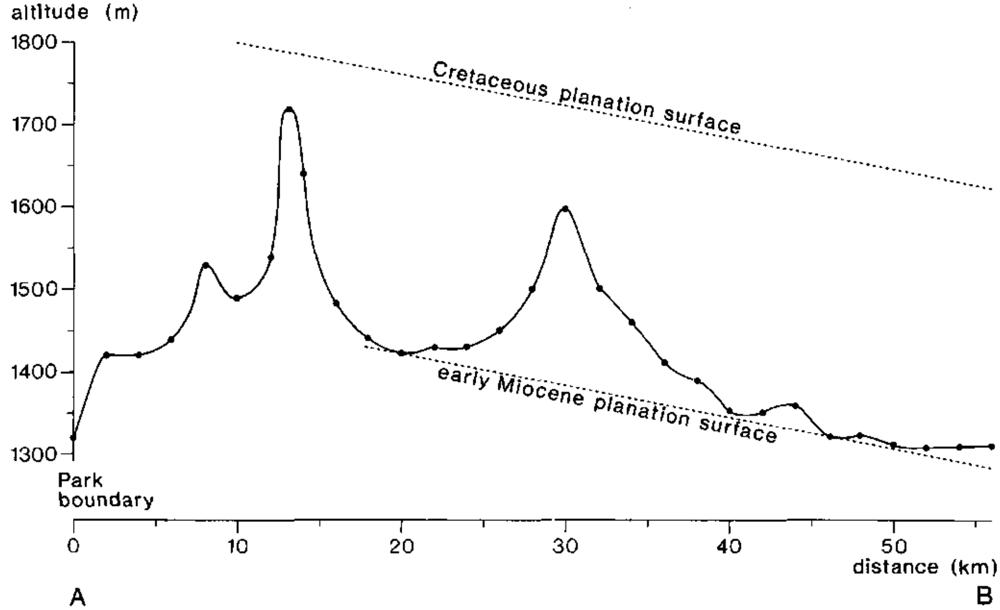


Figure 80. Toposection of the Western Corridor from south-west to north-east.

at a higher altitude, probably about 1600 m. A toposection through the Western Corridor is given (Figure 80).

10.1.3 The Intermediate erosion surface

An intermediate erosion surface as such was not establishd. Several ridges and peaks are present at heights between the late Cretaceous and the early Miocene planation surfaces, but they do not form a clear surface.

10.1.4 The early Miocene erosion surface

According to Oswald (1914, quoted by Williams, 1964) in south-west Kenya, the early Miocene surface was partially covered with Tertiary volcanics. In the Serengeti, such lavas, trachytic phonolytes, appear in the northwestern part, where they cover the early Miocene bevel formed in biotite granite.

The base of the volcanic lavas lies at an altitude of 1400 m, whereas Williams observed it at 5000 ft (1620 m) near the Mara River close to Loldobaith. South of the Mara River (south of Kogatende), relicts of the surface are probably represented by ridges up to a height of 1720 m. Eastwards the bevel reaches a height of 1950 m near Wasso, close to the Great Rift Valley. In the western part of the Northern Extension around Nyamburi the relicts are found at 1560 m. The bevel slope is about 4 m/km, which agrees with the values found by Williams (22 feet per mile). This slope has been

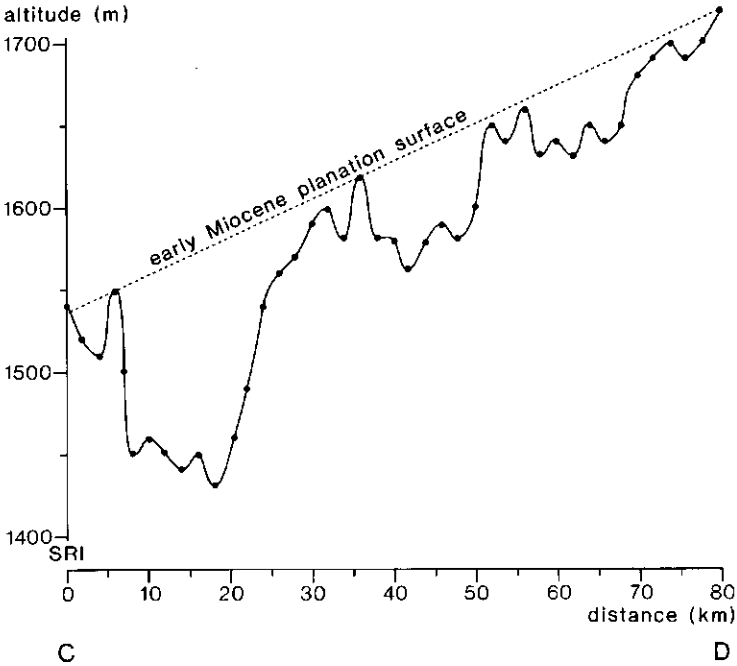


Figure 81. Toposection of the Northern Extension from north-east to south-west.

caused by uplift around the Great Rift Valley.

The difference in height between the late Cretaceous and the early Miocene planation surfaces (about 390 m) also agrees with earlier results (Saggerson, 1966). Southwards from the Isuria Escarpment up to the Kleins Camp track (in the centre of the Rhino Mbali Pali area) the surface slopes up at 15 m/km (from 1400 m to 1710 m). Thence the bevel slopes downwards, to 1620 m at Togoro Plain, which is equal in height to the ridges east of Seronera. The interfluves of the Serengeti Plain also belong to this very extensive planation surface.

The vast plains of the Western Corridor range in altitude from about 1340 m in the east and centre (Musabi Plain, Ndoho Plain, Duma area) to about 1200 m further to the north-west (Kirawira Plain, Nangangwe Plain, Dutwa Plain), where the plains are situated just above the present Ndabaka Flood Plain. So the slope from the northern part of the Serengeti to the western part of the Western Corridor is 5 m/km.

According to Handley (1952) the area south-west of the Serengeti is part of the old African surface, which is equivalent to the early Miocene surface. Toposections through the Western Corridor and Northern Extension are given in Figure 80 and 81.

10.1.5 The late Tertiary erosion surface

Locally a lower more recent erosion surface can be recognized in the Banagi area, that originated in relatively easily weatherable Nyanzian rocks at an altitude of about 1300 m. It tilts down towards the west at 8 m/km. West of Bukumi Hill, it merges into the early Miocene surface. This can be explained only by assuming that either the northwestern part of the Western Corridor has subsided since the early Miocene planation, or that the supposed late Tertiary surface has been uplifted. Faults are present along Nyara Swiga and Kamarishe Hills, the more recent one (probably Plio-Pleistocene; Macfarlane, 1965) with downthrow to the east, the other with downthrow to the west.

So subsidence of the northwestern part of the Western Corridor may have resulted from faulting before the Plio-Pleistocene faulting.

Since the effect of the two faults was opposite, the earlier one must have been more dramatic, causing subsidence of the northwestern part.

Butzer (1976) discusses landforms in the Serengeti National Park. He describes a system in which he recognizes:

- a high upland area of dissected mesaform hills with undulating intermontane plains
- a complex peripheral belt of sloping plains interrupted by selected areas of inselbergs, tors and mesaform residuals
- a lower relatively flat plainland with scattered residuals.

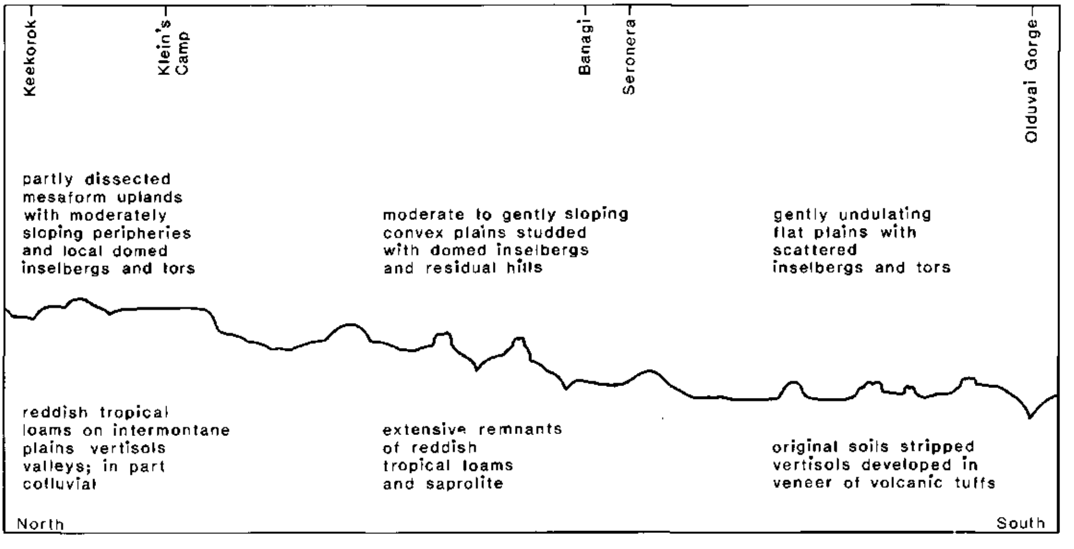


Figure 82. Landform regions of the Serengeti National Park (from Butzer, 1976).

Further he mentions that the flat plains readily match with Büdel's model, presuming the regolith has been removed. This system he considers typical and described it as the 'Serengeti case'.

Büdel (1957, 1965, 1970), as well as Ollier (1959) and Thomas (1974), emphasized the role of deep weathering in savanna plain planation, whereas King (1967, 1972) and Tricart (1972) considered semi-arid pedimentation to be the main process.

A few comments on Butzer's statements are necessary. Firstly the relative altitudes of his toposection in Figure 82 are not correct. The altitude of the Serengeti Plain usually exceeds 1700 m and may even reach 1800 m close to the rift valleys, whereas the altitude at Banagi is 1400 m only. Quartzite ridges of the Serengeti Plain are assumed to belong to the same planation surface as the area described by Butzer as 'convex plains studded with domed inselbergs and residual hills', since the altitudes are similar.

So far, there is no evidence that the flat plains match Büdel's model. The bedrock surface of the Serengeti Plain has never been mapped. This would be an interesting subject for study. The volcanic ash forms a blanket that conceals the underlying bedrock surface, which could very well be identical with the landscape of the Fringe. De Wit (1978) was correct in describing the Serengeti Plain as a sediment plain.

10.2 Nutrient load and transport of the main rivers

Water from the main waterways were analysed periodically (Table 30).

There were high salt concentrations in the Nyabogati River (a tributary of the Orangi River) and the Orangi River (Figure 15).

The water samples of the Orangi are taken above confluence with the Orangi. The Nyabogati River collected run-off from the Fringe. The Orangi joins the Grumeti River.

The catchment area of the upper part of the Orangi River includes alkaline plains east of the Serengeti Park and the non-alkaline central part of the Northern Extension, the northeastern part of which drains directly into the Grumeti.

Downstream from the Nyabogati to the Orangi and Grumeti Rivers, salinity and alkalinity gradually decreases. Still lower electrical conductivity occurs in the Mara River, which collected run-off mainly from an area hardly affected by alkaline ashes from the Ngorongoro Highlands.

Concentration of nutrients depended on the flow: the higher the flow, the lower the concentrations. Leaching of the topsoil is considerable. Sodium, calcium and magnesium ions were the predominant cations; bicarbonates and to a lesser extent chlorides the predominant anions.

There was a remarkable difference of the Nyabogati and Orangi Rivers from the Grumeti sampled at Kirawira. In the Nyabogati and Orangi sodium salts

Table 30. Chemical composition discharge of the main waterways and of rainfall in the Serengeti Woodlands.

	Date	EC_e (mS/cm)	Na^+ (mol/m³)	K^+ (mol/m³)	$\frac{1}{2}(Ca^{2+}+Mg^{2+})$ (mol/m³)	Total cations	$HCO_3^-+\frac{1}{2}CO_3^{2-}$ (mol/m³)	$\frac{1}{2}SO_4^{2-}$ (mol/m³)	Cl^- (mol/m³)	Total anions	Flow
Mara	1975-09-03	0.06	0.32	0.11	0.09	0.52	0.38	0.20	-	0.58	low
Orangi	1975-09-04	0.27	1.26	0.32	0.49	2.07	1.45	0.20	0.29	1.94	moderately low
Nyabogati	1975-09-09	0.64	3.73	0.46	1.59	5.78	4.16	0.68	1.48	6.32	moderately low
Mara	1975-10-02	0.09	0.33	0.11	0.39	0.83	0.62	0.08	0.44	1.14	medium
Orangi	1975-09-29	0.70	3.28	0.38	2.90	6.56	3.54	0.64	1.88	6.06	low
Nyabogati	1975-09-29	0.92	4.73	0.90	3.00	8.63	5.57	1.05	2.82	9.44	low
Grumeti	1975-10-01	0.33	0.82	0.48	1.60	2.90	1.82	0.28	0.84	2.94	very low
Mara	1975-11-06	0.07	0.26	0.10	0.24	0.60	0.20	0.28	0.20	0.68	moderately low
Orangi	1975-10-31	1.05	4.82	0.57	4.17	9.56	5.57	1.13	3.67	10.37	very low
Nyabogati	1975-10-31	0.66	3.45	0.47	2.30	6.22	4.79	0.36	1.63	6.78	very low
Grumeti	1975-10-30	0.27	0.75	0.38	1.14	2.27	2.10	-	0.20	2.30	low
Mara	1975-12-01	0.13	0.38	0.15	0.54	1.07	0.80	0.20	0.20	1.20	low
Grumeti	1975-12-05	0.32	1.17	0.41	1.28	2.86	2.20	0.24	0.50	2.94	low
Mara	1975-01-01	0.20	0.71	0.27	0.64	1.62	1.30	0.20	0.35	1.85	low
Orangi	1975-12-29	0.72	2.87	0.46	3.07	6.40	4.50	0.99	1.80	7.29	very low
Nyabogati	1975-12-29	0.57	2.20	0.47	2.43	5.10	3.80	0.74	1.50	6.04	very low
Grumeti	1975-12-31	0.20	0.73	0.17	0.94	1.84	1.40	0.16	0.40	1.96	low
Mara	1976-12-02	0.36	1.80	0.49	1.29	3.58	2.28	0.86	0.39	3.53	low
Orangi	1976-01-29	0.92	5.21	0.53	3.47	9.21	6.59	0.61	2.28	9.48	standing water
Nyabogati	1976-01-29	1.50	11.39	0.59	3.13	15.11	8.72	2.49	4.37	15.56	standing water
Grumeti	1976-02-01	0.49	2.60	0.42	1.98	5.00	3.24	0.82	0.79	4.85	low
Orangi	1976-02-17	0.25	1.09	0.28	1.04	2.41	1.17	0.82	0.29	2.28	moderately high
Nyabogati	1976-02-17	0.17	0.78	0.30	0.79	1.87	1.01	0.57	-	1.58	moderately high
Mara	1976-03-02	0.30	1.46	0.36	1.19	3.01	1.80	0.95	0.39	3.14	low
Orangi	1976-02-29	0.66	3.13	0.54	3.28	6.95	4.36	1.15	1.29	6.80	very low
Nyabogati	1976-02-29	1.00	6.52	0.60	1.98	9.10	5.63	1.73	2.48	9.84	very low
Grumeti	1976-03-01	0.30	1.27	0.32	1.34	2.93	2.02	0.74	0.24	3.00	low
Mara	1976-04-02	0.22	1.09	0.35	0.99	2.43	1.77	0.10	0.30	2.17	medium
Orangi	1976-04-05	0.98	6.00	0.46	3.81	10.27	7.52	0.83	1.94	10.29	low
Nyabogati	1976-04-05	0.23	0.96	0.12	1.38	2.46	1.88	0.66	0.22	2.76	standing water
Grumeti	1976-04-01	0.20	0.94	0.24	1.18	2.36	1.77	0.16	0.30	2.23	standing water
Mara	1976-05-02	0.24	1.11	0.37	1.18	2.66	1.98	0.08	0.44	2.50	very low
Orangi	1976-04-28	1.00	6.05	0.53	4.30	10.88	7.55	0.90	1.30	9.75	very low
Nyabogati	1976-04-28	0.59	3.73	0.35	1.68	5.76	3.70	0.41	1.45	5.56	low
Grumeti	1976-05-04	0.19	0.78	0.20	0.99	1.97	1.41	0.25	0.30	1.96	medium
Mara	1976-05-27	0.14	0.60	0.24	0.64	1.48	1.50	-	0.13	1.63	moderately high
Grumeti	1976-05-31	0.16	0.61	0.30	0.79	1.70	1.55	-	0.17	1.72	moderately high
Rainwater		0.01	-	-	0.19	0.19	0.10	0.15	0.04	0.29	

predominated, whereas at Kirawira calcium plus magnesium predominated because of non-alkaline 'supply' from the northeastern part of the Northern Extension.

The sediment load was calculated by evaporating a known volume of river-water and weighing the residue. Sediment loads range from 0.2 (standing water) to 2.5 g/l (high flow).

An illustration is given below for the total sediment transport of the Grumeti River with a catchment area of about 10 000 km². The width of the river is about 15 m and the average depth 1.5 m. It was assumed that the total annual flow is similar to 50 days of high flow and that under these conditions the velocity was 2 m/s.

On this basis, the mass flow rate is:

$$2.5 \times 15 \times 1.5 \times 2 \times 3600 \times 24 \quad 10^7 \text{ kg/d}$$

If this rate is maintained for 50 days in the year, the annual discharge of sediment is about 50×10^7 kg.

If 1 mm of soil material were removed in 1 year in the catchment area, the mass rate of sediment transport would be 1.25 (bulk density) $\times 10^{10}$ kg/a. So 40 µm of the solum could be removed in a year in the Grumeti Catchment Area if the assumptions are correct.

With analogous calculations, discharge of soluble minerals could be 50 000 tons a year, mainly of sodium, calcium and magnesium salts from the Grumeti Catchment Area to Lake Victoria.

10.3 SOIL COLOUR

In the Serengeti Woodlands soil colour is determined predominantly by:
- 'rock drainage' and mineral composition of the solum
- content of organic carbon in the solum.

10.3.1 'Rock drainage' and mineral composition

Frequently a change in soil colour was explicable by differences in 'rock drainage'. Cracks, fissures and joints allow weathering to proceed more rapidly. 'Rock drainage' is one of the factors influencing the Fe_2O_3 content, especially of the clay fraction, since iron usually is present as FeO in the parent material.

Contents of FeO, though determined, are not separately reported here, because they were similar for all soils apart from the Mbalageti ash, in which it was relatively high. But even then the content of Fe_2O_3 was about six times as much as of FeO (Appendix F).

Weathering breaks up the coarser fractions. Part of the iron in the fraction is leached and part is fixed by the clay minerals. So Fe_2O_3 contents are higher in the clay fraction when weathering was more intensive or has been active for a longer period. One would expect a correlation between the Fe_2O_3 content of the clay fraction and soil colour. Table 19 shows that in the clay fractions from Nyara Swiga 2 and Bololedi 2, both reddish-brown soils, considerably more and slightly more Fe_2O_3 was present than in those from other woodland sites. Both sites were well drained. At Nyara Swiga 3, an imperfectly drained site, reddish-brown soil colours were again encountered, due to a continous supply of Fe_2O_3 provided by the iron-rich parent material (jaspillite and ironstone). Fe_2O_3 contents of this site are given in Appendix F. High Fe_2O_3 contents in the clay fractions at the Bololedi sites can be explained by assuming a more favourable 'rock drainage', whereas in the Nyara Swiga area they are primarily due to a high iron content of the bedrock.

Fe_2O_3 content of the non-clay fraction was almost zero at the Bololedi and Rhino sites and significantly higher at the other Serengeti Woodlands (and Plain) sites.

Since the volcanic ash would contain the iron compounds and no supply would be expected from the bedrock, except at Nyara Swiga, the soil would turn reddish-brown when the volcanic deposits were more heavily weathered. At Rhino 7, the iron compounds were leached to a great extent. Contents of Fe_2O_3 in the total fine earth fraction were the lowest observed. According to X-ray diffractograms, this was the only site where crystalline clay minerals were present, suggesting that weathering had proceeded to a greater degree than in the rest of the Serengeti Park, or that different ashes had covered the Rhino Mbali Pali area. If so, the low Fe_2O_3 content of the non-clay fraction is not necessarily a result of severe weathering.

A high content of Fe_2O_3 in the non-clay fraction seems to indicate large amounts of only slightly weathered ash. Apparently soils containing very large amounts of X-ray amorphous material are not reddish-brown.

So reddish-brown soils were only found if the underlying bedrock was rich in iron minerals, or if Fe_2O_3 contents of the clay fraction exceeded 10% and only negligible amounts of Fe_2O_3 were present in the non-clay fraction.

The lower Fe_2O_3 content of the non-clay fraction from the Serengeti Woodlands than from the Plain was partly due to the high quartz content, in turn attributable to the combination of weathering of outcropping rocks and termite activity.

10.3.2 Organic carbon content

Soils at Mukoma 1 and 3, and at SRI-2 and Togoro 1 were browner in the subsoil than in the topsoil, despite slightly lower Fe_2O_3 contents in the clay fractions. Contents of Fe_2O_3 in the non-clay fraction were somewhat higher, but would not influence the soil colour. The darker topsoil could be explained by the higher content of organic carbon.

Organic carbon causes darker soil colours, especially when fresh (unweathered) material is present, as was usual in the Serengeti Plain, Fringe and Western Corridor. Less dramatic was the colour change due to organic carbon in the Northern Extension, where the soils were usually more weathered.

10.3.3 Conclusions

- The grey and dark grey to black colours of the Serengeti Plain soils are caused by low contents of Fe_2O_3 in the clay fractions. Soils are still very young, as shown by the high contents of Fe_2O_3 in the non-clay fractions.
- Soils of the Fringe of the Serengeti Plain and Western Corridor that have Fe_2O_3 contents in the clay fractions exceeding 10%, generally had a brown subsoil. Topsoils were darker because of a reaction of unweathered soil material and organic carbon. Reddish-brown soils were only found if the underlying bedrock was rich in iron minerals.
- Soils of the Northern Extension were usually more weathered (Rhino 7, Bololedi 2), so the influence of organic carbon was less striking. Reddish-brown soils were confined to areas with favourable 'rock drainage'.

Summary

The study deals with soil conditions in the woodlands of the Serengeti National Park in northwestern Tanzania. It forms a continuation of work carried out by de Wit on the Serengeti Plain.

The study had three aims:

- to describe the soils and their distribution in the Serengeti Woodlands
- to study chemical and especially physical soil conditions in relation to distribution of the main types of flora and fauna
- to study the influence of soil moisture on factors like grass height, distibution of woody vegetation and wildlife.

Chapter 1 gives a general description of the climate, geology, geomorphology, vegetation, wildlife and hydrology of the project area.

Chapters 2, 3 and 4 discuss the soils of the three soil-landscapes Western Corridor, Northern Extension and Fringe of the Serengeti Plain. The landscapes differed in geomorphology and ash cover. Volcanic ashes that originated from volcances of the Ngorongoro Highlands, southeast of the Serengeti National Park, have influenced the soils to a large extent. Eastern and to a lesser extent southeastern winds have transported the ashes well into the Western Corridor and the Northern Extension. The Fringe has more frequently been covered due to its geographical position.

Because of the high soda content of the ashes, high exchangeable sodium percentage (ESP) values were observed especially in the pediplain soils of the Western Corridor and locally on ridges and ridge slopes in the Fringe of the Serengeti Plain. The pediplain soils underlain by granitic rocks were also characterized by prismatic B horizons. Once the prismatic horizon was moistened, infiltration rates approached zero, so that run-off and erosion were considerable.

The 'granitic' pediplain soils are almost entirely under grassland (*Chrysochloa orientalis*), but here and there mature trees (*Acacia tortilis, Balanites aegyptiaca*) grow on the more shallow phases.

In the Fringe of the Serengeti Plain and Northern Extension no extensive pediplain relicts remain. These landscapes are more strongly dissected and woody vegetation prevails, except on the clayey ridge slopes that are usually under long grass.

Chapters 5 and 6 give the results on detailed investigations on soil-vegetation-wildlife interrelationships in the Kirawira and Rhino Mbali Pali study areas, situated in the Western Corridor and Northern Extension, res-

pectively.

Examples of the effects of past termite activity are given for both areas. Termites did not always improve physical characteristics of the soil.

Maximum available soil moisture was calculated for many sites from water-retention and the maximum depth of fluctuation of soil moisture, measured with a neutron probe (Chapter 7). It determined to a great extent the distribution of woody vegetation in the Serengeti Woodlands.

Besides available soil moisture, evapotranspiration and run-off were measured. Infiltration rates were estimated by the double-ring method with neutron probe as a check. Routine measurements were taken over a period of 15 months.

For areas with a high population of wildebeest effective rainfall was less than half the actual rainfall. Since nutrients are abundant, a change in rainfall pattern would alter grassland productivity drastically.

The maximum depth of fluctuation in soil moisture was almost the same as the depth of penetration after 5 h of infiltration.

Chapter 8 describes the mineralogy of the Serengeti soils. The clay fraction at all sites except one proved by X-ray diffraction to be amorphous. Its properties did not correspond to allophane. The clay fraction from the Serengeti Woodlands must have originated by weathering of volcanic glass and to a lesser extent of biotite erupted by the volcanoes of the Ngorongoro Highlands, in particular Oldoinyo Lengai. According to X-ray diffraction the non-clay fraction contained amorphous and residual components.

Chapter 9 deals with soil classification according to 'Soil Taxonomy'. Soils at all sites classified belonged to the order Mollisols and the suborder Ustolls (ustic or aridic moisture regime). As they usually had an argillic or natric horizon they were attributed to the great groups Natrustoll or Argiustoll.

Chapter 10 describes the distribution of planation surfaces, carriage of minerals in the Grumeti River and the influence of rock structure on soil colour.

In the Serengeti National Park the early Miocene erosion surface is most obvious. Relicts of older and younger surfaces were detected and mapped as well.

Samenvatting

Het Serengeti Research Institute werd opgericht in 1966 teneinde wetenschappelijke gegevens aan te dragen voor het beheer van de wildparken in Tanzania.

In het begin was de aandacht van de onderzoekers vooral geconcentreerd op grote zoogdieren. Bodemkundige studies werden geinitieerd om die bodemfactoren te bestuderen, die hoeveelheid, kwaliteit en verspreiding van de voedselbronnen beinvloeden. Onderzoek naar aard en verspreiding van de bodems in het Serengeti National Park werd aangevangen door De Wit in 1970 met een bodemkundige studie van de Serengeti Plain, het zuidoosteljk deel van het Park.

Het Serengeti National Park beslaat een oppervlak van ca. 13.250 km^2 en is gesitueerd in noordwest Tanzania tussen 1°30' en 3°30' Z.B. en 33°80' en 35°30' O.L. De hoogte varieert van 1140 m nabij het Victoria meer tot 2090 m in het uiterste noordoosten. De regenval varieert van 400 mm in het zuidoosten van de Serengeti Plain tot 1200 mm in het uiterste noordwesten.

De doelstellingen van het onderzoek zijn drieledig:
- het beschrijven van de voorkomende bodemtypes en hun verspreiding
- het bestuderen van de chemische en fysische bodemeigenschappen in relatie tot de verspreiding van vegetatietypes en diersoorten
- het bestuderen van de vochthuishouding van de bodem en hun invloed op factoren als graslengte.

De Serengeti Woodlands beslaan ongeveer driekwart van het totale Parkoppervlak. De vegetatie bestaat uit een open savannaboom- en struikvegetatie afgewisseld met grasvlaktes. De Woodlands zijn onderverdeeld in drie landschappen: de Western Corridor, het westelijke gedeelte van het Park tussen de Serengeti Plain en het Victoria meer; de Northern Extension, het noordelijke deel van het Park; de Fringe of the Serengeti Plain, dat gedeelte van de Woodlands dat direct aan de Plain grenst, uitgezonderd het oostelijk deel van de Western Corridor. De onderscheiden landschappen zijn gemodelleerd, gedurende periodes van sterke erosie zoals in het Krijt, het vroeg-Mioceen en het Tertiair hebben plaatsgevonden, in zeer oude voornamelijk Precambrische gesteenten.

In recentere tijden en vooral gedurende het Pleistoceen is het Park herhaaldelijk bedekt met vulkanische assen afkomstig van de vulkanen van de Ngorongoro Highlands ten zuidoosten van het Park. Met name de assen geërupteerd door de vulkaan Oldoinyo Lengai zijn van groot belang geweest. De laatst waargenomen eruptie van enig belang vond plaats in 1954. De assen zijn door oostelijke en in mindere mate door noordoostelijke winden getransporteerd. Dientengevolge is de as invloed groter in de Western Corridor en de Fringe of the Serengeti Plain dan in de Northern Extension.

De as invloed in de Serengeti Plain en de onmiddellijke omgeving daarvan is vermoedelijk van recenter datum dan op grotere afstand van de vulkanen. Aangezien ook de regenval van het zuidoosten naar het noordwesten toeneemt, kunnen de verschillen in minerale samenstelling behalve door de ouderdom ook door verschillen in verwerings intensiteit beinvloed zijn.

Als gevolg van het hoge sodagehalte van de assen worden vooral in de pediplain-gronden van de Western Corridor en plaatselijk in de ridge- en ridge slope-gronden van de Northern Extension hoge gehaltes uitwisselbaar natrium aan het adsorptiecomplex aangetroffen. Bovendien hebben de pediplain-gronden op granitische gesteenten dikwijls een prismatische inspoelingshorizont. Als deze horizont eenmaal bevochtigd is naderen de infiltratiesnelheden tot nul en dientengevolge is de oppervlakteafstroming hoog, wat op zijn beurt weer de erosie beïnvloedt. Op deze gronden worden dikwijls grote kudden herbivoren aangetroffen, vooral wildebeesten. De vegetatie bestaat hier voornamelijk uit gras (*Chrysochloa orientalis*), maar plaatselijk kunnen ook volgroeide bomen worden aangetroffen (*Acacia tortilis* en *Balanites aegyptiaca*) op de ondiepere gronden. Jonge bomen zijn vrijwel afwezig.

In de Northern Extension en in de Fringe of the Serengeti Plain zijn geen uitgestrekte pediment-vlakten meer aanwezig. Deze landschappen zijn sterker versneden en voornamelijk bedekt met een open boom- en struikvegetatie, afgezien van de kleiige ridge slopes die in het algemeen bedekt zijn met lang gras.

Het zijn vooral de grazing pressure (beweidingsdruk) en de hoeveelheid beschikbaar vocht die de lengte van het gras bepalen. Deze laatste factor bepaalt ook in hoge mate de verspreiding van de boom- en struikvegetatie.

Voor een groot aantal bodemprofielen is het maximaal beschikbare bodemvocht bepaald op basis van de waterretentie-karakteristieken van de bodem en de maximale diepte waarop in het profiel nog bodemvocht-veranderingen zijn waargenomen met de neutronensonde. De aldus gevonden waardes benaderen niet altijd de werkelijkheid maar kunnen gebruikt worden als relatieve maat.

Gedetailleerd onderzoek werd verricht in een tweetal gebieden representatief voor de Western Corridor en de Northern Extension.

Voorbeelden van de invloed van termietenactiviteit op de bodemeigenschappen worden gegeven waaruit blijkt dat de relatie tussen termietenactiviteit en de fysische bodemkarakteristieken niet altijd eenduidig is.

De vochthuishouding van de gronden werd bestudeerd met behulp van een neutronensonde. Schattingen worden gegeven van beschikbaar bodemvocht en van de evapotranspiratie. Berekeningen betreffende de oppervlakteafstroming zijn uitgevoerd voor twee profielen. Het blijkt uit de metingen dat de oppervlakteafstroming meer dan de helft van de regenval kan bedragen, vooral in die gebieden die gekenmerkt worden door de aanwezigheid van hoge wildconcentraties. Dit betekent dat in deze gebieden de effectieve regenval slechts de helft van de werkelijke regenval bedraagt. Omdat in het algemeen de gronden zeer veel voedingsstoffen bevatten zal een verandering in het regenvalpatroon de graslandproduktiviteit drastisch veranderen.

De nauwkeurigheid van de dubbele ringmethode, die gebruikt werd voor de bepaling van infiltratie snelheden, werd gecontroleerd met neutronensondemetingen. Vooral in gronden met een prismatische horizont boven in het profiel blijkt deze methode goed te voldoen.

Uit de metingen bleek verder dat de maximum diepte waarop nog fluctuaties in het vochtgehalte aangetroffen werden bij benadering overeenkomt met de diepte van het vochtfront na 5 uur infiltreren.

Het beschrijven van de mineralogische samenstelling van de gronden in de Serengeti Woodlands bleek een tijdrovende bezigheid. De kleifractie van vrijwel alle geanalyseerde monsters was röntgen-amorf. Ook vertoonde deze fractie niet de eigenschappen van allofaan. Vermoedelijk is de kleifractie ontstaan door verwering van vulkanisch glas en in mindere mate biotiet, geërupteerd door de vulkanen van de Ngorongoro Highlands. De silt- en zandfractie bevat röntgen-amorf materiaal en residuaire mineralen.

De profielen zijn geclassificeerd volgens het systeem beschreven in Soil Taxonomy. Alle profielen behoren tot de orde van de Mollisols en de suborde van de Ustolls ("ustic of aridic vochthuishouding"), en in de meeste gevallen tot de groep van de Argiustolls (klei-inspoeling) of de Natrustolls (indien de klei-inspoelingshorizont een hoge natrium bezetting en een prismatische structuur bezit).

Ook is de verspreiding van de verschillende erosieniveau's in het Park bestudeerd. Vooral de resten van het vroeg-Miocene planatievlak zijn wijd verbreid, vooral in de Western Corridor.

Tenslotte wordt het transport van voedingsstoffen en de invloed van de gesteentestructuur op de bodemkleur besproken.

Appendix A. Methods

SURVEY METHODS

The Project started with the preparation of a photointerpretation map with the help of matt double weight 1:70 000 scale photographs taken by Finnmap in January 1972. Boundaries were drawn on the photographs and checked in the field. Augering proved to be extremely difficult, especially in the Western Corridor, and was possible only in the rainy season, at least when the area under study was accessible. For this reason many soil pits were dug and described according to Handbook 18 (Soil Survey Staff, 1951). For convenience the soil depth classes from the Soil Survey Manual are given below:

	Range in limits (cm)	
	upper	lower
very shallow	0	12.5- 25
shallow	12.5- 25	50 - 75
moderately deep (or moderately shallow)	50 - 75	75 -125
deep	75 -125	125 -150
very deep	125 -150	>150

Grasses, trees and shrubs were named according to Polhill (1974) and Dale & Greenway (1961).

FIELD MEASUREMENTS

Infiltration rate Infiltration experiments were carried out with the double-ring method, the inner ring having a diameter of 30 cm, the outer ring 60 cm. Depth of penetration was estimated after 5 h of infiltration by augering a hole in the centre of the inner ring. The rates were measured over 5 h with a hydraulic head of 5 cm, conditions that prevail only in flood plains and valley bottoms. The experiments were carried out in duplicate or triplicate because of errors caused by mechanical disturbance during the installation of the rings and by slaking during the experiment. Errors due to disturbance are large, especially in the first hours. For this reason rates were compared after five hours. Occasionally depth of penetration may give more meaningful information on moisture availability than infiltration rate because lateral flow is excluded.

Soil moisture Soil moisture contents were measured with a Wallingford soil moisture probe (model 225) connected with a rate scaler (type 604A), in aluminium tubes sealed at the bottom with a welded plug. At the top the pipes were sealed with sunken rubber stops. Hyenas proved to be very persistent in chewing the stopcocks if they were not pushed beyond their reach.

A little bag of silica gel was connected with the stopcock to keep the pipe dry.

LABORATORY MEASUREMENTS

Particle size distribution of the fine earth fraction Fractions coarser than 50 μm were determined by sieving, the finer fractions with the pipette method. Carbonates were removed by a sodium acetate treatment. Organic matter was oxidized by adding 30% H_2O_2 to the sample.

Moisture retention Drums filled with coarse sand and silt, respectively, were used to determine the moisture contents at pF 1 and 2 of undisturbed 100 cm^3 ring samples. The drums were connected with a container of water through a rubber tube, so that the difference in height between the ring samples and the water level could be adjusted accurately. Volume fraction of moisture at pF 3.4 and pF 4.2 was determined by applying on the samples in the membrane suction device a pressure of 250 and 1600 kPa, respectively. After drying at 105 °C, moisture content and bulk density of the ring samples were determined. Equilibration time at pF 1 and 2 ranged from 1 to 5 days depending on the soil texture and from 3 to 4 days for pF 3.4 and 4.2, respectively.

Maximum available moisture in soils was calculated from the difference in volume fraction of moisture with a change in pF from 2 to 4.2 for the depth to which fluctuation in moisture was detected over a year with a neutron probe. Such a maximum may, however, be unrealistically high, since field capacity (pF 2) is never reached. The ability of plants to withstand tensions of 1600 kPa (pF 4.2) (Chapter 7) also casts doubt on the method used to estimate volume fraction of moisture at wilting point (pF 4.2).

COLE values Shrinkage of the ring samples was determined after drying at 105 °C, by filling the rings with fine sand till the edge of the rings (de Wit, 1978). Presuming that the shrink is equal in all directions, the linear shrink can be calculated from the following formula:

$$V = \pi\{0.5(R-x)\}^2 (R-x)$$

in which R is the diameter and x the shrink of the sample. This formula can only be applied if diameter and height of the ring are equal as was the case with the 100 cm³ rings used. The coefficient of linear extension (COLE) can now be calculated according to Soil Taxonomy (1975):

$$COLE = \frac{R_{moist} - R_{dry}}{R_{dry}}$$

pH pH Values were measured with a Pye Unicam model 290 pH meter, using a glass electrode and a calomel electrode, in both the saturation extracts obtained after extracting the soil moisture from saturated soil samples, and the soil pastes.

Electrical conductivity and free salts EC_e values were determined in the saturation extracts with a CENCO conductivity meter. In the same extracts Na^+ and K^+ were analysed flamephotometrically; $\frac{1}{2}(Ca^{2+} + Mg^{2+})$, $\frac{1}{2}SO_4^{2-}$ and $HCO_3^- + \frac{1}{2}CO_3^{2-}$ titrimetrically. Chloride concentrations were determined with the pH meter, using an Ag indicator electrode and a reference electrode of $Hg/HgSO_4$ saturated with K_2SO_4. Nitrates were determined qualitatively with a Vitraton colorimeter.

Cation-exchange capacity and exchangeable cations The samples were percolated with sodium acetate (pH 8.2) and the cation-exchange capacity was determined by measuring the sodium concentration in a second percolate (ammonium acetate, pH 7) by flamephotometer. A second sample was percolated with ammonium acetate only and in this leachate K^+ and Na^+ were determined flamephotometrically and both $\frac{1}{2}Ca^{2+}$ and $\frac{1}{2}Mg^{2+}$ titrimetrically.

Lime Lime was analysed according to the simple method of Wesemael, where the loss of weight is calculated after shaking with HCl.

Organic carbon After oxydating the organic carbon in the soil with $K_2Cr_2O_7$ and H_2SO_4, the amount of potassium dichromate used was determined by titration with ferrous sulphate (Walkley & Black method). Since not all the organic carbon is oxidyzed compared with the dry combustion method a multiplication factor of 1.25 (Anderson & Talbot, 1965) was used to arrive at the total organic carbon content.

pH(NaF) determination Fieldes & Perrot (1966) developed a field test for allophanes. Their data show that 2 minutes after shaking 1 gram of soil with 50 ml NaF (concentration 1 mol/l) the pH exceeds 9.4, or pH 11.0 after 1 hour, if allophanes are present. On the Serengeti Woodlands samples pH(NaF) was determined after 1 hour but no values exceeding 11.0 were observed. Only in the area adjacent to the Serengeti Plain pH values locally exceed 10, one hour after shaking with NaF.

Appendix B. Profile description of the soils of the Serengeti Woodlands

B1
Profile: Mukoma 1

Area: Mukoma Hill
Coordinates: 34° 45'E, 2° 29'N
Aerial photo: 6-23, L9-N
Date: 6-5-1974
Altitude: 1550 m
Soil classification: Typic Natrustoll
Physiography: upper pediment
Topography: subnormal
Slope: 4%
Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: *Themeda triandra*, *Panicum coloratum*, *Eustachus paspaloïdes*, *Acacia tortilis*, *Balanites egyptiaca*
Drainage condition: moderately well drained
Moistness: moist
Root distribution: many small and medium roots to 30 cm
Biological activity: termite activity below 90 cm

A1	0- 15 cm	10YR 2.5/2 when moist; sandy loam; weak fine subangular blocky; hard, very friable, slightly sticky and slightly plastic; many fine and few medium biopores; many small and medium roots; much coarse quartz sand; abrupt and smooth boundary.
B2.1t ca	15- 30 cm	10YR 3/2 when moist; clay; moderately weak very coarse prismatic, consisting of moderately strong medium angular blocky elements; friable, slightly sticky and plastic; common fine and few medium biopores; many small and medium roots; common coarse quartz sand; many continuous clay and pressure cutans; effervescent carbonate reaction of the soil material starting at 22 cm; clear and smooth boundary.
B2.2t ca	30- 45 cm	10YR 3/1 when moist; clay; moderate medium angular blocky; very friable, slightly sticky and slightly plastic; common fine and few medium biopores; few small roots; much coarse quartz sand; common small distinct white carbonate powder spots; effervescent carbonate reaction of the soil material; clear and smooth boundary.
B3.1 ca	45- 60 cm	10YR 3.5/1 when moist; clay; moderately weak fine subangular blocky; very friable, slightly sticky and slightly plastic; common fine and few medium biopores; few small roots; much coarse quartz sand; common small distinct white carbonate powder spots; effervescent carbonate reaction of the soil material; clear and undulating boundary.
B3.2 ca	60- 90 cm	5YR 3/3, 10YR 3/2 (20%) and 7.5YR 5/6 (20%) when moist; clay-loam; moderately weak fine angular blocky; very friable, slightly sticky and slightly plastic; common fine and medium biopores; few small roots; few coarse quartz sand; many large prominent white hard carbonate concretions; effervescent carbonate reaction of the soil material; gradual and smooth boundary.
B3.3 ca	90-120 cm	5YR 4/6, 10YR 2/1 (15%) and 10YR 3/4 (15%) when moist; clay-loam; moderately weak fine angular blocky; friable, slightly

sticky and slightly plastic; many fine and common medium biopores; few small roots; few coarse quartz sand; few carbonate mycelium; few small to large prominent white hard carbonate concretions; many medium distinct soft Fe-concretions 5YR 3/2; effervescent carbonate reaction of the soil material; gradual and smooth boundary.

B3.4 ca 120-150 cm 5YR 4/4 and 10YR 3/4 (10%) when moist; silt loam; moderately weak fine angular blocky; friable, slightly sticky and slightly plastic; many fine and common medium biopores; no roots; few coarse quartz sand; few small to large distinct white hard carbonate concretions; many medium distinct soft Fe-concretions 5YR 3/2; moderate carbonate reaction of the soil material.

B2
Profile: Mukoma 2

Area: Mukoma Plain
Coordinates: 34° 34'E, 2° 29'N
Aerial photo: 3-162, L10-N
Date: 3-5-1974
Altitude: 1540 m
Soil classification: Typic Natrustoll
Physiography: lower pediment
Topography: subnormal
Slope: 2%
Erosion: sheetwash and rill erosion
Parent materials: granitic rocks and volcanic deposits
Vegetation: Sporobolus marginatus, Sporobolus spicatus, Chrysochloa orientalis, Acacia tortilis, Balanites egyptiaca
Drainage condition: imperfectly
Moistness: moist below 80 cm
Root distribution: many small roots to 30 cm
Biological activity: -

A1 0 -10 cm 10YR 3/1.5 when moist, 10YR 4/2 when dry; sandy loam; weak medium subangular blocky; hard, friable, non sticky and slightly plastic; few fine and medium biopores; many small and medium roots; much course quartz sand; clear and smooth boundary.

B2.2t ca 10-32cm 10YR 2/1, when moist and dry; clay; weak coarse prismatic, consisting of strong medium angular blocky elements; very hard, firm, slightly sticky and plastic; few fine and medium biopores; many small roots; much coarse quartz sand; many continuous clay and pressure cutans; clear carbonate reaction of the soil material; clear and smooth boundary.

B2.3 ca 32-56 cm 10YR 2.5/1 when moist, 10YR 3.5/1 when dry; clay; strong fine to medium angular blocky; very hard, firm, slightly sticky and plastic; few fine and medium biopores; few small roots; much coarse quartz sand; effervescent carbonate reaction of the soil material; clear en smooth boundary.

B3.1 ca 56-81 cm 10YR 2.5/1 when moist, 10YR 3.5/1 when dry; clay-loam; moderately weak medium angular blocky; hard, very friable, slightly sticky and slightly plastic; common fine and few medium biopores; few small roots; much coarse quartz sand; few small distinct white hard carbonate concretions; effervescent carbonate reaction of the soil material; clear and smooth boundary.

B3.2 ca 81-138 cm 10YR 3.5/1 and 10YR 6/4 (20%) when moist; clay-loam; moderately weak fine angular blocky; very friable, slightly sticky and slightly plastic; common fine and few medium biopores; no roots; few coarse quartz sand; many small distinct white soft carbonate concretions; effervescent carbonate reaction of the soil material; clear and smooth boundary.

B3.3 ca 138-144 cm 10YR 3.5/3 and 10YR 3/1.5 (20%) when moist; clay-loam; moderate medium angular blocky; friable, slightly sticky and plastic; common fine and few medium biopores; no roots; common coarse quartz sand; common distinct medium white soft carbonate concretions, effervescent carbonate reaction of the soil material; clear and smooth boundary.

B3.4 ca 144+ 10YR 3.5/3 when moist; clay-loam; moderate medium angular blocky; friable, slightly sticky and plastic; common fine and few medium biopores; no roots; few coarse quartz sand; few small white soft carbonate concretions; slight carbonate reaction of the soil material.

B3
Profile: Mukoma 3

Area: Mukoma Plain
Coordinates: 34° 45'E, 2° 29'N
Aerial photo: 3-162, L10-N
Date: 29-4-1974
Altitude: 1530 m
Soil classification: Typic Natrustoll
Physiography: lower pediment
Topography: subnormal
Slope: 1%
Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Themeda triandra
Drainage condition: somewhat imperfectly
Moistness: moist
Root distribution: common small roots to 70 cm
Biological activity: -

A1 0 -10 cm 10YR 3/2 when moist; clay; weak fine subangular blocky; hard, friable, sticky and plastic; common fine and few medium biopores; few small and medium roots; much coarse quartz sand; clear and smooth boundary.

B2.1. ca 10-30 cm 10YR 2.5/1.5 when moist; clay; weak very coarse angular blocky, consisting of moderate medium angular blocky elements; friable, slightly sticky and plastic; few fine and medium biopores; common small and medium roots; much coarse quartz sand; many continuous clay and pressure cutans; clear and smooth boundary.

B2.2t ca 30-60 cm 10YR 3/1.5 when moist; clay; weak very coarse prismatic, consisting of strong medium angular blocky elements; friable, slightly sticky and plastic; few fine and medium biopores; common small and medium roots; much coarse quartz sand; many continuous clay and pressure cutans; few small distinct white hard carbonate concretions; clear carbonate reaction of the soil material; clear and smooth boundary.

B2.3 ca 60-80 cm 10YR 3/2 and 10YR 4/4 (less than 10%) when moist; clay; moderate coarse subangular blocky; friable, slightly sticky and plastic; few fine and medium biopores; few small roots; common coarse quartz sand; few small distinct white hard carbonate concretions; clear carbonate reaction of the soil material; gradual and smooth boundary.

B3.1 ca 80-100 cm 10YR 3/2.5 and 10YR 4/4 (10%) when moist; clay; moderate medium subangular blocky; friable, slightly sticky and plastic; few fine and medium biopores; no roots; common coarse quartz sand; few small distinct white hard carbonate concretions; slight carbonate reaction of the soil material; clear and smooth boundary.

B3.2 ca 100-120 cm 10YR 4/4 and 10YR 3/2 (20%) when moist; silty clay; moderate fine to medium subangular blocky; friable, slightly sticky and slightly plastic; common fine and few medium biopores; few coarse quartz sand; common medium prominent white hard carbonate concretions; common prominent white carbonate powder; slight carbonate reaction of the soil material; clear and smooth boundary.

B3.3 ca 120-160 cm 7.5YR 4/4 and 10YR 3/2 (10%), silt-loam, weak fine to medium angular blocky; firm; slightly sticky and slightly plastic; common fine and few medium biopores; no roots; few coarse quartz sand; many large prominent white hard carbonate concretions; much prominent white carbonate powder; effervescent carbonate reaction of the soil material; many medium distinct soft iron concretions.

B4
Profile: Mukoma 4

Area: Mukoma Plain — Coordinates: 34^{o} 45'E, 2^{o} 30'N
Aerial photo: 3-162, L10-N — Date: 4-5-74
Altitude: 1530 m
Soil classification: Vertic Argiustoll
Physiography: drainage line — Topography: flat or concave
Slope: level — Erosion: -
Parent materials: alluvium derived from granitic rocks and volcanic deposits
Vegetation: Pennisetum mezianum, Themeda triandra, Acacia xanthophloea, Balanites egyptiaca
Drainage condition: poorly
Moistness: moist
Root distribution: many small and medium roots to 48 cm
Biological activity: some evidence of termite activity below 90 cm

B2.1t 0 -20 cm 10YR 2/1 when moist; clay; strong medium subangular blocky; friable, sticky and plastic; few fine and medium biopores; many small and medium roots; much coarse quartz sand; many continuous clay and/or pressure cutans; surface covered with crumb ($\pm$ 2 mm); clear and smooth boundary.

B2.2t ca 20-48 cm 10YR 2.5/1 when moist; clay; strong medium subangular blocky; friable, sticky and plastic; few fine and medium biopores; many small and medium roots; much coarse quartz sand; many continuous clay and pressure cutans; clear carbonate reaction of the soil material; clear and smooth boundary.

B2.3 ca 48-75 cm 10YR 3/1 when moist; clay; moderate medium subangular blocky; friable, sticky and plastic; few fine and medium biopores; few small roots; much coarse quartz sand; common small distinct white hard carbonate concretions; effervescent carbonate reaction of the soil material; clear and smooth boundary.

B3.1 ca 75-161 cm 10YR 2/1 and 10YR 4/4 (10%) when moist; clay; weak fine subangular blocky; friable, slightly sticky and plastic; common small and few medium biopores; no roots; much coarse quartz sand; common distinct small to medium hard white carbonate concretions (to 1 cm); effervescent carbonate reaction of the soil material. At 90 cm round (termite?)

channel with a diameter of 5 cm and filled with lighter coloured material; clear and smooth boundary.

B3.2 ca 161-180 cm 5YR 4/6 and 10YR 4/2.5 (10%) when moist; clay; strong, fine to medium angular blocky; firm, slightly sticky and plastic; common fine and few medium biopores; some small old roots; few coarse quartz sand; few small distinct soft Fe concretions; many prominent large white hard carbonate concretions; clear carbonate reaction of the soil material.

B5
Profile: Mukoma 5

Area: Mukoma Plain
Coordinates: 34° 46'E, 2° 30'N
Aerial photo: 3-162, L10-N
Date: 15-5-1974
Altitude: 1500 m
Soil classification: Typic Natrustoll
Physiography: lower pediment
Topography: subnormal
Slope: 2%
Erosion: sheetwash and rill erosion
Parent materials: granitic rocks and volcanic deposits
Vegetation: Pennisetum mezianum, Themeda triandra, Digitaria macroblephara
Drainage condition: imperfectly
Moistness: moist
Root distribution: many small roots to 30 cm
Biological activity: -

A1 0 -10 cm 10YR 2.5/1 when moist; clay; strong fine subangular blocky; firm, sticky and plastic; few fine and medium biopores; many small and medium roots; common coarse quartz sand; clear and smooth boundary.

B2.2t 10-30 cm 10YR 3.5/1 when moist; clay; weak very coarse prismatic, consisting of strong medium angular blocky elements; firm, sticky and very plastic; few fine biopores; many small roots; few coarse quartz sand; many continuous clay and pressure cutans; few small faint white carbonate mottles; effervescent carbonate reaction of the soil material; clear and smooth boundary.

B2.3 ca 30-60 cm 10YR 2.5/1 when moist; clay; moderate fine to medium angular blocky; friable, sticky and plastic; few fine and medium biopores; few small roots; common coarse quartz sand; few small to medium distinct white carbonate mottles; effervescent carbonate reaction of the soil material; gradual and smooth boundary.

B3.1 ca 60-110 cm 10YR 3/1.5 when moist; clay; moderately weak fine subangular blocky; friable, slightly sticky and slightly plastic; many fine and common medium biopores; no roots; common coarse quartz sand; many medium distinct white carbonate mottles; effervescent carbonate reaction of the soil material; common small distinct black iron/manganese mottles; clear and smooth boundary.

B3.2 ca 110-140 cm 10YR 3/3.5 when moist; clay; moderately weak medium to coarse angular blocky; friable, slightly sticky and plastic; many fine biopores; no roots; few coarse quartz sand; few small faint white carbonate mottles; effervescent carbonate reaction of the soil material; clear and smooth boundary.

B3.3 ca 140-160 cm 10YR 3.5/3 when moist; clay; moderately weak medium to coarse angular blocky; firm, sticky and plastic; few fine and medium biopores; no roots; few coarse quartz sand; few small faint white carbonate mottles; effervescent carbonate reaction of the soil material; common small hard and medium soft distinct iron concretions; clear and smooth boundary.

B3.4 ca 160-180 cm 7.5YR 2.5/4 when moist; clay; moderate fine to medium angular blocky; very firm, sticky and plastic; few fine biopores; no roots; few coarse quartz sand; few small prominent white hard carbonate concretions; slight carbonate reaction of the soil material; common small distinct hard iron concretions (5YR 4/4); clear and smooth boundary.

B3.5 ca 180+ 7.5YR 5/6 when moist; clay; moderate fine to medium angular blocky; firm, sticky and very plastic; few fine biopores; no roots; few coarse quartz sand; few small distinct white hard carbonate concretions; slight carbonate reaction of the soil material; common small distinct hard iron concretions.

B6
Profile: Mbalageti 1

Area: north of airstrip
Coordinates: 34° 42'E, 2° 36'N
Aerial photo: 6-22, L 9-N
Date: 6-9-1975
Altitude: 1550 m
Soil classification: Udic Argiustoll
Physiography: upper pediment
Topography: normal
Slope: 4%
Erosion: some sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Cymbopogon excavatus, Pennisetum mezianum, Themeda triandra
Drainage condition: moderately well drained
Moistness: dry
Root distribution: few medium and small roots to 40 cm
Biological activity: termite activity below 100 cm

A1 0- 14 cm 10YR 2/1,5 when moist, 10YR 3,5/2 when dry; silty clay-loam; moderate fine to medium subangular blocky; hard, friable, sticky and slightly plastic; many fine and common medium biopores; many small and medium roots; very few coarse quartz sand; clear and smooth boundary.

B2.1t 14-40 cm 10YR 2/2 when moist, 10YR 2,5/2 when dry; clay; moderate medium to coarse angular blocky; hard, friable, sticky and very plastic; few fine and common medium biopores; few fine and medium roots; common coarse quartz sand; common continuous clay and pressure cutans; gradual and smooth boundary.

B2.2t 40-70 cm 7.5YR 2/2 when moist, 7.5YR 3/2 when dry; clay; strong very coarse angular blocky; extremely hard, very firm, sticky and very plastic; few fine and medium biopores; few small roots; common coarse quartz sand, many continuous clay and pressure cutans; few very small black slightly hard Fe-Mn concretions; gradual and smooth boundary.

B2.3t 70-100 cm 10YR 3/4 when moist, 10YR 4/4 when dry; clay; moderately strong medium to coarse angular blocky; hard, firm, sticky and

		very plastic; few fine and medium biopores; few small roots; few coarse quartz sand; common continuous clay and pressure cutans; very few small distinct white hard carbonate concretions; gradual and smooth boundary.
B3	100-150 cm	7.5YR 4/5 when moist, 7.5YR 6/4 when dry; silty clay-loam; moderate fine to medium subangular blocky; slightly hard, very friable, sticky and slightly plastic; few fine and medium biopores; no roots; no sand; few small distinct white hard carbonate concretions; some termite fungus.

B7
Profile: Mbalageti 2

Area: Mbalageti airstrip
Coordinates: 34° 42'E, 2° 36'N
Aerial photo: 6-22, L9-N
Date: 6-9-1975
Altitude: 1530 m
Soil classification: Typic Natrustoll
Physiography: lower pediment
Topography: subnormal
Slope: 2%
Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: _Chrysochloa orientalis_, _Themeda triandra_, _Pennisetum mezianum_
Drainage condition: imperfectly
Moistness: dry, except for top soil
Root distribution: common small and few medium roots to 22 cm
Biological activity: termite activity below 58 cm

A1	0 -8 cm	10YR 2/3 when moist; silt-loam; moderate medium to coarse subangular blocky; friable, slightly sticky and slightly plastic; common fine and medium biopores; common small and medium roots; few coarse quartz sand; common very small black slightly hard concretions (clay?); abrupt and smooth boundary.
B2.2t	8-22 cm	10YR 2/3 when moist and dry; clay; weak very coarse prismatic, consisting of strong fine angular blocky elements; very hard, firm, sticky and very plastic; few fine and medium biopores; common small and few medium roots; few coarse quartz sand; common continuous clay and pressure cutans; gradual and smooth boundary.
B2.3 ca	22-58 cm	10YR 3/2 when moist and dry; clay; moderately strong, fine to medium angular blocky; hard, very friable, very sticky and plastic; few fine biopores; few small roots; few coarse quartz sand; few small distinct white hard carbonate concretions; clear carbonate reaction of the soil material; clear and smooth boundary.
B3.1 ca	58-102 cm	10YR 2.5/3 when moist, 10YR 3.5/3 when dry; silty clay; moderate fine to medium angular blocky; hard, very friable, slightly sticky and slightly plastic; common fine and few medium biopores; very few very small roots; few coarse quartz sand; common medium distinct white hard carbonate concretions; clear carbonate reaction of the soil material; common termite fungus; clear and smooth boundary.
B3.2 ca	102-120 cm	10YR 3.5/4 when moist; clay-loam; moderate fine to medium angular blocky; friable, sticky and slightly plastic; common fine and medium biopores; no roots; no quartz sand; common medium distinct white hard carbonate concretions; common termite fungus.

B8
Profile: Nyara Swiga 2

Area: Nyara Swiga Hill — Coordinates: 34° 47'E, 2° 22'N
Aerial photo: 3-165, L 10 — Date: 30-10-1974
Altitude: 1500 m
Soil classification: Udic Argiustoll
Physiography: upper pediment — Topography: normal
Slope: 5% — Erosion: sheetwash
Parent materials: metamorphic Fe-rich rocks and volcanic deposits
Vegetation: Themeda triandra, Acacia clavigera
Drainage condition: moderately well drained
Moistness: topsoil dry, subsoil moist
Root distribution: common small roots
Biological activity: termite activity below 95 cm

A1	0 -19 cm	7.5YR 2/3 when moist, 7.5YR 3/3,5 when dry; sandy clay-loam; moderately weak subangular blocky; hard, very friable, slightly sticky and slightly plastic; abundant fine and common medium biopores; common small and medium roots; few coarse quartz sand and gravel to 1 cm; clear and smooth boundary.
B2.1t	19-62 cm	5YR 2/3 when moist, 5YR 3/3 when dry; clay-loam; moderately weak subangular blocky; slightly hard, friable, sticky and slightly plastic; many fine and common medium biopores; common small and medium roots; few coarse quartz sand and gravel to 0.5 cm; few patchy clay and pressure cutans; clear and smooth boundary.
B2.2t	62-95 cm	5YR when moist, 5YR 3/3 when dry; clay; moderate medium subangular blocky; very hard, friable, sticky and plastic; many fine and common medium biopores; few small roots; few coarse quartz sand; many continuous clay and pressure cutans; gradual and smooth boundary.
B3.1t	95-120 cm	5YR 2/4 when moist, 5YR 3/4 when dry; clay; moderate fine subangular blocky; very hard, friable, very sticky and slightly plastic; many fine and common medium biopores; no roots; very few coarse quartz sand; many to common continuous clay and pressure cutans; some termite channels; clear and smooth boundary.
B3.2t	120-150 cm	5YR 2/6 when moist, 5YR 3/6 when dry; clay-loam; moderately weak fine subangular blocky; very hard, friable, slightly sticky and slightly plastic; common fine and medium biopores; common coarse quartz sand; many to common continuous clay and pressure cutans; very few small faint white hard carbonate concretions; at 140 cm quartzite boulders.

B9
Profile: Nyara Swiga 3

Area: Nyara Swiga Hill — Coordinates: 34° 47'E, 2° 22'N
Aerial photo: 3-164, L10-N — Date: 29-5-1974
Altitude: 1480 m
Soil classification: Typic Natrustoll
Physiography: lower pediment — Topography: subnormal
Slope: 2% — Erosion: step erosion
Parent materials: Nyanzian rocks and volcanic deposits
Vegetation: Themeda triandra, Pennisetum mezianum, Eustachus paspaloides
Drainage condition: imperfectly

Moistness: topsoil dry (0-50 cm)
Root distribution: common small roots to 65 cm
Biological activity: -

A1	0 -16 cm	10YR 2/2 when moist, 10YR 3.5/3 when dry; silt-loam; moderate fine subangular blocky; slightly hard, friable; slightly sticky and slightly plastic; many fine and common medium biopores; many small and medium roots; few coarse quartz sand; abrupt and smooth boundary.
B2.2t	16-36 cm	10YR 5/4 when moist, 10YR 3.5/3 when dry; clay; moderate coarse columnar, consisting of strong fine angular blocky elements; extremely hard, very firm, sticky and very plastic; common fine, few medium and large biopores; many small and common medium roots; few coarse quartz sand; abundant continuous clay and pressure cutans; clear and smooth boundary.
B2.3t	36-65 cm	7.5YR 3/2 when moist; clay; moderate fine angular blocky; very friable, sticky and plastic; common fine and few medium biopores; common small roots; few coarse quartz sand; abundant continuous clay and pressure cutans; few small faint hard white carbonate concretions; clear and smooth boundary.
B3.1t	65-110 cm	7.5YR 3/2 when moist; clay; moderate medium angular blocky; friable, slightly sticky and slightly plastic; common fine, few medium and large biopores; few small roots; few coarse quartz sand; many continuous clay and pressure cutans; few small distinct hard white carbonate concretions; few small distinct hard iron concretions; clear and smooth boundary.
B3.2 t	110-150 cm	5YR 3/4 when moist; clay; moderate medium angular blocky; friable, slightly sticky and slightly plastic; common fine, few medium and large biopores; no roots; very few coarse quartz sand; many continuous clay and pressure cutans; very few small distinct hard white carbonate concretions; few small distinct hard iron concretions.

B10
Profile: Nyara Swiga 5

Area: northeast of Nyara Swiga Hill — Coordinates: 34° 50'E, 2° 21'N
Aerial photo: 3-165, L10-N — Date: 28-5-1974
Altitude: 1460 m
Soil classification: Typic Natrustoll
Physiography: ridge slope — Topography: subnormal
Slope: 2% — Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Themeda triandra, Pennisetum mezianum
Drainage condition: somewhat imperfectly
Moistness: dry
Root distribution: few small roots to 45 cm
Biological activity: termite activity especially in A1 horizon

A1	0 -13 cm	10YR 3/1.5 when moist, 10YR 4/2 when dry; sandy clay; weak fine subangular blocky; very hard, friable, sticky and plastic; common fine and few medium biopores; many small and common medium roots; common coarse quartz sand; abrupt and smooth boundary.
B2.2t	13-30 cm	10YR 3/1.5 when moist and dry; clay; strong coarse columnar, consisting of moderate medium angular blocky elements;

		extremely hard, very firm, sticky and very plastic; few fine biopores; common small and medium roots; few coarse quartz sand; abundant continuous clay and pressure cutans; few small distinct white hard carbonate concretions; clear and smooth boundary.
B2.3t	30-45 cm	10YR 2.5/2 when moist, 10YR 3/2 when dry; clay; moderate medium angular blocky; very hard, friable, sticky and plastic; common fine and few very large biopores; few small roots; few coarse quartz sand; many continuous clay and pressure cutans; common small distinct white hard carbonate concretions; clear and smooth boundary.
B2.4t	45-80 cm	10YR 3/2 when moist, 10YR 3/2.5 when dry; clay; moderate fine to very fine angular blocky; slightly hard, very friable, sticky and slightly plastic; few fine biopores; very few small roots; few coarse sand; many continuous clay and pressure cutans; common small distinct white hard carbonate concretions; slight carbonate reaction of the soil material; gradual and smooth boundary.
B3.1	80-120 cm	7.5YR 3/2 when moist, 7.5YR 4/4 when dry; clay-loam; weak fine angular blocky; hard, very friable, slightly sticky and slightly plastic; few fine and medium biopores; no roots; few coarse quartz sand; common small distinct white hard carbonate concretions; common small distinct black soft iron/manganese mottles; clear and smooth boundary.
B3.2	120-140 cm	7.5YR 3/2 when moist, 7.5YR 4/4 when dry; clay-loam; weak very fine angular blocky; slightly hard, very friable, slightly sticky and slightly plastic; few fine biopores; no roots; few coarse quartz sand; few small distinct white hard carbonate concretions; many small faint soft iron concretions; many small prominent soft black iron/manganese mottles.

B12
Profile: Kamarishe 1

Area: Kamarishe Hill — Coordinates: 34° 39'E, 2° 16'N
Aerial photo: 9-103, L8-N — Date: 7-2-1976
Altitude: 1320 m
Soil classification: Udic Argiustoll
Physiography: upper pediment — Topography: normal
Slope: 4% — Erosion: no evidence
Parent materials: siltstone and volcanic deposits
Vegetation: Acacia clavigera, Acacia senegal, Dichrostachys cinerea
Drainage condition: well drained
Moistness: dry
Root distribution: common small and medium roots to 80 cm
Biological activity: no evidence

A1	0 - 15 cm	10YR 2/2 when moist, 10YR 3/3 when dry; loamy sand; moderate fine subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; common fine and common medium biopores; many small and medium roots; much well rounded gravel to 10 cm; clear and smooth boundary.
B2.1t	15-50 cm	7,5YR 2/2 when moist, 7,5YR 2/3 when dry; sandy clay-loam; moderately strong fine angular blocky; hard, friable, sticky and plastic; common fine and few medium biopores; common small and medium roots; many continuous clay and

pressure cutans; abundant moderately well rounded quartzite gravel to 10 cm; gradual and smooth boundary.

B2.2	50-80 cm	5YR 2/3 when moist, 5YR 2,5/4 when dry; loam; moderately strong fine to very fine angular blocky; slightly hard, friable, sticky and slightly plastic; many fine and common medium biopores; common small and medium roots; few patchy clay and pressure cutans; abundant moderately well rounded quartzite gravel.
C	80 cm +	rotten rock (silt stone); colour 10YR 5/3.

B13
Profile: Kamarishe 2

Area: Kamarishe Hill
Coordinates: 34° 39'E, 2° 16'N
Aerial photo: 9-103, L8-N
Date: 7-1-1976
Altitude: 1300 m
Soil classification: Typic Natrustoll
Physiography: lower pediment
Topography: subnormal
Slope: 2%
Erosion: sheetwash
Parent materials: Nyanzian rocks and volcanic deposits
Vegetation: Pennisetum mezianum, Acacia drepanolobium, Balanites egyptiaca
Drainage condition: poorly
Moistness: dry
Root distribution: few small and medium roots to 30 cm
Biological activity: termite activity especially below 70 cm

A1	0 -10 cm	7.5YR 2/3 when moist and dry; sandy loam; strong coarse angular blocky; very hard, friable, slightly sticky and slightly plastic; many fine and few medium biopores; few small and common medium roots; common coarse sand; clear and smooth boundary.
B2.1t	10-30 cm	7.5YR 2/3 when moist and dry; clay; weak very coarse prismatic, consisting of very strong coarse angular blocky elements; extremely hard, friable, sticky and very plastic; many fine and common medium biopores; few small and common medium roots; few coarse sand; many continuous clay and pressure cutans; clear and smooth boundary.
B2.2t	30-80 cm	7.5YR 2/2 when moist, 7.5YR 2.5/2 when dry; clay; strong medium angular blocky; hard, friable, sticky and plastic; few fine and medium biopores; common small roots; few coarse quartz sand; many continuous clay and pressure cutans; clear carbonate reaction of the soil material below 50 cm; some termite fungus below 70 cm; clear and smooth boundary.
B3. ca	80-120 cm	5YR 3/4 when moist, 5YR 4/4 when dry; clay-loam; moderate fine to medium angular blocky; slightly hard, very friable, slightly sticky and slightly plastic; few fine, medium and large biopores; no roots; few coarse quartz sand; clear carbonate reaction of the soil material; common filled termite channels; some termite fungus.

B14
Profile: Kamarishe 3

Area: Kamarishe Hill | Coordinates: 34° 39'E, 2° 16'N
Aerial photo: 9-103, L8-N | Date: 7-2-1976
Altitude: 1290 m
Soil classification: Typic Natrustoll
Physiography: lower pediment | Topography: subnormal
Slope: 1% | Erosion: sheetwash
Parent materials: Nyanzian rocks and volcanic deposits
Vegetation: Pennisetum mezianum, Acacia seyal
Drainage condition: poorly
Moistness: dry
Root distribution: common small and medium roots to 25 cm
Biological activity: termite activity below 45 cm

A1	0 -2 cm	10YR 2.5/1 when moist, 10YR 4/1 when dry; sandy loam; moderate medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; few fine biopores; common small and medium roots; much coarse quartz sand; clear and smooth boundary.
B2.1t	2-25 cm	10YR 2.5/1 when moist and dry; clay; weak very coarse prismatic, consisting of very strong fine angular blocky elements; very hard, friable, sticky and very plastic; few fine biopores; common small and medium roots; common coarse quartz sand; many continuous clay and pressure cutans; clear and smooth boundary.
B2.2t	25-45 cm	10YR 2.5/1 when moist and dry; clay; strong medium to coarse angular blocky, consisting of very strong small angular blocky elements; very hard, friable, sticky and very plastic; few fine biopores; few small roots; common coarse quartz sand; many continuous clay and pressure cutans; few small distinct white hard carbonate concretions; slight carbonate reaction of the soil material; gradual and smooth boundary.
B3.1 ca	45-80 cm	7.5YR 3/3 when moist, 7.5YR 4/3 when dry; clay-loam; moderate medium angular blocky; hard, very friable, slightly sticky and slightly plastic; few fine biopores; no roots; common coarse quartz sand; few to common medium distinct white hard carbonate concretions; slight carbonate reaction of the soil material; common termite fungus; gradual and smooth boundary.
B3.2 ca	80-125 cm	5YR 3/6 when moist and dry; clay-loam; moderate medium angular blocky; hard, very friable, slightly sticky and slightly plastic; few fine biopores; no roots; common coarse quartz sand; common medium distinct white hard carbonate concretions; slight carbonate reaction of the soil material; many filled termite channels; some termite fungus.

B15
Profile: Ndoho

Area: Ndoho Plain | Coordinates: 34° 28'E, 2° 29'N
Aerial photo: 5-120, L6-N | Date: 9-2-1976
Altitude: 1410 m
Soil classification: Udic Argiustoll
Physiography: pediplain | Topography: subnormal
Slope: 1% | Erosion: no evidence

Parent materials: granitic rocks and volcanic deposits
Vegetation: Digitaria macrobiephara, Themeda triandra
Drainage condition: moderately well
Moistness: dry
Root distribution: common small and few medium roots to 80 cm
Biological activity: termite activity throughout the profile

A1	0 -10 cm	10YR 1.7/1 when moist, 10YR 3.5/1 when dry; sandy loam; moderate fine to medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; few biopores; many small and medium roots; common coarse quartz sand; termite channel Ø 5 cm; clear and smooth boundary.
B1	10-40 cm	10YR 1.7/1 when moist, 10YR 3/1 when dry; loam; very weak very coarse prismatic, consisting of moderately strong medium subangular blocky elements; hard, very friable, slightly sticky and slightly plastic; common fine and mediun biopores; common small and medium roots; common coarse quartz sand; piece of angular jaspis (Ø 7 cm) at 20 cm; gradual and smooth boundary.
B2.t	40-80 cm	10YR 2/1 when moist, 10YR 3/1.5 when dry; clay-loam; moderately strong medium angular blocky; very hard, very friable, sticky and plastic; few fine, medium and large biopores; common small and few medium roots; common coarse quartz sand; many continuous clay and pressure cutans; clear and smooth boundary.
B3.1t	80-110 cm	mixture of 10YR 3/2 and 10YR 2/1 when moist and 10YR 4/2 and 10YR 2/1 when dry; clay-loam; moderate medium angular blocky; hard, very friable, slightly sticky and slightly plastic; few fine, medium and large biopores; few small and medium roots; few to common coarse quartz sand; common continuous clay and pressure cutans; common termite fungus; gradual and smooth boundary.
B3.2t	110-140 cm	7.5YR 4/4 when moist, 7.5YR 5/4 when dry; clayloam; moderate fine angular blocky; hard, very friable, non sticky and non plastic; few fine, medium and large biopores; few small roots; common coarse quartz sand; common continuous clay and pressure cutans; at 140 cm few distinct medium white carbonate mottles.

B16
Profile: Musabi 1

Area: Musabi Plain East — Coordinates: 34° 35'E, 2° 14'N
Aerial photo: 9-103, L8-N — Date: 26-11-74
Altitude: 1290 m
Soil classification: Udic Argiustoll
Physiography: pediplain — Topography: normal
Slope: ca 1% — Erosion: sheetwash
Parent materials: siltstone and volcanic deposits
Vegetation: Sporobolus marginatus, Salvadore persica, Acacia tortilis, Sanseviera sp.
Drainage condition: imperfectly
Moistness: dry, except for topsoil (0-10 cm)
Root distribution: common small roots to 72 cm
Biological activity: termite activity till at least 100 cm

A1	0 - 5 cm	10YR 2/2 when moist; sandy clay-loam; weak fine to medium angular blocky; hard, very friable, slightly sticky and slightly plastic; many fine and common medium biopores; many small

and common medium roots; much coarse quartz sand; clear and smooth boundary.

B2.1t 5 -26 cm 10YR 2/2 when moist and dry; sandy clay; moderate medium subangular blocky, consisting of strong fine angular blocky elements; very hard, friable, sticky and plastic; few fine and medium biopores; many small and few medium roots; common coarse quartz sand; many continuous clay and pressure cutans; clear and smooth boundary.

B2.2t ca 26-72 cm 10YR 2/2 when moist, 10YR 4/2 when dry; clay; moderately strong fine to medium subangular blocky; hard, very friable, sticky and plastic; common fine medium and large biopores; common small roots; common coarse quartz sand; common continuous clay and pressure cutans; common distinct white carbonate mycelium; one rounded piece of gravel at 35 cm (Ø 8 cm); many old termite channels with darker filling; gradual and smooth boundary.

B3.1ca 72-120 cm 10YR 3/3.5 when moist, 10YR 4/3.5 when dry; clay-loam; moderate medium subangular blocky; hard, very friable, sticky and plastic; common fine and few medium biopores; no roots; few coarse quartz sand; common distinct white carbonate mycelium; many old termite channels with darker filling; clear and smooth boundary.

B3.2ca 120-140 cm 7.5YR 4/6 (as well as 10YR 3/31 30%) when moist, 7.5YR 5/6 (and 10YR 4/3) when dry; clay-loam; moderately strong fine subangular blocky; hard, very friable and plastic; many fine common medium and large biopores; no coarse sand; few faint white carbonate mycelium; many old termite channels with darker filling; many distinct bluish soft iron concretions; common prominent small black hard Mn concretions.

160 cm 5YR 3/6 when moist, very hard, possibly hardened plinthite.

B17
Profile: Musabi 2

Area: Musabi Plain West — Coordinates: 34° 32'E, 2° 16'N
Aerial photo: 9-28, L7-S — Date: 26-11-74
Altitude: 1290 m
Soil classification: Vertic Argiustoll
Physiography: depression — Topography: flat or concave
Slope: level — Erosion: sheetwash
Parent materials: alluvium
Vegetation: Chrysochloa orientalis, Panicum coloratum, Acacia drepanolobium
Drainage condition: poorly
Moistness: dry, except top soil
Root distribution: common small and medium roots to 25 cm
Biological activity: no evidence

A1 0 -10 cm 10YR 3/1 when moist; sandy clay; too wet to determine structure; sticky and plastic; few fine biopores; many small and common medium roots; common coarse quartz sand; surface covered with coarse quartz sand; clear and smooth boundary.

B2.1t 10-25 cm 10YR 3/1 when moist and dry; clay; moderate medium subangular blocky, consisting of strong fine angular blocky elements; hard, very friable, sticky and very plastic; common fine biopores; common small and medium roots; common coarse quartz sand; many continuous clay and pressure cutans; clear and smooth boundary.

B2.2t ca	25-48 cm	10YR 3/1.5 when moist and dry; clay; moderate medium subangular blocky, consisting of moderately strong fine subangular blocky elements; hard, very friable, sticky and very plastic; common fine and few medium biopores; few very small roots; few coarse quartz sand; many continuous clay and pressure cutans; few small distinct white hard carbonate concretions; clear and smooth boundary.
B3.1 ca	48-130 cm	10YR 4/2 when moist, 10YR 5/2.5 when dry; clay; moderate fine angular blocky; hard, very friable, sticky and plastic; common fine and few medium biopores; no roots; very few coarse quartz sand; one rounded piece of gravel (9 cm) at 100 cm; common medium distinct white hard carbonate concretions; common medium distinct soft bluïsh Fe concretions.
	150 cm	10YR 5/2.5 when moist, 10YR 6/3 when dry; few small angular quartzite fragments; effervescent carbonate reaction of the soil material.

B18
Profile: Musabi 3

Area: Musabi Plain West — Coordinates: 34° 29'E, 2° 17'N
Aerial photo: 9-130, L7-S — Date: 29-8-1976
Altitude: 1290 m
Soil classification: Udic Argiustoll
Physiography: pediplain — Topography: subnormal
Slope: 1% — Erosion: sheetwash
Parent materials: silt stone and volcanic deposits
Vegetation: *Chrysochloa orientalis*
Drainage condition: imperfectly
Moistness: moist, except topsoil (0-30 cm)
Root distribution: common small roots to 30 cm
Biological activity: no evidence

A1.cn	0 - 3 cm	10YR 3/2.5 when moist, 10YR 4/2.5 when dry; sandy loam; weak fine angular blocky; hard, very friable, slightly sticky and slightly plastic; few biopores; common small and many medium roots; few coarse quartz sand; common small distinct blak hard iron-clay pellets; at surface few mottles (to 20 cm) of quartz, quartzite, silt stone and bounded iron stone; soft thin surface sealing; abrupt and smooth boundary.
B2.2t	3 -30 cm	10YR 2.5/3 when moist or dry; clay; strong coarse angular blocky, consisting of very strong medium and fine angular blocky elements; very hard, friable, sticky and very plastic; few biopores; common small roots; few coarse quartz sand; many continuous clay and pressure cutans; clear and smooth boundary.
B2.3t	30-75 cm	7.5YR 3/3 when moist; clayloam; moderate medium angular blocky; very friable, sticky and plastic; few biopores; few small roots to 50 cm; very few coarse quartz sand; common continuous clay cutans; gradual and smooth boundary.
B3.1t	75-115 cm	7.5YR 3/4 when moist; clay-loam; moderate medium to fine angular blocky; very friable, sticky and slightly plastic; no roots; few coarse sand; common continuous clay cutans.
	140-400 cm	rotten rock, colour 7.5YR 7/2.

B19
Profile: Kirawira 1

Area: Kirawira Research Station — Coordinates: 34° 13'E, 2° 09'N
Aerial photo: 3-218, L4-S — Date: 11-09-74
Altitude: 1200 m
Soil classification: Typic Natrustalf
Physiography: pediplain — Topography: subnormal
Slope: 2% — Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Chrysochloa orientalis, Eragrostis tenuifolia
Drainage condition: imperfectly
Moistness: dry
Root distribution: common small roots to 55 cm
Biological activity: no evidence

A2	0 - 5 cm	10YR 4/1 when moist, 10YR 4/2 when dry; loamy sand; weak very fine subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; no biopores; common small and medium roots; common coarse quartz sand; abrupt and smooth boundary.
B2.t	5 -29 cm	10YR 3.5/1 when moist, 10YR 3.5/2 when dry; sandy clay-loam; strong very coarse prismatic; extremely hard, very firm, sticky and plastic; no biopores; common small roots; much coarse quartz sand; ped faces coated with very fine to coarse sand, colour 10YR 7/1, clear and smooth boundary.
B3 ca	29-55 cm	10YR 3.5/1 when moist, 10YR 4/4.5 when dry; sandy clay-loam; moderate fine to medium subangular blocky; slightly hard, friable, sticky and plastic; no biopores; common small roots; much coarse quartz sand; common small prominent white hard carbonate concretions.
	J 55 cm	some angular, but mostly very well rounded gravel.

Remark: Clay cutans in the B2.t horizon are probably obscured by sand coatings.

B20
Profile: Kirawira 2

Area: Kirawira Research Station — Coordinates: 34° 14'E, 2° 09'N
Aerial photo: 3-218, L4-S — Date: 12-9-74
Altitude: 1210 m
Soil classification: Typic Natrustoll
Physiography: pediplain — Topography: subnormal
Slope: 2% — Erosion: sheetwash
Parent materials: Nyanzian rocks and volcanic deposits
Vegetation: Pennisetum mezianum, Microchloa kunthii, Balanites egyptiaca, Acacia senegal
Drainage condition: moderately well
Moistness: dry
Root distribution: few small roots to 69 cm
Biological activity: no evidence

A1	0 -20 cm	7.5YR 3/1 when moist, 7.5YR 3/2 when dry; sandy clay; moderate medium to coarse subangular blocky; very hard, friable, sticky and plastic; common fine and few medium biopores; common small roots; common coarse quartz sand; clear and smooth boundary.
B2.1t	20-35 cm	7.5YR 2.5/2 when moist, 7.5YR 3.5/3 when dry; clay; moderately weak coarse to very coarse prismatic consisting of strong

coarse angular blocky elements; very hard, friable, sticky and plastic; common fine and few medium biopores; few small roots; common coarse mainly quartz sand; common continuous clay and pressure cutans; gradual and smooth boundary.

B2.2t 35-68 cm 7.5YR 2.5/2 when moist, 7.5YR 3.5/3 when dry; clay; weak very coarse prismatic, consisting of strong coarse angular blocky elements; very hard, friable, sticky and very plastic; few fine and medium biopores; few small roots; common to much coarse, mainly quartz sand; many continuous clay and pressure cutans.

J 68 cm predominantly rounded quartz gravel.

B21
Profile: Kirawira 3

Area: west of Kirawira Research Station
Coordinates: 34^{o} 13'E, 2^{o} 07'N
Aerial photo: 3-218, L4-S
Date: 12-9-74
Altitude: 1190 m
Soil classification: Typic Natraquoll
Physiography: pediplain slope
Topography: subnormal
Slope: 1%
Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Chrysochloa orientalis, Digitaria macroblephara, Balanites egyptiaca
Drainage condition: poorly drained
Moistness: moist
Root distribution: common small roots to 50 cm
Biological activity: no evidence

B1 0 -27 cm 10YR 3.5/1 when moist, 10YR 4.5/1 when dry; clay; very strong very coarse prismatic; extremely hard, extremely firm, sticky and very plastic; common fine and few medium biopores; few small and medium roots; common coarse quartz sand; pedfaces coated with very fine sand, 10YR 6/1 when dry; small cracks; abrupt and smooth boundary.

B2.1t ca 27-54 cm 2.5YR 3.5/1 when moist; clay; moderately weak medium to coarse subangular blocky; friable, slightly sticky and very plastic, common fine and few medium biopores; few small and medium roots; common coarse quartz sand; few patchy clay and/or pressure cutans; effervescent carbonate reaction of the soil material; few distinct small white carbonate mottles; gradual and smooth boundary.

B2.2t ca 54-100 cm 10YR 3/1 when moist; clay; weak medium to coarse subangular blocky, sticky and plastic; common fine and few medium biopores; few small roots to 70 cm; common coarse quartz sand; common continuous clay and pressure cutans; clear carbonate reaction of the soil material; few distinct small white carbonate mottles; gradual and smooth boundary.

B2.3t ca J100 (-150) cm 2.5YR 3.5/1 when moist; clay; weak medium to coarse subangular blocky, slightly sticky and plastic; common fine and few medium biopores; no roots; common coarse quartz sand; common continuous clay and pressure cutans; clear carbonate reaction of the soil material; few small distinct white hard carbonate concretions and few distinct small white carbonate mottles.

B22
Profile: Kirawira 4

Area: south of Grumeti crossing — Coordinates: 34° 14'E, 2° 12'N
Aerial photo: 3-218, L4-S — Date: 11-11-75
Altitude: 1220 m
Soil classification: Typic Natrustoll
Physiography: lower pediment (depression) — Topography: subnormal
Slope: 1% — Erosion: no evidence
Parent materials: Nyanzian rocks and volcanic deposits
Vegetation: Chrysochloa orientalis, Microchloa kunthii, Acacia clavigera
Drainage condition: moderately well drained
Moistness: dry
Root distribution: common small and medium roots to 35 cm
Biological activity: no evidence

A1 cn	0 -14 cm	7.5YR 3/1 when moist, 7.5YR 3.5/2 when dry; loam; moderate medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; many fine and medium biopores; common small and many medium roots; common coarse quartz sand; few small distinct black hard iron-clay pellets; clear and smooth boundary.
B1 cn	14-35 cm	5YR 3/1 when moist, 5YR 3/1.5 when dry; clay-loam; moderate medium subangular blocky; slightly hard, friable, sticky and plastic; many fine and medium; common large biopores; common small and medium roots; common quartz sand; few small distinct black hard iron-clay pellets; abrupt and smooth boundary.
B2.1t	35-73 cm	5YR 3/4 when moist or dry; clay; strong very coarse prismatic; consisting of strong coarse angular blocky elements; very hard, friable, sticky and plastic; very few fine biopores; few small and medium roots; very few coarse quartz sand; many continuous clay and pressure cutans; cracks ca 1 cm wide; gradual and smooth boundary.
B2.2t	73-110 cm	5YR 3/4 when moist or dry; clay; strong coarse to very coarse angular blocky; very hard, friable, sticky and plastic; very few fine biopores; few small and medium roots; very few coarse quartz sand; many continuous clay and pressure cutans; cracks ca 1 cm wide, clearly developed tilted wedges; clear and smooth boundary.
B2.3t	110-140 cm	5YR 3/6 when moist, 5YR 5/6 when dry; clay; moderately strong coarse angular blocky; hard, friable, sticky and plastic; common fine and few medium biopores; no roots; very few coarse quartz sand; many continuous clay and pressure cutans; few weakly developed tilted wedges; some old termite channels with darker filling.

Remark: Because the cracks are not open up to the surface and no polyhedrons are recognized in the topsoil, this profile is not classified as a Vertisol, despite the presence of tilted wedges.

B23
Profile: Kirawira 5

Area: south of Grumeti crossing — Coordinates: 34° 14'E, 2° 12'N
Aerial photo: 3-218, L4-5 — Date: 11-11-1975
Altitude: 1220 m
Soil classification: Typic Natrustoll

Physiography: lower pediment — Topography: subnormal
Slope: 1% — Erosion: sheetwash
Parent materials: Nyanzian rocks and volcanic deposits
Vegetation: Chrysochloa orientalis, Themeda triandra, Microchloa kunthii
Drainage condition: imperfectly
Moistness: dry
Root distribution: common small and few medium roots to 69 cm
Biological activity: termite activity below 69 cm

A1 cn 0 - 5 cm 10YR 3/2 when moist, 10YR 4/2 when dry; sandy loam; moderate medium to coarse subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; few fine and medium biopores; many small and medium roots; few coarse quartz sand; common to much small distinct black hard iron-clay pellets; soft platy surface sealing (1 cm); abrupt and smooth boundary.

B2.2t.ca.cn 5 -20 cm 7.5YR 3.5/2 when moist or dry; clay; strong very coarse columnar, consisting of strong medium angular blocky elements; very hard, friable, sticky and very plastic; few fine biopores; many small and common medium roots; few coarse quartz sand; many continuous clay and pressure cutans; few small distinct black hard iron-clay pellets; clear and smooth boundary.

B2.3t.ca.cn 20-43 cm 7.5YR 3.5/2 when moist or dry; clay; strong fine angular blocky; very hard, friable, sticky and very plastic; very few fine biopores; common small and medium roots; few coarse quartz sand; many continuous clay and pressure cutans; very few small distinct black hard iron-clay pellets, few small prominent white hard carbonate concretions; gradual and smooth boundary.

B3.1t.ca.cn 43-69 cm 7.5YR 3.5/3 when moist, 7.5YR 4/4 when dry; clay; strong fine to very fine angular blocky; very hard, friable, sticky and plastic; very few fine biopores; common small and few medium roots; very few quartz sand; many continuous clay and pressure cutans; very few small distinct black slightly hard iron-clay pellets; common medium prominent white hard carbonate concretions; gradual and smooth boundary.

B3.2 t ca 69-99 cm 5YR 3.5/4 when moist, 5YR 4/6 when dry; clay; strong fine to very fine angular blocky; very hard. friable, sticky and plastic; no biopores; few small roots; many continuous clay and pressure cutans; few small distinct white hard carbonate concretions; few termite fungus; gradual and smooth boundary.

B3.3t 99-130 cm 5YR 3.5/4 when moist, 5YR 4/7 when dry; clay; moderate medium to coarse angular blocky consisting of strong fine to very fine angular blocky elements; very hard, friable, sticky and plastic; few fine biopores; many continuous clay and pressure cutans; very few small distinct white hard carbonate concretions, few termite channels.

Remark: From 240-400 cm many hard purple carbonate concretions (ca 3 cm and more) Soil colour (D): 5YR 5/8.

B25
Profile: Kirawira 7

Area: Kirawira Plain — Coordinates: 34° 14'E, 2° 07'N
Aerial photo: 3-217, L4-S — Date: 20-5-76
Altitude: 1200 m
Soil classification: Typic Natrustoll
Physiography: pediplain slope — Topography: subnormal
Slope: 1% — Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Digitaria scalarum, Chrysochloa orientalis, Mariscus mollipes, Balanites egyptiaca
Drainage condition: imperfectly
Moistness: dry, except A1
Root distribution: many small and medium roots to 10 cm
Biological activity: no evidence

A1	0 -10 cm	10YR 4/2 when moist, 10YR 5.5/2 when dry; clayey sand; weak fine subangular blocky; loose, non sticky and non plastic; few biopores; many small and medium roots; much coarse quartz sand; abrupt and smooth boundary.
B2.1	10-40 cm	10YR 4/1.5 when moist, 10YR 4.5/1.5 when dry; sandy clay; very coarse cemented strong prismatic, consisting of coarse to very coarse angular blocky elements; very hard, firm, slightly sticky and plastic; few biopores; few small roots; much coarse quartz sand; clear and smooth boundary.
B2.2 ca	40-85 cm	10YR 4/1.5 when moist, 10YR 4.5/1.5 when dry; sandy clay; moderate coarse to very coarse angular blocky; hard, friable, sticky and plastic; few biopores; very few small roots; much coarse quartz sand; clear carbonate reaction; few small prominent white soft carbonate mottles; gradual and smooth boundary.
B2.3 ca	85-130 cm	10YR 3/1.5 when moist, 10YR 4/2 when dry; sandy clay; moderate medium angular blocky; slightly hard, friable, sticky and plastic; few biopores; no roots; much coarse quartz sand; clear carbonate reaction; few small white soft carbonate mottles.
	at 250 cm	10YR 5.5/3 when moist and 10YR 6/2 when dry.

B26
Profile: Kirawira 8

Area: Kirawira Plain — Coordinates: 34° 14'E, 2° 17'N
Aerial photo: 3-217, L4-S — Date: 20-5-76
Altitude: 1200 m
Soil classification: Udic Haplustoll
Physiography: pediplain slope — Topography: subnormal
Slope: 1% — Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Sporobolus marginatus, Digitaria scalarum, Digitaria macroblephara
Drainage condition: moderately well
Moistness: topsoil (0-40 cm) moist
Root distribution: common small, medium and large roots to 40 cm
Biological activity: old termite mound

A1	0 -20 cm	10YR 3/15 when moist; very sandy clay; weak medium subangular blocky; very friable, sticky and plastic; biopores difficult to distinguish; many small and medium roots, common large roots; much coarse quartz sand; clear and smooth boundary.

B1	20-40 cm	10YR 3/1.5 when moist; very sandy clay; moderate coarse to very coarse subangular blocky; very friable, sticky and plastic; common fine and few medium biopores; common small, medium and large roots; much coarse quartz sand; clear and smooth boundary.
B2.2	40-80 cm	10YR 2.5/2 when moist, 10YR 3.5/2 when dry; sandy clay; strong cemented very coarse angular blocky; hard, friable, sticky and plastic; few fine and medium biopores; few small roots; much coarse quartz sand; gradual and smooth boundary.
B2.3	80-120 cm	10YR 2.5/2 when moist, 10YR 3.5/2 when dry; sandy clay; moderate coarse angular blocky; slightly hard, friable, sticky and plastic; few fine and medium biopores; no roots; much coarse quartz sand; few round lamellated balls (dungballs?).

B27
Profile: Dutwa 1

Area: Dutwa Plain
Coordinates: 34° 11'E, 2° 17'N
Aerial photo: 5-27, L3-N
Date: 24-9-74
Altitude: 1220 m
Soil classification: Typic Natrustoll
Physiography: plain
Topography: subnormal
Slope: 1%
Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Chrysochloa orientalis, Microchloa kunthii, Balanites egyptiaca
Drainage condition: imperfectly
Moistness: dry
Root distribution: common small roots to 40 cm
Biological activity: no evidence

A1	0 -21 cm	10YR 3/1 when moist, 10YR 5/1 when dry; sandy loam; weak fine subangular blocky; slightly hard, very friable, slightly sticky and non plastic; few fine and medium biopores; common small roots; much coarse quartz sand; clear and smooth boundary.
B2.1ca	21-40 cm	10YR 3/3 when moist, 10YR 4/3 when dry; sandy clay; moderate fine to medium subangular blocky; slightly hard, very friable, sticky and plastic; few fine and medium biopores; common small roots; much coarse quartz sand; very few small faint white hard carbonate concretions; clear and smooth boundary.
B2.2ca	40-62 cm	10YR 4/3 when moist, 10YR 4.5/3 when dry; clay; moderately weak very fine subangular blocky; slightly hard, very friable, sticky and slightly plastic; common fine, few medium and few large biopores; few small roots; much coarse quartz sand; common small distinct white hard carbonate concretions; clear and smooth boundary.
B3.1ca	62-80 cm	10YR 5/3 when moist, 10YR 6/3 when dry; clay; moderately weak very fine to fine subangular blocky; slightly hard, very friable, sticky and slightly plastic; many fine and common medium biopores; very few small roots; common coarse quartz sand; few small faint white hard carbonate concretions; clear and smooth boundary.
B3.2ca	80-100 cm	10YR 6/3 when moist and dry; clay; moderately weak very fine to fine subangular blocky; slightly hard, very friable, sticky and slightly plastic; common fine and medium biopores; much coarse quartz sand and both angular and well rounded gravel to 6 cm; few small faint white hard carbonate concretions.

B28
Profile: Dutwa 2

Area: Dutwa Plain north
Coordinates: 34^{o} 10'E, 2^{o} 16'N
Aerial photo: 5-27, L3-N
Date: 13-9-74
Altitude: 1210 m
Soil classification: Typic Natrustoll
Physiography: river levee
Topography: subnormal
Slope: 1%
Erosion: -
Parent materials: alluvium and volcanic deposits
Vegetation: Chrysochloa orientalis, Themeda triandra, Chloris gayana, Balanites egyptiaca
Drainage condition: moderately well
Moistness: dry
Root distribution: common small and medium roots to 22 cm
Biological activity: past termite activity below 110 cm

A1	0 -22 cm	10YR 3/1 when moist, 10YR 3/2 when dry; clayey sand; weak fine to medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; few fine medium and large biopores; common small and medium roots; clear and smooth boundary.
II B2.t ca	22-110 cm	10YR 3.5/1 when moist and dry; clay; moderately strong coarse subangular blocky; extremely hard firm, sticky and very plastic; few small roots; common coarse quartz sand, and few rounded quartz gravel to 2 cm; many continuous clay and pressure cutans; few distinct small white hard carbonate concretions; effervescent carbonate reaction of the soil material, starting at 60 cm; clear and smooth boundary.
II B3.1 ca	110-200 cm	10YR 4/2 when moist, 10YR 4.5/2 when dry; clay; moderate fine subangular blocky; hard, friable, sticky and plastic; few fine and medium biopores; no roots; very few coarse quartz sand; few patchy clay and/or pressure cutans; many distinct medium white hard carbonate concretions; effervescent carbonate reaction of soil material.

B29
Profile: Dutwa 3

Area: Dutwa Plain north
Coordinates: 34^{o} 11'E, 2^{o} 17'N
Aerial photo: 5-27, L3-N
Date: 24-9-74
Altitude: 1210 m
Soil classification: Entic Pellustert
Physiography: depression
Topography: flat or concave
Slope: level
Erosion: -
Parent materials: alluvium
Vegetation: Sporobolus fimbriatus, Chloris gayana, Themeda triandra
Drainage condition: poorly
Moistness: dry
Root distribution: common small roots to 70 cm
Biological activity: past termite activity below 70 cm

A ca	0 -10 cm	10YR 3.5/1 when moist, 10YR 3/1 when dry; clay; moderately strong, medium subangular blocky; very hard, friable, sticky and plastic; common fine and few medium biopores; few small and common medium roots; much coarse quartz sand; many continuous probably pressure cutans; very few small distinct white hard carbonate concretions; clear and smooth boundary.

B2.t ca 10-70 cm 10YR 3.5/1 when moist and dry; clay; moderate very coarse prismatic, consisting of strong medium angular blocky elements, very hard, friable, slightly sticky and very plastic; common fine and few medium biopores; few small and medium roots; common coarse quartz sand; many continuous clay and pressure cutans; few very small distinct white hard carbonate concretions; cracks ca. 1 cm wide at 50 cm; some wedgeshape tilted aggregates; clear and smooth boundary.

B3.t ca 70-110 cm mixture of 10YR 6/3 and 10YR 4.5/1.5 when moist and 10YR 5/3 and 10YR 3.5/1.5 when dry; clay; moderate very fine to fine subangular blocky; hard, very friable, slightly sticky and plastic; common fine and few medium biopores; few small mainly old roots; common coarse quartz sand; many distinct white hard carbonate concretions (up to 5 cm); several termite channels filled with darker material.

B30
Profile: Simiti 1

Area: Simiti Hill — Coordinates: 34^{o} 11'E, 2^{o} 14'N
Aerial photo: 5-28, L3-N — Date: 19-5-1976
Altitude: 1210 m
Soil classification: Udic Argiustoll
Physiography: lower pediment — Topography: subnormal
Slope: ca 1% — Erosion: sheetwash
Parent materials: Nyanzian rocks and volcanic deposits
Vegetation: <u>Themeda triandra</u>, <u>Pennisetum mezianum</u>, <u>Acacia seyal</u>, <u>Acacia drepanolobium</u>
Drainage condition: poorly
Moistness: topsoil moist
Root distribution: common small and medium roots to 25 cm
Biological activity: termite activity below 100 cm

A1 0 - 4 cm 10YR 2/2 when moist or dry; sandy clay-loam; moderate medium angular to subangular blocky; friable, sticky and plastic; few fine and medium biopores; many small and medium roots; common coarse quartz sand; clear and smooth boundary.

B2.2t 4 -65 cm 10YR 2/2.5 when moist or dry; clay; moderate coarse prismatic, consisting of very strong medium angular blocky elements; very hard, friable, sticky and very plastic; few fine and medium biopores; few small and medium mainly dead roots; few coarse quartz sand; many continuous clay and pressure cutans; clear and smooth boundary.

B2.3t 65-100 cm 7.5YR 2.5/3 when moist or dry; clay; very strong medium angular blocky; very hard, friable, sticky and very plastic; very few fine and medium biopores; very few small mainly dead roots; very few coarse quartz sand; common continuous clay and pressure cutans; very few small distinct white hard carbonate concretions; clear and smooth boundary.

B3 100-130 cm 5YR 3.5/6 when moist, 5YR 4/6 when dry; clay-loam; moderate medium angular blocky; very hard, very friable, sticky and plastic; very few fine and medium biopores; few dead roots; no sand; few patchy clay and pressure cutans; few small distinct white hard carbonate concretions; few old termite channels.

B31
Profile: Simiti 2

Area: south of Simiti Hills
Coordinates: 34° 13'E, 2° 15'N
Aerial photo: 3-219, L4-S
Date: 19-5-1976
Altitude: 1220 m
Soil classification: Typic Natrustoll
Physiography: pediplain
Topography: subnormal
Slope: 1%
Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Chrysochloa orientalis, Themeda triandra
Drainage condition: imperfectly
Moistness: dry, except topsoil (0-10 cm)
Root distribution: many small and medium roots to 10 cm
Biological activity: past termite activity below 60 cm

A1	0 -10 cm	10YR 2/2 when moist; clayey sand; moderate coarse subangular blocky; very friable, slightly sticky and slightly plastic; few fine and medium biopores; many small and medium roots; much coarse quartz sand; abrupt and smooth boundary.
B2.2t	10-30 cm	10YR 2/1.5 when moist and dry; clay; very coarse prismatic consisting of very strong medium angular blocky elements; very hard, friable, sticky and very plastic; few fine and medium biopores; many small roots; common coarse quartz sand; many continuous clay and pressure cutans; gradual and smooth boundary.
B2.3ca	30-60 cm	10YR 2.5/2 when moist or dry; sandy clay-loam; moderate medium subangular blocky; slightly hard; friable, sticky and plastic; no biopores; no roots; much coarse quartz sand; few very small faint white hard carbonate concretions; clear and smooth boundary.
B3.1ca	60-80 cm	7.5YR 3.5/3 when moist, 7.5YR 4/3 when dry; sandy clay-loam; moderately weak medium angular blocky; soft, very friable sticky and plastic; no biopores; common coarse quartz sand and few pieces of moderately well rounded quartzite gravel; many small distinct white hard carbonate concretions; few old termite channels; clear and smooth boundary.
B3.2ca	80-120 cm	7.5YR 5/6 when moist, 7.5YR 6/6 when dry; loam; weak medium angular blocky; soft, very friable, slightly sticky and slightly plastic; no biopores; few coarse quartz sand; many medium prominent white hard carbonate concretions; few old termite channels.

B32
Profile: Ndabaka 1

Area: Ndabaka Plain east
Coordinates: 34° 01'E, 2° 11'N
Aerial photo: 4-164, L2-S
Date: 12-9-74
Altitude: 1160 m
Soil classification: Typic Pellustert
Physiography: flood plain
Topography: flat or concave
Slope: level
Erosion: -
Parent materials: alluvium
Vegetation: Echinochloa haploclada, Panicum coloratum
Drainage condition: poorly
Moistness: moist, except top soil
Root distribution: common small and few medium roots
Biological activity: no evidence

A	0 -50 cm	10YR 3/1 when moist and dry; clay; moderate very coarse prismatic, consisting of strong coarse subangular blocky elements; extremely hard, firm, sticky and very plastic; common fine and medium biopores; common small and few medium roots; common coarse quartz sand; common patchy probably pressure cutans; cracks at surface ca. 5 cm wide and at 50 cm; clear and smooth boundary.
B2.1t ca	50-80 cm	10YR 2/1 when moist; clay; moderately strong medium to coarse subangular blocky; firm, sticky and very plastic; few fine and medium biopores; no roots, few coarse quartz sand; common patchy clay and/or pressure cutans; few prominent small white hard carbonate concretions; clear and smooth boundary.
B2.2t ca	80-110 cm	10YR 3/1.5 when moist; clay; moderate medium to fine subangular blocky; firm, sticky and plastic; common coarse quartz sand; common continuous clay and pressure cutans; common prominent white carbonate mycelium; few prominent small white hard carbonate concretions; at 90 cm clear carbonate reaction of the soil material; some wedgeshaped aggregates.

B33
Profile: Ndabaka 2

Area: Ndabaka Plain east
Coordinates: 34° 00'E, 2° 10'N
Aerial photo: 4-64, L2-S
Date: 23-9-74
Altitude: 1160 m
Soil classification: Typic Natrustoll
Physiography: floodplain
Topography: flat or concave
Slope: level
Erosion: -
Parent materials: alluvium
Vegetation: *Chrysochloa orientalis*, *Sporobolus marginatus*, *Balanites egyptiaca*
Drainage condition: poorly
Moistness: dry
Root distribution: common small roots to 55 cm
Biological activity: no evidence

A	0 -10 cm	10YR 3/1 when moist, 10YR 3.5/1 when dry; clay; strong fine to medium subangular blocky; very hard, friable, sticky and plastic; few fine and medium biopores; few small and common medium roots; few coarse quartz sand; many continuous pressure and/or clay cutans; clear and smooth boundary.
B2.1t ca	10-55 cm	10YR 3/1 when moist, 10YR 3.5/1 when dry; clay; moderate very coarse columnar consisting of strong fine angular blocky elements; very hard, friable, sticky and very plastic; few fine, medium and large biopores; common small and few medium roots; many continuous pressure and clay cutans; few faint small hard white carbonate concretions; clear carbonate reaction of the soil material starting at 40 cm; clear and smooth boundary.
B2.2t ca	55-100 cm	10YR 4/1.5 when moist, 10YR 5/1.5 when dry; clay; moderate medium subangular blocky; hard, friable, very sticky and plastic; common to many small biopores increasing with depth, few small roots; few coarse quartz sand; many continuous clay and pressure cutans; few faint small hard white carbonate concretions; common faint (10YR 6/2) small to medium carbonate mottles; effervescent carbonate reaction of the soil material.

B34
Profile: Banagi 3

Area: Banagi Hill | Coordinates: 34^{o} 50'E, 2^{o} 20'N
Aerial photo: 3-165, L10-N | Date: 25-7-1975
Altitude: 1470 m
Soil classification: Typic Natrustoll
Physiography: slope | Topography: subnormal
Slope: level | Erosion: -
Parent materials: Nyanzian rocks and volcanic deposits
Vegetation: Pennisetum mezianum, Panicum coloratum, Digitaria macroblephara
Drainage condition: poorly drained
Moistness: dry
Root distribution: common small and medium roots to 15 cm
Biological activity: no evidence

A1.cn	0 - 15 cm	10YR 3/3 when moist, 10YR 4/3 when dry; clay-loam; weak very coarse angular blocky, consisting of moderate fine angular blocky elements; slightly hard, friable, sticky and slightly plastic; many fine, common medium and large biopores; common small and medium roots; common slightly rounded quartzite and iron stone gravel at surface; common small slightly hard black round iron-manganese concretions; clear and smooth boundary.
B2.2t	15-45 cm	10YR 3/3 when moist, 10YR 2.5/2 when dry; clay; moderate very coarse columnar, consisting of strong fine angular blocky elements; very hard, very firm, sticky and very plastic; many fine biopores; few small and medium roots; few coarse quartz sand; many continuous clay and pressure cutans, very few small distinct white hard carbonate concretions; clear and smooth boundary.
B2.3	45-70 cm	5YR 2/3 when moist, 5YR 3/3 when dry; clay-loam; moderate medium subangular blocky; hard, friable, sticky and plastic; common fine and medium biopores; very few small roots; few small angular quartz and iron stone gravel; few slightly hard small black round iron-manganese concretions; few very small faint white hard carbonate concretions; gradual and smooth boundary.
B3.cn	70-110 cm	5YR 3/4 when moist, 5YR 3.5/6 when dry; clay-loam; moderate weak medium subangular blocky; slightly hard, very friable, sticky and slightly plastic; few fine biopores; no roots; few small angular quartzite and ironstone gravel; common small slightly hard black iron-manganese concretions; few very small faint white hard carbonate concretions.

B35
Profile: Banagi 4

Area: Banagi airstrip | Coordinates: 34^{o} 51'E, 2^{o} 19'N
Aerial photo: 3-165, L10-N | Date: 27-7-1975
Altitude: 1400 m
Soil classification: Typic Natrustoll
Physiography: ridge slope | Topography: subnormal
Slope: level | Erosion: -
Parent materials: Nyanzian rocks and volcanic deposits
Vegetation: Pennisetum mezianum, Digitaria macroblephara
Drainage condition: poorly drained
Moistness: dry
Root distribution: few small and common medium roots to 22 cm
Biological activity: termite activity below 60 cm

A1	0 - 2 cm	10YR 2.5/3 when moist, 10YR 4/4 when dry; sandy loam; moderate fine angular blocky; slightly hard, friable, slightly sticky and slightly plastic; common fine and medium biopores; common small and many medium roots; clear and smooth boundary.
B2.1t	2 -15 cm	10YR 2/2 when moist and dry; clay; weak very coarse prismatic, consisting of strong medium angular blocky elements; very hard, friable sticky and very plastic; common fine and few medium biopores; common small and few medium roots; few coarse "Nyanzian" sand; many continuous clay and pressure cutans; clear and smooth boundary.
B2.2tca	15-50 cm	10YR 2/2 when moist and dry; clay; moderate very coarse angular blocky; consisting of strong medium angular blocky elements; very hard, firm, sticky and very plastic; few fine biopores; few small roots; few coarse sand; many continuous clay and pressure cutans; few small distinct white hard carbonate concretions; clear carbonate reaction of the soil material; gradual and smooth boundary.
B3.1ca	50-70 cm	10YR 2/3 and 7.5YR 3/3.5 when moist, 10YR 3/3 and 7.5YR 4/4 when dry; clay-loam; moderate medium to coarse angular blocky; hard, friable, sticky and plastic; common fine and few large biopores; very few small roots; few termite channels filled with fungus or darker soil material; clear carbonate reaction of soil material; gradual and smooth boundary.
B3.2ca	70-100 cm	5YR 3/6 when moist, 5YR 4/6 when dry; clay-loam; moderate fine to medium angular blocky; hard, very friable, slightly sticky and slightly plastic; few fine and large biopores; no roots; common termite channels filled with fungus or darker soil material; few small faint hard carbonate concretions; weak carbonate reaction of soil material, clear and smooth boundary.
B3.3ca	100-130 cm	5YR 3/6 when moist, 5YR 4/6 when dry; clay-loam; moderate fine to medium angular blocky; hard very friable, slightly sticky and slightly plastic; few fine and large biopores; many termite channels filled with fungus or darker soil material; few small distinct slightly hard black ion concretions; common small distinct white hard carbonate concretions; effervescent carbonate reaction of the soil material.

Remark: Carbonate concretions increase to 200 cm. At greater depths a slight decrease. At 350 cm further augering proved to be impossible (gravel?, concretions?).

B36
Profile: Banagi 5

Area: close to airstrip — Coordinates: 34° 51'E, 2° 13'N
Aerial photo: 3-166, L10-N — Date: 29-8-1975
Altitude: 1410 m
Soil classification: Udic Argiustoll
Physiography: ridge slope — Topography: normal
Slope: 3-4% — Erosion: sheetwash
Parent materials: Nyanzian schists
Vegetation: _Digitaria macroblephara_, _Sporobolus marginatus_, _Acacia hockii_, _Acacia clavigera_
Drainage condition: well drained
Moistness: dry

Root distribution: few small and medium roots to 35 cm
Biological activity: no evidence

A1.1	0 -10 cm	10YR 3/3 when moist, 10YR 4/2 when dry; loam; moderate coarse angular blocky, consisting of moderate medium angular blocky elements; slightly hard, friable, slightly sticky and slightly plastic; few fine and medium biopores; few small and common medium roots, common coarse sand derived from Nyanzian rocks; soft surface sealing; clear and smooth boundary.
A1.2	10-30 cm	5YR 2/4 when moist, 5YR 3.5/5 when dry; loam; moderate medium angular blocky; slightly hard, friable, sticky and plastic; many fine and medium biopores; few small and medium roots; common coarse "Nyanzian" sand; gradual and smooth boundary.
B2.1	30-60 cm	5YR 2/4 when moist, 5YR 3.5/6 when dry; clay-loam; moderate medium angular blocky; hard, friable, sticky and plastic; many fine and medium biopores; few small roots; common coarse sand; gradual and smooth boundary.
B2.2	60-80 cm	5YR 2/4 when moist, 5YR 5/6 when dry; clay-loam; moderate medium angular blocky; hard, friable, very sticky and plastic; many fine and medium biopores; no roots; much coarse sand and small gravel.
	> 80 cm	rotten rock with carbonate illuviation, colour 10YR 5/3.

B37
Profile: Togoro 1

Area: Togoro Plain — Coordinates: 35° 01'E, 2° 10'N
Aerial photo: 3-91, L11-S — Date: 28-11-1974
Altitude: 1610 m
Soil classification: Udic Argiustoll
Physiography: ridge top — Topography: subnormal
Slope: nearly level — Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Eustachus paspaloïdes, Digitaria macroblephara, Acacia tortilis (sparse regeneration)
Drainage condition: moderately well
Moistness: dry
Root distribution: common small and common medium roots to 86 cm
Biological activity: past termite activity below 86 cm

A1	0 -18 cm	10YR 3/1.5 when moist, 10YR 4.5/2 when dry; sandy loam; moderate medium angular blocky; slightly hard, very friable, slightly sticky and slightly plastic; many fine and few medium biopores; few small and many medium roots; few coarse quartz sand; thin soft laminated surface sealing; gradual and smooth boundary.
B1	18-41 cm	10YR 2.5/1.5 when moist, 10YR 3.5/2 when dry; sandy clay-loam; moderate medium angular blocky; slightly hard, very friable, slightly sticky and slightly plastic; many fine and common medium biopores; few small and common medium roots; common coarse quartz sand; gradual and smooth boundary.
B2.2t	41-86 cm	10YR 3/2 when moist, 10YR 4/2.5 when dry; clay; weak coarse prismatic consisting of strong medium angular blocky elements; very hard, friable, sticky and plastic; many fine, few medium and large biopores; common small and medium roots; few coarse quartz sand; many continuous clay and pressure cutans; gradual and smooth boundary.

B2.3t 86-135 cm 5YR 3/4 when moist, 7.5YR 5/6 when dry; clay-loam; moderately strong medium angular blocky; very hard, firm, slightly sticky and slightly plastic; many fine, few medium and large biopores; no roots; few coarse quartz sand; common continuous clay and pressure cutans; common distinct medium bluïsh soft Fe concretions; common old termite channels filled with darker material.

B39
Profile: Togoro 3

Area: Togoro Plain
Coordinates: 35° 00'E, 2° 10'N
Aerial photo: 3-91, L11-S
Date: 23-2-1976
Altitude: 1605 m
Soil classification: Udic Argiustoll
Physiography: ridge top
Topography: normal
Slope: 3%
Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Digitaria macroblephara, Eustachus paspaloïdes, Acacia nilotica
Drainage condition: moderately well
Moistness: dry
Root distribution: common small and medium roots to 50 cm
Biological activity: no evidence

A1 0 -20 cm 10YR 2/1.5 when moist, 10YR 3/1.5 when dry; sandy loam; moderate medium subangular blocky; slightly hard, very friable, non sticky and slightly plastic; common fine and few medium biopores; many small and medium roots; common coarse quartz sand; clear and smooth boundary.

B1 20-50 cm 10YR 3/2 when moist, 10YR 3/2.5 when dry; loam; moderate coarse angular blocky; hard, very friable, sticky and plastic; common fine and few medium biopores; common small and medium roots; common coarse quartz sand.

B2 50-85 cm 10YR 3/2 when moist, 10YR 3/2.5 when dry; sandy clay-loam; moderate coarse to very coarse angular blocky; hard, very friable, slightly sticky and plastic; common fine and medium biopores; few small and medium roots; much coarse quartz sand (coarser than in A1 and B1 horizon); few patchy clay and/or pressure cutans; clear and smooth boundary.

85-105 cm rounded iron stained quartz gravel (to 7 cm), some of the smaller gravel is rounded very well.

B40
Profile: Togoro 4

Area: near Togoro Plain
Coordinates: 34° 59'E, 2° 09'N
Aerial photo: 3-91, L11-S
Date: 23-2-1976
Altitude: 1580 m
Soil classification: Udic Argiustoll
Physiography: ridge slope
Topography: normal
Slope: 4%
Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Themeda triandra, Digitaria macroblephara, Eustachus paspaloïdes, Acacia nilotica
Drainage condition: well drained
Moistness: dry, except 30-55 cm
Root distribution: common small and medium roots to 55 cm
Biological activity: termite activity throughout the profile

A1	0 -30 cm	7.5YR 2/1.5 when moist, 7.5YR 3/2 when dry; sandy loam; moderately weak medium subangular blocky; slightly hard, very friable, non sticky and slightly plastic; common fine and medium biopores; many small and medium roots; few coarse quartz sand; termite channel (8 cm); clear and smooth boundary.
B1	30-55 cm	5YR 2/2 when moist; loam; moderate medium subangular blocky; very friable, slightly sticky and slightly plastic; common fine and medium biopores; common small and medium roots; few coarse quartz sand; clear and smooth boundary.
B2.1	55-80 cm	5YR 2/4 when moist, 5YR 3/4.5 when dry; loam; moderate coarse angular blocky; hard, friable, sticky and slightly plastic; common fine and medium biopores; few small and medium roots; few coarse quartz sand; few patchy clay and/or pressure cutans; termite channel (8 cm); clear and gradual boundary.
B2.2t	80-135 cm	2.5YR 5/4 when moist, 2.5YR 3/4 when dry; sandy clay-loam; strong coarse blocky; very hard, very friable, sticky and plastic; few fine and medium biopores; few small and medium roots; few coarse quartz sand; at 125 cm piece of angular clear quartz (3 cm); many continuous clay and pressure cutans; two large termite channeld (8 cm) filled with fungus.

B41
Profile: Togoro 5

Area: near Togoro Plain
Coordinates: 35° 00'E, 2° 08'N
Aerial photo: 3-91, L11-S
Date: 28-6-1976
Altitude: 1580 m
Soil classification: Typic Natrustoll
Physiography: ridge slope
Topography: subnormal
Slope: 3%
Erosion: step erosion and sheet erosion
Parent materials: granitic rocks and volcanic deposits
Vegetation: *Themeda triandra*, *Pennisetum mezianum*, *Acacia drepanolobium*
Drainage condition: poorly
Moistness: moist, except topsoil (0-20 cm)
Root distribution: common small and medium roots to 60 cm
Biological activity: past termite activity below 60 cm

B2.2t	0 -20 cm	10YR 1.7/1 when moist or dry; sandy clay; weak coarse columnar, consisting of strong medium angular blocky elements; very hard, friable, sticky and very plastic; few fine and medium biopores; many small and medium roots; common coarse quartz sand; many continuous clay and pressure cutans; thin soft surface sealing; gradual and smooth boundary.
B2.3ca	20-60 cm	10YR 2/1 when moist; sandy clay; moderately strong medium to coarse angular blocky; friable, very sticky and plastic; few fine and medium biopores; common small and medium roots; common coarse quartz sand; few patchy clay and/or pressure cutans; few very small distinct white hard carbonate concretions; clear carbonate reaction of the soil material; gradual and smooth boundary.
B3.1ca	60-110 cm	7.5YR 4/4 when moist; sandy clay-loam; moderately weak medium angular blocky; very friable, sticky and slightly plastic; common fine and few medium biopores; few small roots; few coarse quartz sand; common to much distinct white carbonate mycelium; few to common medium distinct white hard carbonate concretions; no carbonate reaction of the soil material; common old termite channels filled with darker topsoil material.

B42
Profile: Bololedi 1

Area: close to airstrip
Coordinates: 35^{o} 09'E, 2^{o} 08'N
Aerial photo: 7-53, L13-S
Date: 12-6-1975
Altitude: 1670 m
Soil classification: Lithic Haplustoll
Physiography: ridge top
Topography: normal
Slope: nearly level
Erosion: sheetwash
Parent materials: granitic gneisses and volcanic deposits
Vegetation: Digitaria macroblephara, Harpachne schimperi, Microchloa kunthii, Acacia tortilis, Acacia clavigera
Drainage condition: moderately well
Moistness: dry
Root distribution: common small and medium roots to 33 cm
Biological activity: no evidence

A1.1	0 -10 cm	10YR 2.5/3 when moist, 10YR 3.5/3 when dry; sandy loam; moderate fine to medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; common fine and medium, and few large biopores; many small and medium roots; few coarse quartz sand; clear and smooth boundary.
A1.2	10-33 cm	10YR 2.5/3 when moist, 10YR 3.5/3 when dry; sandy loam; moderate coarse to medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; many fine medium and large biopores; common small and medium roots; few coarse quartz sand; clear and smooth boundary.
B	33-45 cm	7.5YR 2/3 when moist, 7.5YR 3/4 when dry; loam; moderate medium to coarse subangular blocky; hard, very friable sticky and slightly plastic; many fine, medium and large biopores; common small and few medium roots; few coarse quartz sand; common slightly weathered rock fragments.
	at 45 cm	angular gravel underlain by bedrock.

B43
Profile: Bololedi 2

Area: airstrip
Coordinates: 35^{o} 09'E, 2^{o} 08'N
Aerial photo: 7-53, L13-S
Date: 12-6-1975
Altitude: 1665 m
Soil classification: Udic Argiustoll
Physiography: ridge slope (convex)
Topography: normal
Slope: 3%
Erosion: sheetwash
Parent materials: granitic gneiss and volcanic deposits
Vegetation: Eustachus paspaloïdes, Microchloa kuntii, Digitaria macroblephara, Harpachne schimperi
Drainage condition: moderately well
Moistness: dry
Root distribution: common small and few medium roots to 28 cm
Biological activity: past termite activity below 110 cm

A1.1	0 -20 cm	5YR 2/2 when moist, 5YR 3/3 when dry; sandy loam; moderate medium to coarse subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; many fine and medium biopores; common small and medium roots; few iron stained coarse quartz sand; clear and smooth boundary.
B1.1	20-30 cm	5YR 2/3 when moist, 5YR 3/4 when dry; sandy clay-loam; moderate medium to coarse subangular blocky; slightly hard, very

friable, sticky and slightly plastic; many fine and medium biopores; common small and few medium roots, few iron stained coarse quartz sand; clear and smooth boundary.

B1.2	30-60 cm	5YR 2/4 when moist, 5YR 3/5 when dry; sandy clay-loam; moderate medium to coarse subangular blocky; hard, very friable, sticky and slightly plastic; many fine and medium biopores; few small and medium roots; few iron stained coarse quartz sand; gradual and smooth boundary.
B2.1	60-100 cm	5YR 2/5 when moist, 5YR 3/6 when dry; clay-loam; moderate medium subangular blocky; hard, very friable, sticky and slightly plastic; many fine and medium biopores; few small roots; few iron stained coarse quartz sand; few patchy clay and/or pressure cutans; very few small distinct black hard Fe concretions; common termite channels filled with darker topsoil; gradual and smooth boundary.
B2.2t	100-130 cm	5YR 3/6 when moist, 5YR 4/7 when dry; clay-loam; moderate fine to medium subangular blocky; hard, very friable, sticky and slightly plastic; many fine and medium biopores; very few small roots; few iron stained coarse quartz sand; few to common patchy clay and/or pressure cutans; few small distinct black hard Fe concretions; many termite channels filled with darker topsoil.
	at 140 cm	5YR 4/8 when moist, 5YR 5/8 when dry.

B44
Profile: Bololedi 3

Area: near airstrip — Coordinates: 35° 09'E, 2° 08'N
Aerial photo: 7-53, L13-S — Date: 8-11-1975
Altitude: 1660 m
Soil classification: Udic Argiustoll
Physiography: ridge slope — Topography: normal
Slope: 2% — Erosion: sheetwash
Parent materials: granitic gneiss and volcanic deposits
Vegetation: _Eustachus paspaloïdes_, _Harpachne schimperi_, _Sporobolus fimbriatus_, _Acacia drepanolobium_, _Acacia clavigera_
Drainage condition: moderately well
Moistness: dry
Root distribution: few small and medium roots to 70 cm
Biological activity: past termite activity below 70 cm

A1	0 -20 cm	10YR 2/2 when moist, 10YR 4/2.5 when dry; sandy loam; moderate medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; many fine and medium biopores; common small and medium roots; much fine quartz sand; thin soft surface sealing; gradual and smooth boundary.
B1	20-40 cm	5YR 3/2 when moist, 5YR 4/4 when dry; sandy clay-loam; moderate medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; many fine and medium biopores; common small and few medium roots; much fine quartz sand; clear and smooth boundary.
B2.1	40-70 cm	2.5YR 3/3 when moist, 2.5YR 3/4 when dry; clay-loam; moderately coarse subangular blocky consisting of moderate medium subangular blocky elements; slightly hard, friable, slightly sticky and slightly plastic; many fine and medium biopores; few small and medium roots; few patchy clay and/or pressure cutans; gradual and smooth boundary.

B2.2t 70-120 cm 2.5YR 3/4 when moist, 2.5YR 3/5 when dry; clay-loam; moderate coarse angular blocky, consisting of moderate medium angular blocky elements; hard, friable, sticky and plastic; common small and few medium biopores; very few small roots; common patchy clay and/or pressure cutans; common old termite channels filled with darker topsoil material.

B46
Profile: Rhino 2

Area: Rhino-Mbali Pali area Coordinates: 34° 56'E, 1° 45'N
Aerial photo: 8-40, L11-N Date: 24-6-76
Altitude: 1660 m
Soil classification: Petroferric Argiustoll
Physiography: ridge top Topography: normal
Slope: 4% Erosion: no evidence
Parent materials: gneissic rocks
Vegetation: Themeda triandra, Cymbopogon excavatus, Hyparrhenia sp., Acacia clavigera
Drainage condition: well drained
Moistness: moist throughout
Root distribution: many small and common medium roots to 30 cm
Biological activity: no evidence

A1 0 -15 cm 10YR 2/1 when moist; sandy loam; moderate medium subangular blocky; very friable, slightly sticky and slightly plastic; biopores difficult to distinguish; many small and medium roots; few coarse quartz sand; clear and smooth boundary.

B 15-30 cm 10YR 3/1.5 when moist; sandy clay-loam; friable, sticky and plastic; few fine and medium biopores; many small and common medium roots; few coarse quartz sand; no cutans; abrupt and smooth boundary.

at 30 cm hardened plinthite, includes somewhat rounded quartz gravel; probably underlain by bedrock.

B47
Profile: Rhino 3

Area: Rhino-Mbali Pali area Coordinates: 34° 56'E, 1° 45'N
Aerial photo: 8-40, L11-N Date: 25-6-76
Altitude: 1650 m
Soil classification: Typic Argiustoll
Physiography: ridge slope Topography: normal
Slope: 4% Erosion: step erosion and sheetwash
Parent materials: gneissic and volcanic deposits
Vegetation: Themeda triandra, Sporobolus fimbriatus, Mariscus mollipes, Merua edulis
Drainage condition: imperfectly
Moistness: moist throughout
Root distribution: common small and medium roots to 55 cm
Biological activity: termite activity below 55 cm

A 0 - 5 cm 10YR 2/1 when moist; sandy loam; moderately weak fine to medium subangular blocky; very friable, slightly sticky and slightly plastic; biopores difficult to distinguish; many small and medium roots; few coarse quartz sand; clear and smooth boundary.

B2.1	5 -28 cm	10YR 2/1 when moist; sandy clay; moderate very coarse prismatic, consisting of strong coarse angular blocky elements; friable, sticky and plastic; common fine and medium biopores; many small and common medium roots; common coarse quartz sand; fine sand on pedfaces prisms; no clay cutans visible; gradual and smooth boundary.
B2.2t	28-55 cm	10YR 3/1 when moist; sandy clay; strong very coarse prismatic consisting of strong coarse angular blocky elements; friable sticky and plastic; few fine and medium biopores; common small and few medium roots; common coarse quartz sand; many continuous clay and pressure cutans; fine sand on pedfaces prisms; gradual and smooth boundary.
B3.1 ca	55-95 cm	10YR 3/1.5 when moist; clay-loam; moderately weak medium angular blocky; friable, sticky and plastic; few fine, medium and large biopores; few small and medium roots; common coarse quartz sand; few patchy clay and/or pressure cutans; few small distinct white hard carbonate concretions; few faint carbonate mycelium; few to common fungus filled termite channels; abrupt and smooth boundary.
	at 95 cm	unsorted somewhat rounded gravel with in between yellowish (2.5Y 7/4) sandy clay and Fe mottles (10YR 5/8); effervescent carbonate reaction of the soil material.

Remark: The soil pit is located on a termite mound line.

B48
Profile: Rhino 4

Area: Rhino-Mbali Pali area
Coordinates: 34^{o} 56'E, 1^{o} 45'N
Aerial photo: 8-40, L11-N
Date: 25-6-76
Altitude: 1650 m
Soil classification: Udic Argiustoll
Physiography: ridge slope
Topography: normal
Slope: 4%
Erosion: step erosion and sheetwash
Parent materials: gneissic rocks and volcanic deposits
Vegetation: Themeda triandra, Sporobolus fimbriatus
Drainage condition: imperfectly
Moistness: moist throughout
Root distribution: common small and medium roots to 56 cm
Biological activity: below 56 cm some termite activity

A1	0 -18 cm	10YR 1.7/1 when moist; sandy loam; moderately weak fine to medium subangular blocky; very friable, slightly sticky and slightly plastic; biopores difficult to distinguish; many small and medium roots; few coarse quartz sand; clear and smooth boundary.
B2.2t	18-56 cm	10YR 3/1 when moist; sandy clay; very coarse strong prismatic to columnar, consisting of strong medium angular blocky elements; friable; sticky and very plastic; few fine and medium biopores; common small and medium roots; common coarse quartz sand; many continuous clay and pressure cutans; cracks to 56 cm, up to 2 cm wide; white sand coatings on prism faces; abrupt and smooth boundary.
B2.3 ca	56-75 cm	10YR 3/2 when moist; sandy clay-loam; moderate medium angular blocky; friable, sticky and plastic; few fine and medium biopores; few small and medium roots; common coarse quartz

sand; few patchy clay and/or pressure cutans; few small distinct white hard carbonate concretions; few faint white carbonate mycelium; few fungus filled termite channels.

at 75 cm somewhat rounded quartz gravel, with yellowish (2.5Y 7/4) sandy clay and Fe mottles (10YR 5/8); probably underlain by bedrock; no carbonate reaction of the soil material.

B49
Profile: Rhino 5

Area: Thino-Mbali Pali area
Coordinates: 34° 57'E, 1° 45'N
Aerial photo: 8-40, L11-N
Date: 24-6-76
Altitude: 1670 m
Soil classification: Udic Haplustoll
Physiography: ridge top
Topography: normal
Slope: nearly level
Erosion: no evidence
Parent materials: gneissic rocks
Vegetation: Elyomirus argenterus, Rhus natalensis, Terminalia mollis
Drainage condition: well drained
Moistness: moist throughout
Root distribution: common small and medium roots to 80 cm
Biological activity: no evidence

A1	0 -18 cm	10YR 2/2 when moist; loamy sand; weak fine to medium subangular blocky; very friable, non sticky and non plastic; many fine and common medium biopores; many small and medium roots; few small angular quartz gravel; clear and smooth boundary.
B2	18-50 cm	7.5YR 3/3 when moist; loamy sand; weak medium subangular blocky; very friable, non sticky and non plastic; common fine and few medium biopores; common small and medium roots; few small angular quartz gravel; gradual and smooth boundary.
B3	50-80 cm	5YR 3/4 when moist; loamy sand; very friable, non sticky and non plastic; common fine and few medium biopores; common small and medium roots; few small angular quartz gravel; abrupt and smooth boundary.
	at 80 cm	hardened plinthite, includes somewhat rounded quartz gravel and Fe concretions.

B50
Profile: Rhino 6

Area: Rhino-Mbali Pali area
Coordinates: 34° 57'E, 1° 45'N
Aerial photo: 8-40, L11-N
Date: 24-6-76
Altitude: 1655 m
Soil classification: Petroferric Haplustoll
Physiography: upper ridge slope
Topography: normal
Slope: 4%
Erosion: step erosion and sheetwash
Parent materials: gneissic rocks
Vegetation: Themeda triandra
Drainage condition: imperfectly
Moistness: moist
Root distribution: many small and medium roots to 20 cm
Biological activity: no evidence

A1	0 -20 cm	10YR 2/1.5 when moist; very sandy loam; weak medium subangular blocky; very friable, non sticky and slightly plastic; biopores difficult to distinguish; many small and medium roots; much coarse quartz sand; abrupt and smooth boundary.
	at 20 cm	hardened plinthite, containing slightly rounded quartz gravel (to ca. 5 cm); probably underlain by bedrock.

Remark: Pit is located inbetween termite mound lines.

B51
Profile: Rhino 7

Area: Rhino-Mbali Pali area
Coordinates: 34° 57'E, 1° 45'N
Aerial photo: 8-40, L11-N
Date: 24-6-76
Altitude: 1655 m
Soil classification: Typic Argiustoll
Physiography: ridge slope
Topography: normal
Slope: 4%
Erosion: step erosion and sheetwash
Parent materials: gneissic rocks and volcanic deposits
Vegetation: *Themeda triandra*
Drainage condition: imperfectly
Moistness: moist throughout the profile
Root distribution: common small and medium roots to 75 cm
Biological activity: termite activity below 75 cm

A1	0 -10 cm	10YR 2/1 when moist; sandy loam; weak fine to medium subangular blocky; very friable, slightly sticky and slightly plastic; common fine and medium biopores; many small and medium roots; much coarse quartz sand; clear and smooth boundary.
B2.2t	10-55 cm	10YR 3/1 when moist; sandy clay-loam; very coarse strong prismatic, consisting of strong coarse angular blocky elements; friable, sticky and very plastic; few fine and medium biopores, many small and common medium roots; common coarse quartz sand; prisms have coatings of white sand; many continuous clay and pressure cutans; clear and smooth boundary.
B2.3t ca	55-75 cm	10YR 3/1.5 when moist; sandy clay-loam; moderate medium angular blocky; friable, sticky and plastic; few fine and medium biopores; common medium and small roots; common coarse quartz sand; common continous clay and pressure cutans; few distinct white carbonate mycelium; clear carbonate reaction of the soil material; gradual and smooth boundary.
B3.1 ca	75-100 cm	10YR 3.5/2 when moist; sandy clay; moderate medium angular blocky; friable, sticky and plastic; common fine and few medium biopores; very few small and medium roots; common coarse quartz sand; few patchy clay and/or pressure cutans; few distinct white carbonate mycelium; few small distinct white hard carbonate concretions; clear carbonate reaction of the soil material; few termite channels filled with fungus; clear and smooth boundary.
B3.2 ca	100-150 cm	10YR 5/3 when moist; clay; weak medium angular blocky; friable, very sticky and plastic; few fine and medium biopores; no roots; few coarse quartz sand; many medium distinct white hard carbonate concretions; effervescent carbonate reaction of the soil material; common termite channels filled with fungus and darker top soil (10YR 2/1).

below 150 cm Fe mottles (10YR 5/8) and black mottles as well as concretions appear; also somewhat rounded small quartz gravel is present and coarse sand content increases.

Remark: This pit is located on a termite mound line.

B52
Profile: Mbali Pali 2

Area: Rhino-Mbali area — Coordinates: 34° 54'E, 1° 44'N
Aerial photo: 8-40, L11-N — Date: 28-5-76
Altitude: 1655 m
Soil classification: Udic Argiustoll
Physiography: ridge slope — Topography: normal
Slope: 5% — Erosion: step erosion and sheetwash
Parent materials: gneissic rocks and volcanic deposits
Vegetation: *Themeda triandra*, *Sporobolus fimbriatus*
Drainage condition: moderately well
Moistness: dry, except top soil (0-60 cm)
Root distribution: many small and medium roots to 30 cm
Biological activity: below 100 cm

A1 0 -30 cm 10YR 1.7/1 when moist; loamy sand; weak medium subangular blocky; very friable to loose, non sticky and non plastic; biopores difficult to distinguish; many small and medium roots; abrupt and smooth boundary.

B2.2t 30-60 cm 10YR 2.5/1 when moist; sandy clay; moderate very coarse prismatic, consisting of coarse to very coarse angular blocky elements; friable sticky and very plastic; few biopores; common small and few medium roots, part of them being dead; common coarse quartz sand; many continuous clay and pressure cutans; clear and smooth boundary.

B2.3t ca 60-100 cm 10YR 2.5/2 when moist, 10YR 3.5/2 when dry; sandy clay; moderate medium to coarse angular blocky; slightly hard, very friable, very sticky and plastic; common fine, few medium and few large biopores; common small, mainly dead roots; common coarse quartz sand; common patchy clay and pressure cutans; common distinct white carbonate mycelium; clear and smooth boundary.

B3.t 100-145 cm 10YR 5/1 when moist, 10YR 4/2 when dry; sandy clay; moderate medium angular blocky; slightly hard, very friable, very sticky and plastic; few fine, medium and large biopores; no roots; common coarse quartz sand; common patchy, clay and pressure cutans; very few faint white carbonate mycelium; some round structures (diameter 8 cm), perhaps related to termite or dung beetle activity.

220 cm 10YR 4/1.5 when moist, 10YR 5/3 when dry.

Remark: Pit is located in between termite mound lines.

B53
Profile: Mbali Pali 3

Area: Rhino-Mbali Pali area
Coordinates: 34° 54'E, 1° 44'N
Aerial photo: 8-40, L11-N
Date: 28-5-76
Altitude: 1655 m
Soil classification: Udic Argiustoll
Physiography: ridge slope
Topography: normal
Slope: 5%
Erosion: step erosion and sheetwash
Parent materials: gneissic rocks and volcanic deposits
Vegetation: Cynodon dactylon, Sporobolus marginatus, Mariscus mollipes
Drainage condition: moderately well
Moistness: dry, except top soil (0-15 cm)
Root distribution: many small and medium roots to 15 cm
Biological activity: termite activity throughout the profile

A1	0 -15 cm	10YR 2/1.5 when moist; very sandy clay-loam; friable, sticky and plastic; few fine and medium biopores; many small and medium roots; few coarse quartz sand; clear and smooth boundary.
B2.2	10-45 cm	10YR 2.5/2 when moist, 10YR 4/2 when dry; sandy clay-loam; moderate coarse angular blocky; slightly hard, friable, sticky and plastic; common small and few medium biopores; common small and medium, mainly dead roots; common coarse quartz sand; few patch clay and/or pressure cutans; few faint white carbonate mycelium; common small and some large (10 cm) open termite channels; clear and smooth boundary.
B2.3 ca	45-70 cm	10YR 5/2 when moist, 10YR 4/2 when dry; sandy clay-loam; moderate medium angular blocky; slightly hard, friable, very sticky and plastic; common to many fine and few medium biopores; few small dead roots; common coarse quartz sand; some large (10 cm) open termite channels; few prominent white carbonate mycelium; very few distinct small white hard carbonate concretions; clear and smooth boundary.
B3	70-130 cm	10YR 4/3 when moist, 10YR 5/3 when dry; sandy clay-loam; moderate medium angular blocky; slightly hard, friable, very sticky and plastic; common fine and few medium biopores; no roots; common coarse quartz sand; common distinct medium white mottles, probably termite fungus (no carbonate reaction).
	at 200 cm	10YR 5/3 when moist, 10YR 6/3 when dry.

Remark: Pit is located on termite mound line.

B54
Profile: Mbali Pali 4

Area: Rhino-Mbali Pali area
Coordinates: 34° 54'E, 1° 44'N
Aerial photo: 8-40, L11-N
Date: 23-6-76
Altitude: 1645 m
Soil classification: Aquic Argiustoll
Physiography: lower ridge slope
Topography: normal
Slope: 3%
Erosion: -
Parent materials: gneissic rocks and volcanic deposits
Vegetation: Themeda triandra
Drainage condition: imperfectly
Moistness: moist throughout
Root distribution: common small and medium roots to 45 cm

Biological activity: termite and worm activity throughout the profile

A1	0 -25 cm	10YR 1.7/1 when moist; sandy loam; moderately weak medium subangular blocky; very friable, slightly sticky and slightly plastic; few fine and medium biopores; many small and medium roots; common coarse quartz sand; at 25 cm round termite channel (diameter 5 cm); abrupt and smooth boundary.
B2.2t	25-45 cm	10YR 3/1 when moist; sandy clay; moderately strong very coarse angular blocky consisting of strong coarse angular blocky elements; friable, sticky and very plastic; few fine and medium biopores; common small and medium roots; common coarse quartz sand, many continuous clay and pressure cutans; clear and smooth boundary.
B2.3t	45-85 cm	10YR 3.5/1 and both 10YR 6/3 and 10YR 3/1 (each 10%); sandy clay-loam; moderate medium angular blocky; friable, sticky and plastic; few small and medium biopores; few small mainly dead roots; common coarse quartz sand; common patch clay and/or pressure cutans; some worms; gradual and smooth boundary.
B3 ca	85-110 cm	2.5YR 6/4 and 2.5YR 4/1 (10%) when moist; sandy clay loam; moderately weak medium angular blocky; friable, sticky and plastic; few fine and medium biopores; no roots; common coarse quartz sand; common small prominent Mn concretions (crushable by teeth) and common medium distinct hard, Fe concretions; effervescent carbonate reaction of the soil material.

B55
Profile: Lamai 1

Area: Lamai wedge — Coordinates: 34° 54'E, 1° 31'N
Aerial photo: 3-180, L10-N — Date: 27-5-1976
Altitude: 1440 m
Soil classification: Petroferric Haplustoll
Physiography: ridge top — Topography: normal
Slope: nearly level — Erosion: -
Parent materials: trachytic phonolites
Vegetation: Themeda triandra, Sporobolus staphianus, Rhus natalensis
Drainage condition: well drained
Moistness: moist
Root distribution: common small and medium roots to 50 cm
Biological activity: no evidence

A1	0 -15 cm	7.5YR 2/2.5 when moist; sandy loam; moderate medium subangular blocky; very friable, slightly sticky and slightly plastic; few fine and medium biopores; many small and medium roots; few slightly rounded quartz gravel (4 cm); common smaller slightly rounded and angular gravel at 15 cm; abrupt and smooth boundary.
B2	15-50 cm	7.5YR 3/4 when moist; plinthite (moderately hard) and loam; common small and medium roots; plinthite does not contain gravel; abrupt and smooth boundary.
B3	50-80 cm	continuous moderately hard plinthite (can be broken by hand).
	at 80 cm	rotten rock

B56
Profile: Lamai 2

Area: Lamai wedge — Coordinates: 34° 54'E, 1° 31'N
Aerial photo: 3-180, L10-N — Date: 27-5-1976
Altitude: 1435 m
Soil classification: Udic Argiustoll
Physiography: ridge slope — Topography: subnormal
Slope: 1% — Erosion: no evidence
Parent materials: trachytic phonolites and volcanic deposits
Vegetation: Themeda triandra, Sporobolus staphianus, Balanites egyptiaca
Drainage condition: imperfectly
Moistness: dry, except topsoil (0-50 cm)
Root distribution: many small and common medium (partly dead) roots to 50 cm
Biological activity: no evidence

A1.cn	0 - 5 cm	10YR 1.7/1 when moist; sandy clay-loam; moderate medium subangular blocky; friable, sticky and plastic; biopores difficult to distinguish; many small and medium roots; few coarse quartz sand; few small shot (iron - manganese - clay pellets); clear and smooth boundary.
B2.2t	5 -20 cm	10YR 1.7/1 when moist; clay; moderate very coarse prismatic, consisting of strong medium to coarse angular blocky elements; friable, sticky and very plastic; few fine and medium biopores; many small and common medium roots (partly dead); few coarse quartz sand; many continuous clay and pressure cutans; few slightly rounded quartz gravel; clear and smooth boundary.
B2.3t	20-50 cm	10YR 2/1 when moist; clay; moderate very coarse angular blocky, consisting of strong fine angular blocky elements; friable sticky and plastic; few fine and medium biopores; many small and common medium roots (partly dead); few coarse quartz sand; common continuous clay and pressure cutans; few slightly rounded gravel; clear and smooth boundary.
B3.1t ca	50-80 cm	10YR 5/4 when moist and dry; clay; moderately strong fine angular blocky; slightly hard, friable, sticky and plastic; few fine and common biopores; no roots; very few coarse quartz sand; common patchy clay and/or pressure cutans; few small angular rock fragments (phonolite); common to many distinct medium white hard carbonate concretions; few distinct small black hard angular Fe concretions; clear and wavy boundary.
B3.2t ca	80-110 cm	10YR 5/4 when moist and dry; gravelly clay; moderate fine angular blocky; few fine and medium biopores, many angular rock fragments; common continuous clay and/or pressure cutans; few distinct small white hard carbonate concretions; common distinct white carbonate mycelium; no carbonate reaction of the soil material.

B57
Profile: SRI 1

Area: SRI — Coordinates: 34° 51'E, 2° 26'N
Aerial photo: 3-164, L10-N — Date: 27-3-1975
Altitude: 1545 m
Soil classification: Udic Argiustoll
Physiography: ridge top — Topography: normal
Slope: 3% — Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Digitaria macroblephara, Sporobolus fimbriatus, Acacia tortilis

Albizia harveyi
Drainage condition: well drained
Moistness: dry
Root distribution: common small and medium roots to 30 cm
Biological activity: no evidence

A1	0 - 9 cm	10YR 2/2 when moist, 10YR 3.5/2 when dry; sandy triable loam; moderate medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; common fine and medium, few large biopores; common small end medium roots; much coarse quartz sand; clear and smooth boundary.
B2.1	9 -30 cm	10YR 2/2 when moist, 10YR 2.5/3 when dry; sandy clay-loam; moderate medium to coarse subangular blocky; slightly hard, very friable, slightly sticky and plastic; common fine and medium, few large biopores; common small and medium roots; much coarse quartz sand; clear and smooth boundary.
B2.2	30-80 cm	10YR 2/2 when moist, 10YR 2.5/3 when dry; clay; moderate medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; common fine, few medium and large biopores; few small and medium roots; much coarse quartz sand; clear and smooth boundary.
B3.1	> 80 cm	10YR 2/2 when moist, 10YR 2.5/3 when dry; clayey gravel; weak fine subangular blocky; loose, non sticky and non plastic; common fine and few medium biopores; no roots, few boulders (to 14 cm); common distinct white carbonate mycelium; clear carbonate reaction of the soil material.

B58
Profile: SRI-2

Area: SRI
Coordinates: 34° 51'E, 2° 26'N
Aerial photo: 3-164, L10-N
Date: 19-8-1975
Altitude: 1540 m
Soil classification: Typic Natrustoll
Physiography: ridge slope
Topography: normal
Slope: 3%
Erosion: sheetwash (severe)
Parent materials: granitic rocks and volcanic deposits
Vegetation: Digitaria macroblephara, Chrysochloa orientalis
Drainage condition: imperfectly
Moistness: dry
Root distribution: common small roots to 19 cm
Biological activity: below 80 cm past termite activity

A1	0 - 9 cm	10YR 3/2 when moist, 10YR 4/2.5 when dry; sandy clay-loam; moderate medium angular blocky, topsoil (0-3 cm) lamellated; slightly hard, very friable, slightly sticky and slightly plastic; common fine and few medium biopores; common small and medium roots; much coarse quartz sand; clear and smooth boundary.
B2.2t	9 -19 cm	10YR when moist and dry; sandy clay; weak coarse prismatic, consisting of strong coarse blocky elements; extremely hard, firm, slightly sticky and plastic; few fine and medium biopores; common small roots; much coarse quartz sand; many continuous clay and pressure cutans; clear and smooth boundary.
B2.3ca	19-33 cm	10YR 3/2 when moist, 10YR 3/3 when dry; sandy clay; moderate coarse angular blocky, consisting of moderate fine angular blocky elements; hard, friable, slightly sticky and plastic; few fine and medium biopores; common very small roots; much

coarse quartz sand, few small distinct white hard carbonate concretions; clear carbonate reaction of the soil material; clear and smooth boundary.

B3.1ca	33-80 cm	10YR 2/2 when moist and dry; clay; moderate coarse angular blocky, consisting of moderate fine angular blocky elements; hard, very friable, slightly sticky and slightly plastic; few fine, medium and large biopores; no roots; much coarse sand; few small faint grey hard carbonate concretions; clear carbonate reaction of the soil material; gradual and irregular boundary.
B3.2ca	80-130 cm	10YR 4/2 and 7.5YR 5/2 when moist, 10YR 5/2 and 7.5YR 6/2 when dry; clay; moderate fine to medium angular blocky; slightly hard, very friable; slightly sticky and slightly plastic; common fine and medium biopores; much coarse quartz sand; common medium prominent black ion mottles; common medium distinct white hard carbonate concretions; clear carbonate reaction of the soil material; few to common old termite channels filled with darker soil material.

B59
Profile: SRI-3

Area: SRI — Coordinates: 34° 51'E, 2° 26'N
Aerial photo: 3-164, L10-N — Date: 27-3-1975
Altitude: 1530 m
Soil classification: Vertic Argiustoll
Physiography: valley bottom — Topography: concave
Slope: nearly level — Erosion: -
Parent materials: granitic rocks and volcanic deposits
Vegetation: Pennisetum mezianum, Acacia clavigera (on the riverbank), Acacia tortilis
Drainage condition: poorly drained
Moistness: moist, except for topsoil (0-6 cm)
Root distribution: few small and common medium roots to 42 cm
Biological activity: no evidence

A1	0 - 6 cm	10YR 2/2.5 when moist, 10YR 3.5/2 when dry; sandy clay-loam; moderate medium subangular blocky; hard, very friable, slightly sticky and slightly plastic; many fine, common medium and few large biopores, few small and common medium roots, common coarse quartz sand, upper topsoil (1 cm) laminated; clear and smooth boundary.
B2.2t	6 -42 cm	10YR 2/1.5 when moist; clay; strong medium angular blocky; very hard, very friable, sticky and plastic, few fine biopores; few small and common medium roots; common coarse quartz sand; many continuous clay and pressure cutans; gradual and smooth boundary.
B2.3t	42-67 cm	10YR 3/2 when moist; clay; moderate medium angular blocky; very hard, very friable, sticky and plastic; few fine biopores; few small and medium roots; common coarse quartz sand; many continuous clay and pressure cutans; clear carbonate reaction of the soil material; gradual and smooth boundary.
B3.1ca	67-87 cm	10YR 3/2.5 when moist; clay; moderate medium angular blocky; slightly hard, very friable, very sticky and plastic; few fine biopores; few small and medium roots; common coarse quartz sand; few patchy clay and/or pressure cutans; clear carbonate reaction of the soil material; clear and smooth boundary.

B3.2ca 87-104 cm 10YR 4/2.5 when moist; clay; moderate medium to coarse subangular blocky; slightly hard, very friable, very sticky and plastic; few fine biopores; no roots; common coarse quartz sand; from 86-96 cm few medium white hard carbonate concretions and few small clods of volcanic tuff, at 140 cm common medium white hard carbonate concretions; clear carbonate reaction of the soil material.

B60
Profile: Larale 1

Area: Larale Medungi
Coordinates: 35° 04'E, 2° 31'N
Aerial photo: 7-70, L13-S
Date: 18-6-1975
Altitude: 1740 m
Soil classification: Aridic Argiustoll
Physiography: ridge top
Topography: subnormal
Slope: nearly level
Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Pennisetum mezianum, Microchloa kunthii, Digitaria macroblephara, Acacia tortilis (regeneration stage only)
Drainage condition: moderately well drained
Moistness: dry
Root distribution: common small and medium roots to 50 cm
Biological activity: past termite activity in B2 horizon

A1 0 -15 cm 10YR 3/2 when moist, 10YR 5/2 when dry; loam; moderate medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; common fine and few medium biopores; common small and medium roots; no coarse sand; thin soft surface sealing; clear and smooth boundary.

B2.1ca 15-50 cm 10YR 3/2 when moist, 10YR 4.5/3 when dry; loam; moderate fine to medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; common fine, medium and large biopores; common small and medium roots; few old termite channels coated with carbonates; effervescent carbonate reaction of the soil material starting at 20 cm; clear and smooth boundary.

B2.2ca 50-90 cm 10YR 4/2.5 when moist, 10YR 5/3 when dry; clay-loam; moderate fine to medium subangular blocky; slightly hard, very friable, slightly sticky and slightly plastic; few fine biopores; few small and medium roots; common to many old termite channels coated with carbonates; effervescent carbonate reaction of the soil material.

B3.1ca 90-100 cm 10YR 4.5/3 when moist, 10YR 6/2 when dry; silt-loam; moderate medium subangular blocky; slightly hard, friable slightly sticky and slightly plastic; few fine biopores; very few small roots; much carbonate mycelium; effervescent carbonate reaction of the soil material; clear and smooth boundary.

B3.2ca 100-135 cm 10YR 5/4 when moist, 10YR 6/3 when dry; loam; weak fine to medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; few fine biopores; no roots; few coarse quartz sand; common medium distinct white hard carbonate concretions (to 8 cm); at 135 somewhat rounded quartz gravel (to 15 cm).

B61
Profile: Larale 2

Area: Larale Medungi
Coordinates: 35° 09'E, 2° 31'N
Aerial photo: 7-70, L13-S
Date: 18-11-1975
Altitude: 1730 m
Soil classification: Typic Natrustoll
Physiography: ridge slope
Topography: subnormal
Slope: 2%
Erosion: sheetwash
Parent materials: granitic rocks and volcanic deposits
Vegetation: Acacia tortilis, Commiphora trothae
Drainage condition: imperfectly drained
Moistness: topsoil dry (0-70 cm)
Root distribution: common small and medium roots to 30 cm
Biological activity: no evidence

A1	0 -14 cm	10YR 3/2 when moist, 10YR 4/2 when dry; loam; moderate medium subangular blocky; slightly hard, friable, slightly sticky and slightly plastic; few fine biopores; many small and medium roots; common coarse quartz sand; very few small angular quartz gravel; abrupt and smooth boundary.
B2.2t ca	14-30 cm	10YR 4/2 when moist and dry; clay; weak coarse prismatic, consisting of strong fine to medium angular blocky elements; very hard, friable, sticky and very plastic; few fine biopores; common small and medium roots, as well as tree roots; common coarse quartz sand; many continuous clay and pressure cutans; common prominent carbonate mottles; effervescent carbonate reaction of the soil material; clear and smooth boundary.
B2.3t ca	30-70 cm	10YR 5/3 when moist, 10YR 6/3 when dry; clay; moderately weak medium angular blocky, consisting of moderate fine angular blocky elements; slightly hard, friable, sticky and very plastic; common fine and few large biopores; few small roots; common coarse quartz sand; common patchy clay and pressure cutans; many to abundant distinct carbonate mottles; effervescent carbonate reaction of the soil material; gradual and smooth boundary.
B3.1ca	70-100 cm	10YR 4/3 when moist; clay-loam; moderate medium angular blocky; friable, sticky and plastic; very few fine biopores; no roots; few coarse quartz sand; common patchy clay and pressure cutans; few faint carbonate mottles; effervescent carbonate reaction of the soil material; gradual and smooth boundary.
B3.2ca	70-130 cm	7.5YR 4/4 when moist; clay-loam; moderate medium angular blocky; friable, sticky and plastic; very few small biopores; few coarse quartz sand; common patchy clay and pressure cutans; very few faint carbonate mottles; effervescent carbonate reaction of the soil material; at 110 cm piece of angular gravel (2 cm).

APPENDIX C. PARTICLE SIZE DISTRIBUTION SOILS OF THE SERENGETI WOODLANDS (g/100g)

Sample number	Site	Depth (cm)	Particle size in µm							
			<2	2/16	16/50	50/100	100/250	250/500	500/1000	1000/1700
166	Togoro 1	0- 20	18.0	9.4	13.4	14.3	21.2	15.4	6.5	1.8
167		20- 40	25.0	8.0	13.3	8.9	23.4	15.0	5.1	1.3
168		40- 84	45.1	6.0	10.9	7.0	16.2	10.5	3.2	1.1
169		84-135	32.2	19.2	20.6	5.5	11.7	7.5	2.6	0.7
170	Rhino 7	0- 10	13.8	12.7	4.7	9.4	26.0	21.6	10.1	1.7
171		10- 55	30.7	3.9	10.2	4.5	17.2	19.2	12.2	2.1
172		55- 75	29.3	4.9	8.6	4.8	18.0	19.5	12.6	2.3
173		75-100	36.7	7.8	10.2	5.5	14.3	15.2	9.1	1.2
174		100-150	41.3	10.8	11.6	5.1	12.5	11.4	6.2	1.1
175	Mukoma 3	0- 10	54.2	6.4	6.1	2.8	7.8	9.9	9.8	3.0
176		10- 30	57.0	6.0	9.0	2.5	6.3	8.1	8.1	3.0
177		30- 60	58.4	8.0	7.2	2.5	6.0	7.3	8.2	2.4
178		60- 80	56.7	13.2	6.8	2.3	5.1	6.5	6.6	2.8
179		80-100	52.7	16.6	12.1	1.9	5.0	5.6	4.7	1.4
180		100-120	45.0	25.9	14.5	1.8	4.1	4.4	3.4	0.9
181		120-150	26.1	29.1	27.7	2.4	5.0	5.0	3.6	1.1
182		150-160	22.6	30.1	23.9	3.7	7.2	6.7	4.5	1.3
183	Bololedi 2	0- 20	19.5	6.4	16.7	7.9	28.0	15.6	5.1	0.8
184		20- 30	28.4	7.2	11.5	9.1	25.4	14.0	3.7	0.7
185		30- 60	33.3	3.1	11.3	8.3	24.0	15.1	4.2	0.7
186		60-100	39.8	6.8	12.2	6.7	18.1	12.3	3.5	0.6
290		100-130	33.7	13.8	13.8	9.0	16.5	10.1	2.6	0.5
187	Dutwa 1	0- 20	16.6	7.4	10.7	3.1	14.6	19.6	19.8	8.2
188		20- 40	39.3	5.1	6.8	2.1	9.9	14.4	14.8	7.6
189		40- 80	40.8	13.0	9.0	2.8	7.6	10.3	10.3	6.2
190		80-100	47.4	16.6	9.2	3.5	5.6	6.4	7.4	3.9
191	SRI-2	0- 9	31.6	5.8	10.0	5.6	11.3	12.8	15.5	7.4
192		9- 19	39.4	6.0	7.3	4.4	9.9	12.5	14.3	6.2
193		19- 33	39.5	7.1	8.2	4.6	10.3	12.9	12.5	4.9
291		33- 80	44.9	9.6	9.3	5.2	9.5	9.9	8.5	3.1
194		80-130	40.5	18.9	16.0	3.8	6.3	6.4	5.5	2.6
195	SRI-1	0- 9	19.7	7.7	14.4	8.4	16.8	15.0	12.9	5.1
196		9- 30	28.5	6.6	12.9	8.1	16.0	13.7	9.6	4.6
197		30- 80	41.8	6.5	11.4	6.4	10.7	10.1	8.6	4.5
198	Musabi 1	0- 5	14.4	7.4	9.9	6.3	17.8	22.6	17.3	4.3
199		5- 26	40.2	8.7	7.0	3.8	10.3	14.5	11.7	3.8
200		26- 72	31.4	14.5	11.4	4.0	10.7	13.7	11.4	2.9
201		72-120	29.1	16.6	13.6	5.4	12.3	13.1	8.0	1.9
289		120-140	31.3	15.8	13.6	5.9	12.7	12.2	6.9	1.6
202	SRI-3	0- 6	28.4	12.6	12.3	3.7	8.8	12.5	14.5	7.2
203		6- 32	53.3	9.1	7.4	2.8	6.1	8.2	9.2	3.9
204		32- 42	50.9	10.4	7.1	2.4	6.1	9.3	9.9	3.9
205		42- 67	49.6	11.7	7.9	2.4	5.6	8.6	9.5	4.7
206		67- 87	48.8	10.6	10.3	1.5	5.4	8.6	10.2	4.6
207		87-104	41.1	18.3	9.4	2.6	5.7	9.6	9.6	3.7
208	Mukoma 1	0- 15	16.9	7.2	13.0	9.5	17.6	15.6	14.9	5.3
209		15- 30	43.3	4.8	9.7	5.5	12.0	11.6	9.6	3.5
210		30- 45	43.1	6.2	12.8	3.7	10.6	11.0	9.6	3.0
211		45- 60	49.5	8.7	12.2	4.0	7.4	8.2	7.7	2.3
212		60- 90	28.4	22.0	16.9	5.2	8.4	8.7	7.9	2.5
213		90-120	29.6	28.2	18.1	3.8	6.3	6.2	6.0	1.8
214		120-150	15.7	32.7	24.4	4.8	9.0	7.1	4.7	1.6
215	Nyara Swiga 2	0- 19	23.3	8.2	13.9	10.0	19.2	17.3	6.1	2.0
216		19- 62	35.9	7.4	12.2	7.1	13.5	14.3	7.5	2.1
271		62- 95	40.8	12.4	15.4	5.2	9.7	9.6	5.1	1.8
218		95-150	43.7	12.8	15.9	4.6	7.6	8.0	5.2	2.2

Sample number	Site	Depth (cm)	Particle size in µm							
			<2	2/16	16/50	50/100	100/250	250/500	500/1000	1000/1700
219	Mbalageti 1	0- 14	34.7	31.4	17.3	3.7	5.0	3.6	3.4	0.9
220		14- 40	44.8	23.0	16.4	3.1	5.4	3.8	2.7	0.8
221		40- 70	55.6	14.3	12.5	2.6	5.8	4.6	3.6	1.0
222		70-100	55.6	16.9	13.2	2.5	4.6	3.6	2.6	1.0
223		100-150	29.8	34.3	25.2	2.7	3.6	2.3	2.3	0.4
224	Mbalageti 2	0- 6	21.2	23.2	27.9	6.6	7.9	5.6	5.3	2.3
225		6- 20	43.6	22.7	15.6	4.0	5.4	4.1	3.7	0.9
226		20- 60	58.2	16.4	13.7	2.4	3.2	2.6	2.5	1.0
227		60- 77	30.3	31.0	29.0	2.3	2.8	2.0	2.0	0.6
228		77- 92	33.5	27.4	31.0	2.2	2.3	1.5	1.4	0.7
229		92-117	32.7	28.0	32.9	1.4	1.8	1.5	1.2	0.5
240	Kirawira 2	0- 20	38.4	6.7	10.2	6.7	15.3	12.5	8.0	2.2
241		20- 35	50.7	6.0	8.7	5.4	11.7	9.6	6.3	1.6
242		35- 68	53.5	8.5	7.8	4.8	11.1	8.6	4.4	1.3
243	Kirawira 5	0- 20	59.3	5.1	13.1	2.5	5.2	6.1	6.6	2.1
245		20- 43	55.8	11.9	7.9	2.5	5.8	7.0	6.9	2.2
245		43- 69	56.8	15.3	11.2	2.3	4.5	5.0	3.9	1.0
246		69- 99	56.7	17.2	16.8	0.7	3.2	2.8	1.9	0.7
247		99-130	58.8	21.5	9.6	1.6	3.0	3.0	1.9	0.6
248	Banagi 4	0- 2	25.6	32.0	20.4	3.6	8.0	5.8	3.4	1.2
249		2- 15	34.0	42.6	14.3	0.9	3.5	2.5	1.5	0.7
250		15- 50	58.3	14.1	13.3	2.4	5.2	4.2	2.0	0.5
251		50- 70	54.3	19.8	12.8	2.3	4.0	3.5	2.5	0.8
252		70-100	47.0	25.1	12.4	2.9	5.8	4.0	2.2	0.6
253		100-130	46.7	22.1	12.8	3.0	5.2	4.4	4.2	1.6
254	Rhino 5	0- 18	6.9	3.6	6.9	10.5	32.9	23.7	13.6	1.9
255		18- 50	7.7	3.7	8.2	8.7	31.1	22.1	15.4	3.1
256		50- 80	8.7	3.5	7.9	9.5	35.1	21.6	12.0	1.7
257	Mukoma 4	0- 20	63.5	6.0	7.1	1.6	4.3	7.3	7.6	2.6
258		20- 48	60.5	7.5	5.7	1.5	3.7	7.1	10.1	3.9
259		48- 75	52.9	12.4	4.5	1.5	5.2	10.3	10.6	2.6
260		75- 91	50.8	10.6	3.6	1.5	4.6	10.2	14.0	4.7
261		91-131	52.6	9.9	4.2	1.4	3.8	10.0	14.1	4.0
262	Banagi 5	0- 10	21.6	16.1	21.2	7.4	14.7	10.3	6.5	2.2
263		10- 30	16.0	16.9	16.3	8.7	18.6	13.0	8.0	2.5
264		30- 60	28.1	16.7	17.5	6.7	13.0	9.3	6.2	2.5
265		60- 80	36.8	19.4	16.8	5.5	9.1	6.8	4.1	1.5
266	Larale 1	0- 15	23.5	17.3	17.4	9.5	14.7	9.0	6.0	2.6
267		15- 50	27.5	14.7	16.7	10.1	15.8	8.7	4.7	1.8
268		50- 90	29.2	19.3	17.4	8.7	12.9	7.0	3.8	1.7
269		90-100	11.8	30.0	27.8	5.3	13.4	6.5	3.7	1.5
270		100-130	9.7	24.7	25.7	8.9	15.3	8.4	5.4	1.9
271	Larale 2	0- 14	24.3	23.3	17.6	8.7	11.4	7.0	5.4	2.3
272		14- 30	54.6	13.6	9.5	4.2	6.4	4.9	4.8	2.0
273		30- 70	44.3	20.9	12.1	4.6	7.4	5.3	4.0	1.4
274		70-100	38.2	27.4	14.8	4.6	6.9	4.5	2.8	0.8
276	Simiyu	0- 12	31.2	17.2	20.6	2.7	10.2	9.0	6.9	2.2
277		12- 25	39.4	13.8	17.9	4.9	8.8	8.3	5.4	1.5
278		25- 55	64.8	13.5	8.1	2.3	4.0	3.9	2.7	0.7
279		55- 85	58.1	21.1	9.3	2.8	3.4	2.8	1.9	0.6
280		85-110	34.1	36.8	17.5	2.1	3.2	3.1	2.5	0.7
281		110-130	19.5	28.4	23.0	3.8	7.3	8.8	7.4	1.8
282	Nyara Swiga 3	0- 16	24.6	33.1	20.4	3.7	6.6	6.7	3.8	1.1
283		16- 65	48.0	17.3	11.9	2.5	6.1	8.2	4.8	1.2
284		65-110	44.7	21.6	11.5	3.2	6.2	7.6	3.9	1.3
285		110-150	49.5	21.1	12.0	3.2	5.3	5.6	2.5	0.8
286	Kirawira 1	0- 15	9.8	5.5	10.7	7.3	21.9	22.5	18.4	3.9
287		15- 29	21.6	5.2	8.9	5.3	14.8	16.5	19.5	8.2
288		29- 55	27.0	7.4	13.1	5.1	16.2	14.2	11.5	4.6
304	Mbalageti ash		5.2	22.3	40.0	1.4	8.0	9.4	6.6	7.1

APPENDIX D. CHEMICAL COMPOSITION SATURATED SOIL EXTRACTS, MASS FRACTION OF LIME, ROOTS, COARSE MATERIAL AND ORGANIC CARBON OF THE SOILS OF THE SERENGETI WOODLANDS

Depth (cm)	SP (g/100g)	pH_p	pH_e	EC_e (mS cm^{-1})	Ionic equivalents (mmol/l)									(mmol/kg)					ESP	Lime (g/100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/100g)
					$\frac{1}{2}Ca^{2+}$ + $\frac{1}{2}Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $\frac{1}{2}CO_3^{2-}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	CEC	K^+ exch.	Na^+ exch.	$\frac{1}{2}Ca^{2+}$ exch.	$\frac{1}{2}Mg^{2+}$ exch.					
D1: MUKOMA 1																							
0- 15	31.8	7.74	7.57	0.49	1.08	2.75	0.77	4.60	3.92	0.54	0.30	-	4.76	108.9	10.1	10.9	72.9	39.6	10.0	0.5	14.84	0.15	1.49
15- 30	54.6	7.61	8.76	1.35	1.01	11.13	0.23	12.37	9.64	2.54	-	-	12.18	263.5	18.8	70.1	158.3	89.6	26.6	0.8	6.37	0.15	1.00
30- 45	70.9	8.38	8.74	2.28	1.04	20.96	0.15	22.15	5.89	4.58	8.76	-	19.23	252.7	12.1	100.5	162.5	47.9	39.7	8.0	6.06	-	0.72
45- 60	69.4	8.45	8.65	1.90	1.14	17.39	0.10	18.53	5.65	6.25	3.20	-	15.10	309.7	16.2	126.6	152.0	58.4	40.8	7.5	10.10	-	0.40
60- 75	58.9	8.15	8.55	1.70	1.31	15.04	0.08	16.43	5.52	8.66	-	-	14.18							5.3	15.68	-	0.16
														301.6	11.7	128.8	187.5	-	42.7				
75- 90	64.6	8.30	8.75	1.52	1.01	13.04	0.08	14.13	5.42	8.26	0.50	-	14.18							5.5	19.09	-	0.10
90-105	48.7	8.30	8.76	1.52	0.81	13.04	0.08	13.93	5.69	7.30	0.33	-	13.32							3.7	11.11	-	0.08
														301.6	9.5	127.7	168.7	29.2	42.3				
105-120	50.3	8.19	8.90	1.26	0.74	11.30	0.08	12.12	6.53	6.29	-	-	12.82							1.7	8.42	-	0.02
120-135	68.2	8.31	8.84	1.11	0.81	10.04	0.10	11.85	6.02	4.18	0.33	-	10.58							2.2	9.97	-	0.01
														290.7	9.3	121.7	152.0	39.5	41.8				
135-150	47.9	8.05	8.87	1.10	0.87	9.96	0.16	10.99	6.53	2.69	-	-	9.22							1.0	18.11	-	-
D2: MUKOMA 2																							
0- 10	37.6	7.22	8.65	1.55	2.10	12.22	0.13	14.45	5.26	5.68	1.90	-	12.84	163.0	7.9	28.6	133.3	-	17.5	-	0.60	0.35	1.80
10- 32	54.4	7.95	8.74	1.10	0.66	11.47	0.01	13.14	6.20	4.00	1.72	-	11.92	307.3	5.7	70.6	231.2	6.3	22.9	0.5	0.60	0.05	1.35
32- 56	73.6	8.20	8.78	2.06	0.69	17.39	0.03	18.11	5.16	13.21	0.99	-	19.36	318.2	11.5	104.2	227.0	54.2	32.7	3.2	0.30	0.05	1.35
56- 81	70.2	8.15	8.41	4.85	3.00	48.47	0.08	51.55	3.50	47.20	0.83	1.0	52.53	400.4	17.7	161.8	220.8	10.4	40.4	3.0	0.40	-	0.97
81-125	74.7	8.28	8.45	4.74	2.03	52.40	0.04	54.52	3.00	45.79	0.09	2.0	51.78	367.8	20.6	175.2	185.4	-	47.6	6.5	0.30	-	0.54
D3: MUKOMA 3																							
0- 10	72.9	6.47	7.90	0.44	1.88	1.95	0.41	4.24	3.65	1.12	0.33	-	5.10	307.0	33.7	10.6	206.2	77.1	2.0	0.3	0.6	1.15	2.08
10- 20	85.2	6.50	7.65	0.34	2.62	1.01	0.23	3.86	2.47	0.72	0.33	-	3.52							-	1.0	0.70	1.26
														347.8	25.2	11.1	293.7	52.1	2.1				
20- 30	75.2	7.24	8.25	0.45	3.29	1.31	0.13	4.73	3.95	0.06	0.23	-	4.29							1.7	2.7	0.15	1.16
30- 40	78.8	7.86	7.86	0.45	2.69	2.03	0.08	4.80	3.92	0.03	0.20	-	4.15							3.2	2.2	0.10	1.12
40- 50	76.9	7.97	7.67	0.48	1.95	2.30	0.08	4.33	3.92	0.06	0.23	-	4.21	336.9	16.1	16.7	300.0	77.0	4.1	3.7	5.4	0.10	1.01
50- 60	77.6	8.03	8.52	0.51	1.48	3.26	0.08	4.82	4.08	-	0.23	-	4.31							3.5	3.4	-	0.93
60- 70	87.0	8.06	8.55	0.51	0.88	3.70	0.08	4.66	3.88	0.10	0.16	-	4.14							2.5	3.8	-	0.83
														347.8	21.2	49.5	254.1	77.1	13.3				
70- 80	82.4	8.00	8.70	0.70	0.64	5.57	0.08	6.24	5.15	0.16	0.20	-	5.51							2.2	3.6	-	0.74
80- 90	87.4	8.11	8.76	0.75	0.34	6.43	0.09	6.86	5.59	0.26	0.16	-	6.01							1.7	3.4	-	0.72
														434.8	27.0	90.8	195.8	79.2	28.8				
90-100	78.3	8.18	8.82	0.90	-	7.65	0.09	7.74	5.85	0.48	0.26	-	6.59							2.5	3.0	-	0.61
100-120	76.5	8.23	8.83	1.28	0.13	10.91	0.11	11.15	5.62	1.44	1.10	3.0	11.16	385.9	31.1	129.9	154.1	85.4	42.5	1.7	7.2	-	0.52

Depth (cm)	SP (g/100g)	pH_p	pH_e	EC_e (mS cm^{-1})	Ionic equivalents (mmol/l) $\frac{1}{2}Ca^{2+}$ + $\frac{1}{2}Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $\frac{1}{2}CO_3^{2-}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	(mmol/kg) CEC	K^+ exch.	Na^+ exch.	$\frac{1}{2}Ca^{2+}$ exch.	$\frac{1}{2}Mg^{2+}$ exch.	ESP	Lime (g/100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/100g)
120-130	61.0	8.45	8.75	3.40	0.91	29.13	0.25	30.29	5.29	11.77	12.16	1.2	30.42							15.7	9.5	-	0.25
130-140	57.9	8.34	8.57	4.56	1.58	43.65	0.31	45.54	4.15	29.54	15.06	1.0	49.75	309.7	28.7	160.9	129.1	70.4	62.5	7.7	7.8	-	0.23
140-150	55.6	8.33	8.69	3.50	1.31	30.35	0.23	31.89	4.72	18.01	9.39	0.5	32.62							8.7	5.5	-	0.21
150-160	55.7	8.32	8.63	2.60	0.81	22.78	0.16	23.75	5.64	13.35	5.00	0.2	24.06							5.2			
D4: MUKOMA 4																							
0- 20	87.4	6.77	8.25	0.50	1.46	3.04	0.17	4.67	4.30	0.38	0.41	-	5.09	438.3	31.8	32.0	283.3	76.0	7.3	0.3	0.9	0.25	1.96
20- 48	101.7	8.06	8.67	0.80	0.97	6.53	0.09	7.59	6.26	0.70	0.44	-	7.40	468.2	22.7	52.5	391.6	52.1	11.2	8.0	2.4	0.05	1.49
48- 75	117.5	8.51	8.81	1.84	0.72	17.08	0.12	17.92	6.67	3.76	5.86	-	16.29	380.0	25.3	138.5	260.3	42.7	36.4	12.5	5.0	-	1.20
75- 91	81.1	8.60	8.34	1.40	0.40	13.43	0.10	13.93	5.25	6.44	1.10	0.2	12.99	396.3	26.8	161.1	225.0	14.5	40.6	9.0	11.2	-	1.00
91-131	80.6	8.62	8.82	1.72	0.26	16.00	0.13	16.39	5.23	10.08	0.26	-	15.57	347.4	27.5	160.7	172.9	12.5	46.2	4.5	9.0	-	0.82
D5: MUKOMA 5																							
0- 10	85.2	7.86	8.73	1.32	1.21	9.96	0.11	11.28	11.24	0.64	0.66	-	12.54	394.0	24.9	66.8	351.7		12.5	7.0	0.2	0.85	1.92
10- 20	127.0	8.30	8.75	1.54	0.60	12.48	0.05	13.13	11.76	1.03	0.83	-	13.62							10.5	0.4	0.55	1.69
														380.4	23.0	167.9	219.5		29.7				
20- 30	133.6	8.56	8.71	1.88	0.60	16.09	0.06	16.75	13.07	2.39	0.83	-	16.27							10.5	0.4	0.35	1.47
30- 40	138.2	8.80	8.94	2.32	0.50	18.00	0.08	18.58	12.33	5.40	0.99	-	18.72							10.5	0.2	0.05	1.46
														388.5	27.5	220.4	143.0		43.0				
40- 60	106.1	8.81	8.87	4.00	0.80	34.78	0.16	35.02	8.45	20.50	1.83	-	30.78							13.0	0.4	0.05	1.09
60- 80	102.0	8.75	8.42	3.12	0.70	26.87	0.14	27.71	6.73	22.50	0.50	0.2	29.73							16.5	0.7	-	0.75
80- 90	110.0	8.76	8.37	3.30	0.70	29.48	0.16	30.34	6.02	25.80	0.33	0.2	32.15	347.8	29.3	235.7	124.2		85.7	17.2	0.9	-	0.59
90-110	121.1	8.80	8.07	3.35	0.80	29.48	0.16	30.44	4.82	28.17	0.33	-	33.32							14.5	1.8	-	0.43
110-120	134.9	8.83	8.20	3.41	0.90	29.91	0.16	30.97	4.72	29.07	0.40	-	34.19							12.5	1.8	-	0.39
120-130	132.7	8.81	8.38	4.39	1.21	38.35	0.21	39.77	3.77	35.10	0.84	1.5	41.26	383.6	31.2	249.9	158.8		65.1	11.0	1.7	-	0.37
130-140	146.6	8.72	7.37	4.58	1.31	40.96	0.22	42.49	3.66	37.73	1.56	2.5	45.45							9.5	1.7	-	0.36
140-150	165.3	8.80	7.30	4.54	1.31	40.30	0.21	41.82	3.62	36.77	2.33	3.0	45.72							9.0	2.9	-	0.34
														413.5	31.0	247.2	166.2		59.7				
150-160	165.3	8.78	7.96	3.80	1.01	34.43	0.18	35.62	4.05	28.03	2.53	4.0	38.61							8.2	2.2	-	0.35
160-170	175.7	8.87	8.47	3.00	0.70	25.13	0.14	25.97	4.43	16.62	2.16	4.0	27.21							6.5	3.8	-	0.34
														433.8	31.9	277.2	168.7		63.9				
170-180	170.3	8.78	8.24	2.75	0.70	23.91	0.12	24.73	5.00	17.26	1.90	3.5	27.66							2.5	7.5	-	0.30
180-200	167.5	8.71	8.54	2.56	0.65	19.97	0.12	20.68	5.81	10.80	1.33	3.5	21.44							3.0	15.6	-	0.25
D6: MBALAGETI 1																							
0- 14	50.7	6.20	7.47	0.50	3.10	1.48	0.96	5.54	4.06	1.13	0.77	-	5.96	219.0	4.7	18.4	137.2	51.4	8.4	0.7	0.1	0.30	2.07
14- 40	48.8	6.02	7.37	0.43	2.00	1.73	0.76	4.49	3.28	-	0.58	-	3.86	213.5	4.5	13.0	118.9	65.4	6.0	-	0.1	0.10	1.38
40- 70	59.7	6.55	7.94	0.34	0.38	1.98	0.35	2.71	2.59	-	0.24	-	2.83	219.0	4.7	16.8	113.1	39.5	7.6	-	0.9	-	0.57
70-100	62.1	7.09	8.21	0.35	0.94	2.69	0.25	3.88	2.49	0.58	0.24	-	3.31	229.8	4.7	19.0	167.7	51.0	8.2	-	0.7	-	0.35
100-115	51.1	7.72	8.67	0.60	1.24	4.86	0.30	6.40	4.69	0.92	0.58	-	6.19	286.4	5.2	32.0	161.6	119.6	11.1	0.7	2.8	-	0.25

Depth (cm)	SP (g/100g)	pH_p	pH_e	EC_e ($mS\,cm^{-1}$)	Ionic equivalents														ESP	Lime (g/100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/100g)
					(mmol/l)									(mmol/kg)									
					$\frac{1}{2}Ca^{2+}$ + $\frac{1}{2}Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $\frac{1}{2}CO_3^{2-}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	CEC	K^+ exch.	Na^+ exch.	$\frac{1}{2}Ca^{2+}$ exch.	$\frac{1}{2}Mg^{2+}$ exch.					
D7: MBALAGETI 2																							
0- 6	31.6	6.67	8.17	0.70	1.73	5.30	0.47	7.50	6.51	-	1.40	-	7.91	177.7	2.7	15.2	76.2	67.5	8.5	-	2.4	0.90	1.22
6- 20	70.6	7.57	8.64	1.10	0.99	10.60	0.23	11.82	9.80	-	1.40	-	11.20	270.1	4.0	63.0	161.6	25.9	23.3	-	0.6	0.05	1.00
20- 60	65.7	8.30	8.83	1.80	1.68	15.65	0.13	17.46	8.31	6.09	2.56	-	16.96	313.5	4.2	149.4	176.9	41.8	47.6	2.7	0.5	-	0.73
60- 77	52.7	8.16	8.79	2.40	1.64	20.86	0.17	22.67	6.71	12.97	3.53	-	23.21	309.2	4.2	162.5	140.3	50.3	52.5	1.5	1.8	-	0.34
77-102	49.8	8.20	8.76	2.40	1.49	20.60	0.17	22.26	6.13	12.45	3.14	2.0	23.72	287.5	4.4	160.0	146.4	37.9	55.6	1.2	5.8	-	0.27
102-117	55.6	8.23	8.78	2.10	0.79	18.98	0.15	19.92	6.13	9.29	3.62	2.5	21.54	309.2	5.1	178.8	143.3	44.2	57.8	1.7	18.6	-	0.15
D8: NYARA SWIGA 2																							
0- 19	21.9	6.21	7.71	0.47	2.80	1.46	1.02	5.28	1.50	2.51	1.35	-	5.36	100.4	11.5	1.7	66.6	31.3	1.6	-	8.9	0.65	1.20
19- 62	32.8	6.45	7.95	0.23	1.20	0.65	0.13	1.98	0.90	0.60	0.54	-	2.04	204.7	7.4	3.0	135.4	35.4	1.4	-	6.4	0.65	0.92
62- 95	36.3	6.66	8.01	0.21	1.10	1.29	0.07	2.46	0.95	-	1.62	-	2.57	208.1	7.2	3.3	150.6	66.6	1.5	-	4.1	-	0.75
95-120	33.0	7.11	7.97	0.96	3.90	6.43	0.07	10.40	1.15	3.37	3.99	0.7	9.21	235.3	12.5	21.6	175.0	62.5	9.1	-	8.2	-	0.47
D9: NYARA SWIGA 3																							
0- 16	36.3	5.90	7.62	0.34	1.00	2.35	0.42	3.69	0.40	1.34	1.45	-	3.19	246.1	24.9	18.8	118.7	85.4	7.6	-	2.87	1.85	3.28
16- 65	44.7	7.54	8.67	1.52	1.00	16.00	0.14	17.14	8.00	1.98	(7.00)	-	(16.98)	278.8	19.9	67.7	158.3	75.0	24.2	-	2.89	0.13	1.40
65-110	34.5	7.79	8.29	1.60	5.20	43.66	0.39	49.25	2.00	27.69	20.73	1.0	51.42	331.7	17.9	102.6	177.0	73.0	30.9	0.3	-	-	0.69
110-150	27.1	7.75	8.27	5.30	7.80	60.86	0.47	69.13	3.00	29.15	26.56	3.0	61.71	320.8	17.5	94.9	164.5	83.4	29.5	-	3.35	-	0.53
D10: NYARA SWIGA 5																							
0- 13	25.7	6.16	7.17	0.34	0.70	1.93	0.47	3.10	1.85	0.20	0.54	-	2.59	179.5	14.1	16.0	81.2	31.3	8.9	-	12.7	1.45	2.27
13- 30	69.1	7.71	8.75	0.99	0.70	7.86	0.14	8.70	6.10	-	2.05	-	8.15	288.2	22.2	58.0	158.3	58.3	20.1	-	4.8	-	1.44
30- 45	34.0	8.05	8.76	1.30	0.70	11.35	0.11	12.16	5.20	2.60	2.48	-	10.28	308.2	18.1	90.4	202.0	52.1	29.3	0.5	7.4	-	0.79
45- 80	58.2	7.93	8.72	1.20	0.50	11.35	0.08	11.93	4.70	5.20	0.54	-	10.44	308.2	17.4	89.8	189.5	52.1	29.1	0.3	6.9	-	0.73
80-120	48.0	7.71	8.72	1.25	0.50	10.91	0.08	11.49	4.60	4.38	1.18	-	10.16	297.3	16.7	82.4	189.5	48.0	27.7	-	6.8	-	0.24
120-140	50.4	7.65	8.67	1.10	0.50	9.17	0.08	9.75	3.60	5.01	0.59	0.5	9.70	281.0	16.0	79.8	179.1	64.6	28.3	-	11.5	-	0.25
D11: NYARA SWIGA 6																							
0- 9	53.3	6.36	7.62	0.99	0.99	2.08	0.16	3.23	2.00	0.75	0.79	-	3.54	328.4	19.7	11.9	204.0	108.5	3.6	0.2	2.6	0.25	1.8
9- 45	75.9	7.65	7.95	1.19	1.19	6.26	0.06	7.51	6.01	0.37	1.09	-	7.47	439.6	10.8	38.0	266.8	102.8	8.6	0.5	1.3	0.15	1.3
45- 90	68.4	7.88	8.15	0.79	0.79	6.78	0.08	7.65	4.83	1.50	0.54	-	6.87	427.4	15.6	61.4	260.4	99.9	14.3	1.1	10.6	-	1.2
90-125	66.8	7.45	7.54	0.69	0.69	7.08	0.14	7.91	4.64	3.00	0.59	-	8.23	404.3	25.7	60.5	231.4	76.1	14.9	-	0.7	-	0.7

Depth (cm)	SP (g/100g)	pH_p	pH_e	EC_e ($mS\ cm^{-1}$)	Ionic equivalents (mmol/l): $½Ca^{2+}$ + $½Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $½CO_3^{2-}$	$½SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	(mmol/kg): CEC	K^+ exch.	Na^+ exch.	$½Ca^{2+}$ exch.	$½Mg^{2+}$ exch.	ESP	Lime (g/100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/100g)
D13: KAMARISHE 2																							
0- 10	26.2	6.47	7.90	0.53	1.19	4.69	0.19	6.07	4.02	1.33	0.87	-	6.22	142.6	5.3	15.2	108.4	32.2	10.6	-	4.2	0.15	1.40
10- 30	31.8	6.61	7.50	0.44	0.89	5.73	0.08	6.70	4.34	1.41	0.62	-	6.37	189.1	4.1	23.9	126.5	42.1	12.6	-	4.8	-	1.27
30- 90	66.8	6.90	7.61	0.90	0.99	9.21	0.10	10.30	8.18	1.58	0.48	-	10.24	305.7	11.3	56.2	206.8	56.0	18.3	1.7	2.4	-	1.08
90-120	51.5	7.70	7.44	1.00	1.79	10.08	0.08	11.95	8.76	1.96	0.62	1.0	12.34	320.6	13.2	63.5	210.4	56.0	19.8	0.7	2.0	-	0.49
D14: KAMARISHE 3																							
2- 25	75.9	7.51	7.78	0.78	1.39	7.91	0.13	9.43	7.64	1.25	0.48	-	9.37	379.8	18.3	45.3	245.5	51.3	11.9	0.6	0.9	0.45	1.70
25- 45	85.9	7.90	7.93	0.92	0.99	10.00	0.13	11.12	8.84	1.29	0.48	-	10.61	393.4	18.2	63.0	235.9	51.6	16.0	1.9	1.6	-	1.21
45- 80	55.3	7.78	7.62	1.15	0.74	11.47	0.12	12.33	7.75	4.08	0.62	-	12.45	336.4	21.1	78.9	213.6	39.5	23.4	1.4	6.9	-	0.52
80-125	59.1	7.86	7.97	2.02	1.09	19.04	0.16	20.29	5.89	5.00	1.30	8.0	20.19	360.8	19.7	108.6	191.3	46.2	30.0	1.0	12.5	-	0.26
D15: NDOHO																							
0- 10	36.0	6.13	6.90	0.41	2.09	1.02	0.92	4.03	3.22	0.58	0.69	-	4.47	157.6	17.7	8.1	102.0	19.8	5.1	-	2.9	2.75	2.61
10- 40	41.0	5.80	7.08	0.38	2.09	0.57	1.07	4.11	3.43	0.83	0.38	-	4.64	206.0	31.7	10.8	111.6	44.6	5.2	0.1	2.5	0.25	1.41
40- 80	44.3	6.22	7.47	0.39	1.29	0.86	1.34	3.49	3.16	-	0.62	-	3.78	251.2	54.0	7.0	130.7	66.1	2.7	0.1	2.7	-	0.88
80-110	46.9	6.84	7.15	0.35	0.99	1.10	1.42	3.51	2.18	0.58	0.38	-	3.14	277.1	72.3	6.5	143.4	69.1	2.3	0.1	3.6	-	0.68
110-140	44.0	6.94	8.45	0.70	1.24	2.63	2.65	6.52	1.96	4.29	0.58	-	6.83	250.2	84.6	4.8	124.3	53.8	1.9	0.4	6.4	-	0.41
D16: MUSABI 1																							
0- 5	19.20	6.07	7.80	0.48	0.70	3.31	0.23	4.24	3.90	0.80	0.60	-	5.30	106.4	0.9	6.4	81.2	-	6.0	-	4.7	0.65	1.37
5- 26	57.10	7.34	8.15	1.11	1.30	10.04	0.06	11.40	8.02	1.92	1.11	-	10.67	243.0	1.5	41.3	199.3	3.8	16.9	-	4.4	0.20	1.25
26- 72	47.60	7.95	8.52	2.20	1.80	18.47	0.09	20.36	7.65	9.75	1.62	1.5	20.52	258.6	1.7	64.6	212.1	18.3	24.9	0.5	4.2	-	0.72
72-120	47.80	7.96	8.34	1.43	0.70	12.65	0.06	13.41	5.24	4.12	1.57	2.0	12.93	226.0	1.9	64.8	196.8	-	28.6	0.7	5.5	-	0.48
>120	45.40	7.75	8.40	1.48	0.55	10.00	0.08	10.63	4.87	1.88	1.46	2.5	10.71	231.4	2.2	65.3	170.9	13.4	28.2	-	5.4	-	0.22
D17: MUSABI 2																							
0- 10	51.41	6.50	7.40	0.60	-	4.89	0.11	5.00	5.60	0.35	-	-	5.95	195.6	1.8	23.5	135.0	52.5	15.1	-	4.7	0.25	1.70
10- 25	102.78	7.70	8.13	0.92	0.75	8.03	0.07	8.85	6.68	-	0.45	-	7.13	339.7	3.8	65.9	244.3	43.2	19.3	0.3	3.8	0.05	1.22
25- 48	77.35	8.15	8.50	1.35	0.55	9.13	0.09	9.72	7.40	0.51	0.50	-	8.41	334.5	4.1	91.7	173.6	101.4	33.4	1.8	10.0	-	0.65
48-130	87.44	8.05	8.35	2.10	0.70	17.03	0.12	17.85	4.22	9.02	2.73	1.5	17.47	353.2	4.4	125.7	183.2	94.9	38.5	0.8	11.6	-	0.30
D18: MUSABI 3																							
0- 3	46.3	6.64	8.00	0.90	2.58	4.78	1.96	9.32	7.02	1.75	1.45	-	10.22	226.9	28.9	11.9	127.5	35.0	5.2	-	3.5	-	3.46
3- 30	49.4	6.47	8.07	0.57	0.59	5.47	0.22	6.28	4.80	1.25	1.01	-	7.06	208.1	4.8	6.2	140.3	40.9	2.9	-	3.1	0.05	1.30
30- 50	73.6	7.82	8.71	0.92	0.69	8.86	0.11	9.66	6.65	2.45	0.62	-	9.72	413.8	20.2	68.4	242.3	70.2	16.5	-	0.3	-	0.99
50- 75	59.6	7.73	8.65	1.18	0.89	10.95	0.15	11.99	4.69	4.50	0.58	2.5	12.27	378.5	23.8	60.3	229.5	58.0	15.9	0.5	0.4	-	0.77
75-115	54.8	7.50	8.30	1.86	1.99	16.43	0.23	18.65	3.82	6.16	0.67	8.0	18.65	354.0	23.1	64.6	226.4	57.9	18.2	-	0.5	-	0.60

Depth (cm)	SP (g/100g)	pH_p	pH_e	EC_e ($mS\ cm^{-1}$)	Ionic equivalents (mmol/l) $\frac{1}{2}Ca^{2+}$ + $\frac{1}{2}Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $\frac{1}{2}CO_3^{2-}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	Ionic equivalents (mmol/kg) CEC	K^+ exch.	Na^+ exch.	$\frac{1}{2}Ca^{2+}$ exch.	$\frac{1}{2}Mg^{2+}$ exch.	ESP	Lime (g/100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/100g)
D19: KIRAWIRA 1																							
5- 29	35.7	5.84	7.55	0.84	2.13	6.86	0.04	9.03	4.56	2.55	0.86	-	7.97	119.5	1.4	20.6	90.9	21.9	17.2	-	13.9	0.05	1.32
29- 55	52.0	7.67	8.26	2.00	4.36	17.46	0.06	21.88	5.03	13.07	3.16	-	21.26	217.3	3.0	39.0	193.7	50.0	17.9	1.5	10.8	0.05	0.52
D20: KIRAWIRA 2																							
0- 20	39.3	5.32	6.75	0.19	1.16	1.42	0.04	2.75	1.13	0.91	0.16	-	2.20	139.5	4.7	12.3	112.5	34.6	8.8	-	0.3	0.20	1.63
20- 35	53.3	5.19	6.85	0.19	1.13	0.82	0.06	2.00	1.06	0.73	0.16	-	1.95	163.0	4.7	23.0	131.2	15.7	14.1	-	0.2	0.05	1.01
35- 68	54.5	5.50	7.75	0.16	0.86	0.91	0.17	1.84	0.99	0.91	0.16	-	2.06	233.6	4.7	9.4	207.7		4.0	-	0.2	0.10	0.84
D21: KIRAWIRA 3																							
0- 30	31.6	5.66	7.75	0.45	0.66	4.36	0.02	5.04	1.28	2.01	1.50	-	4.79	119.5	0.6	16.7	106.2	12.3	13.9	-	0.2	0.15	1.03
30- 50	44.3	7.67	8.54	1.26	1.63	12.22	0.09	13.94	8.73	2.70	1.50	-	12.43	152.1	2.4	31.7	143.7	31.3	20.8	1.5	0.2	-	0.63
50- 75	45.7	7.86	8.35	2.98	4.86	22.59	0.21	27.66	3.66	24.09	3.16	-	30.91	167.6	4.1	45.9	168.7	20.3	27.3	1.5	0.2	-	0.42
75-100	47.1	7.87	8.15	3.50	4.76	28.82	0.19	33.77	2.70	23.62	3.83	2.5	32.65	151.3	4.0	48.1	125.0	22.8	31.7	0.5	0.4	-	0.36
100-115	46.6	7.76	8.10	3.50	3.73	30.13	0.13	33.99	2.66	16.88	5.49	3.0	28.03	222.8	4.0	53.1	168.7	31.3	23.8	1.0	0.5	-	0.36
D22: KIRAWIRA 4																							
0- 14	39.1	5.88	7.30	0.28	1.50	0.92	0.36	2.78	1.50	0.44	0.49	-	2.43	245.7	20.0	22.2	131.2	53.1	9.2	-	0.7	2.40	2.05
14- 35	38.7	5.52	7.10	0.23	1.00	1.00	0.32	2.32	0.89	0.68	0.99	0.2	2.56	251.6	17.9	27.1	100.0	50.0	10.7	-	0.8	0.15	1.03
35- 73	71.8	6.20	7.25	0.25	1.00	1.07	0.54	2.61	1.04	0.64	0.59	0.2	2.47	275.3	22.9	44.5	134.3	71.9	16.2	-	0.6	-	0.35
73- 91	66.8	7.04	7.25	0.20	0.90	1.43	0.40	2.73	1.72	0.60	0.39	0.2	2.91	295.1	24.8	41.8	168.7	78.1	14.1	-	0.6	-	0.25
91-110	89.7	7.21	7.66	0.30	0.75	1.83	0.16	2.74	1.82	0.56	0.24	-	2.62	301.6	24.8	28.8	184.3	75.0	9.5	-	0.5	-	0.22
110-140	50.6	7.07	7.15	0.34	0.75	2.29	0.23	3.27	2.50	0.48	0.54	-	3.52	285.3	22.4	35.8	178.1	81.2	12.5	-	0.8	-	0.12
D23: KIRAWIRA 5																							
0- 5	36.6	6.31	7.86	0.43	1.40	2.26	0.49	4.15	3.07	0.24	0.54	0.2	4.05	187.5	17.8	33.6	90.6	53.1	17.9	-	6.7	1.75	2.51
5- 20	71.1	6.81	7.90	0.43	0.70	3.91	0.13	4.74	3.54	0.76	0.29	-	4.59	282.0	21.2	57.0	134.3	96.9	20.2	-	2.0	0.15	1.20
20- 43	75.8	7.89	8.55	0.90	1.00	8.60	0.11	9.71	7.12	1.18	0.39	-	8.69	297.2	10.0	69.5	150.0	109.3	23.3	-	2.4	-	0.90
43- 69	66.6	8.06	8.40	1.02	1.00	9.39	0.15	10.54	7.54	1.52	0.49	-	9.55	313.5	21.2	83.1	143.7	100.0	26.5	-	3.7	-	0.40
69- 99	58.6	8.00	8.80	0.85	0.70	8.34	0.17	9.21	6.61	0.64	0.89	0.2	8.34	329.8	24.6	74.4	162.5	93.7	22.5	0.5	3.2	-	0.05
99-130	67.7	7.80	8.87	0.78	0.60	6.78	0.13	7.51	6.09	0.64	0.49	0.2	7.34	313.5	23.7	74.4	146.8	112.5	23.7	-	0.7	-	0.01
D24: KIRAWIRA 6																							
0- 5	30.2	6.53	8.10	0.76	3.48	2.78	1.65	7.91	5.94	1.16	1.30	-	8.40	135.5	16.0	11.9	95.6	23.1	8.7	-	1.2	1.35	2.40
5- 30	42.6	6.45	8.05	0.84	1.59	7.39	0.35	9.33	7.86	1.04	0.96	-	9.86	252.1	9.0	59.7	137.1	50.4	23.6	-	4.6	0.15	1.43
30- 60	62.0	7.78	8.60	1.45	2.09	13.04	0.12	15.25	9.60	1.25	4.83	-	15.68	261.8	11.2	34.9	200.8	55.4	13.3	1.2	1.9	-	0.91

Depth (cm)	SP (g/100g)	pH_p	pH_e	EC_e ($mS\,cm^{-1}$)	Ionic equivalents (mmol/l) $\frac{1}{2}Ca^{2+}$ + $\frac{1}{2}Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $\frac{1}{2}CO_3^{2-}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	(mmol/kg) CEC	K^+ exch.	Na^+ exch.	$\frac{1}{2}Ca^{2+}$ exch.	$\frac{1}{2}Mg^{2+}$ exch.	ESP	Lime (g/100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/100g)
D25: KIRAWIRA 7																							
0- 10	19.6	5.68	6.28	0.16	0.75	1.18	0.04	1.97	0.87	0.50	0.35	-	1.72	44.8	0.7	3.3	40.4	8.3	7.3	-	0.33	1.40	0.77
10- 20	20.2	5.60	7.50	0.65	1.00	5.56	0.11	6.67	3.81	1.53	1.25	-	6.59	73.6	0.9	15.3	56.3	6.9	20.7	0.12	2.36	0.05	0.81
20- 40	26.9	5.70	8.09	0.85	1.10	7.73	0.10	8.93	4.13	3.21	0.77	-	8.11	12.14	0.9	18.4	82.9	10.2	15.1	-	5.92	-	0.76
40- 80	35.3	7.83	7.26	2.05	3.20	18.26	0.11	21.57	3.92	13.95	2.32	-	20.19	208.4	2.4	42.3	146.6	27.3	20.2	1.05	2.55	-	0.30
80-120	47.3	7.86	7.27	1.88	1.98	16.00	0.08	18.06	2.63	9.33	3.22	3.0	18.18	24.10	2.6	48.3	75.3	20.4	20.0	0.66	2.77	-	0.18
D26: KIRAWIRA 8																							
0- 10	26.9	6.36	7.40	0.95	5.70	4.17	0.17	10.04	1.75	1.08	1.32	6.0	10.15	154.0	2.8	5.4	121.1	15.5	3.5	-	-	0.45	0.86
10- 20	28.9	6.63	7.60	1.15	7.80	3.91	0.12	11.83	3.60	1.33	1.67	4.5	11.10	164.9	1.4	3.8	137.1	18.2	2.3	-	3.77	0.20	0.71
20- 40	29.2	6.30	7.70	0.72	3.15	3.56	0.06	6.77	2.16	0.86	1.30	2.0	6.32	175.8	0.8	4.8	153.0	8.5	2.7	-	3.64	-	0.38
40- 80	30.6	6.83	8.02	0.65	1.65	5.30	0.04	6.99	4.27	0.83	0.52	1.0	6.62	186.6	1.0	14.6	153.0	11.6	7.8	-	3.44	-	0.18
80-120	41.4	7.80	7.84	0.92	1.50	7.91	0.04	9.45	4.33	1.12	2.12	1.0	8.57	230.1	1.5	33.6	172.1	14.2	14.6	0.89	3.32	-	0.17
D27: DUTWA 1																							
0- 20	25.2	6.15	-	2.70	2.40	13.97	0.56	16.93	6.34	3.48	8.49	-	18.36	78.6	5.2	21.3	43.7	6.3	30.1	-	16.7	0.15	2.31
20- 50	31.7	7.70	8.22	4.95	3.86	47.16	0.51	51.53	6.19	19.95	24.50	-	50.64	195.6	21.8	59.7	90.6	40.6	30.5	-	11.3	-	0.89
50- 80	60.1	7.88	8.31	6.50	3.40	52.40	0.58	56.38	5.09	30.96	28.66	-	64.71	239.1	26.6	111.1	126.7		46.4	0.5	11.7	-	0.40
80-100	54.6	7.88	8.32	9.20	5.06	95.65	0.66	101.37	3.43	62.24	31.90	1.0	98.57	271.7	28.0	136.1	105.4		50.0	-	10.0	-	0.39
D28: DUTWA 2																							
0- 20	27.3	7.68	8.38	0.72	4.50	2.35	0.22	7.07	4.20	0.91	2.16	-	7.27	160.0	5.2	54.5	121.3		34.0	-	-	0.45	0.89
20- 60	99.5	7.95	8.68	0.78	0.59	7.86	0.01	8.46	4.93	1.23	0.99	-	7.15	433.1	5.7	62.8	323.8		14.5	-	0.1	-	1.52
60-110	120.5	8.19	8.64	2.00	0.89	17.90	0.02	18.81	5.53	8.66	4.50	-	18.69	405.6	7.9	133.0	257.1		32.7	2.5	0.3	-	0.97
110-200	92.5	8.43	8.84	2.80	0.43	26.20	0.03	26.66	6.59	7.33	11.83	-	25.75	405.6	8.8	209.4	165.9		51.6	1.0	0.6	-	0.36
D29: DUTWA 3																							
0- 10	72.7	7.15	8.46	0.52	2.40	3.27	0.04	5.71	4.40	1.10	0.50	-	6.00	378.1	6.2	18.4	312.6		4.8	0.3	0.3	0.35	1.84
10- 40	80.3	7.69	8.53	0.64	0.99	5.24	0.04	6.27	4.63	1.05	0.16	-	5.84	378.1	6.9	31.9	299.3		8.4	0.3	0.5	0.05	1.01
40- 70	126.8	7.87	8.55	0.92	0.69	8.73	0.06	9.48	7.39	1.42	0.40	-	9.21	433.1	13.6	51.9	219.8		13.8	1.0	0.4	-	1.16
70-100	89.4	7.97	8.10	0.82	0.43	7.17	0.05	7.65	5.33	1.00	0.91	-	7.24	350.8	17.2	71.7	287.5		20.4	1.8	11.1	-	0.66
D30: SIMITI 1																							
4- 65	84.7	7.25	7.90	0.55	0.79	4.34	0.09	5.22	4.75	0.50	0.44	-	5.69	414.9	15.1	29.3	216.8	106.2	7.0	0.30	0.86	0.15	1.16
65-100	94.6	8.00	7.50	2.35	7.70	17.21	0.28	25.19	1.97	22.66	0.57	0.5	25.20	436.6	19.2	53.2	216.8	124.8	12.1	0.92	1.08	-	0.80
100-130	72.5	7.80	6.73	4.38	25.20	28.52	0.26	53.98	1.69	47.66	1.32	-	51.17	414.9	15.6	50.5	223.2	121.6	12.1	0.60	3.04	-	0.38

Depth (cm)	SP (g/100g)	pH_p	pH_e	EC_e ($mS\,cm^{-1}$)	Ionic equivalents (mmol/l) $\frac{1}{2}Ca^{2+}$ + $\frac{1}{2}Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $\frac{1}{2}CO_3^{2-}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	(mmol/kg) CEC	K^+ exch.	Na^+ exch.	$\frac{1}{2}Ca^{2+}$ exch.	$\frac{1}{2}Mg^{2+}$ exch.	ESP	Lime (g/100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/100g)
D31: SIMITI 2																							
0- 10	28.7	6.21	6.98	0.35	0.79	2.60	0.16	3.55	2.13	0.41	0.57	-	3.11	154.0	6.0	15.2	76.5	35.0	9.8	-	19.60	0.35	1.71
10- 30	66.0	6.57	7.53	0.70	1.20	5.56	0.08	6.84	3.28	1.00	2.07	-	6.35	294.3	6.2	30.9	165.8	76.4	10.4	-	8.51	0.10	1.17
30- 60	63.2	7.98	7.90	1.08	1.65	9.04	0.06	10.75	5.28	0.91	3.62	-	9.81	349.7	5.5	51.0	204.0	75.5	14.5	0.74	11.35	-	0.98
60- 80	55.6	7.80	7.89	1.53	2.40	11.13	0.25	13.78	4.38	1.41	3.97	3.0	12.76	349.7	12.0	50.0	194.5	81.9	14.2	1.61	21.94	-	0.45
80-120	63.7	7.63	8.52	1.17	1.80	9.73	0.16	11.69	4.38	1.00	1.50	6.0	12.88	317.1	13.6	42.9	216.8	65.8	13.5	1.24	24.67	-	0.26
D32: NDABAKA 1																							
0- 50	94.5	6.32	7.70	0.26	0.73	2.09	0.18	3.00	1.71	1.05	0.23	-	2.99	375.0	7.4	27.1	246.8	96.9	7.2	-	0.1	0.10	1.44
50- 80	110.3	7.02	7.79	0.32	0.66	2.62	0.10	3.38	2.10	1.14	0.23	-	3.47	467.3	11.0	39.7	290.6	75.0	8.4	-	-	-	1.12
>80	103.8	7.65	8.50	0.56	0.83	4.80	0.01	5.64	3.20	1.05	1.23	-	5.48	389.6	19.6	38.2	246.8	81.1	9.8	0.3	0.2	-	0.79
D33: NDABAKA 2																							
0- 10	52.9	6.50	8.37	0.77	1.56	6.11	0.09	7.76	3.86	1.14	2.16	-	7.16	227.3	14.6	26.2	150.0	52.9	11.5	-	0.1	0.75	1.91
10- 40	88.3	7.52	8.52	0.80	0.99	6.98	0.01	7.89	6.79	0.45	0.66	-	7.90	319.7	19.4	48.0	209.3	79.2	15.0	0.3	-	0.10	1.07
40- 55	87.5	7.95	7.97	1.00	0.93	8.95	0.01	9.89	5.79	1.28	2.50	0.2	9.82	368.8	21.5	61.3	187.5	118.7	16.6	1.5	-	0.05	0.93
>55	90.9	7.93	8.29	1.15	0.93	9.17	0.01	10.11	3.86	4.12	2.66	1.0	11.64	372.3	18.7	67.4	209.3	87.5	18.1	1.5	-	-	0.74
D34: BANAGI 3																							
0- 15	72.7	6.00	7.01	0.26	1.25	1.65	1.34	4.24	2.15	0.94	0.21	-	3.30	249.4	27.2	9.8	149.5	26.9	3.9	0.3	10.1	0.55	2.72
15- 45	74.3	7.49	8.09	1.15	1.30	8.69	0.14	10.13	7.60	2.13	0.85	-	10.58	336.4	19.8	59.4	260.0	26.6	17.6	0.5	4.0	0.10	1.10
45- 70	47.5	7.83	7.50	1.51	1.50	10.78	0.12	12.40	3.40	10.53	0.53	-	14.46	369.0	20.3	72.9	257.7	44.7	19.7	1.0	5.8	-	0.52
70-100	94.1	7.80	7.48	1.40	1.25	9.73	0.12	11.10	3.10	10.03	0.37	-	13.50	352.7	21.5	69.5	245.0	38.5	19.7	0.5	5.0	-	0.42
D35: BANAGI 4																							
0- 2	44.8	6.21	7.69	0.49	1.95	1.77	1.00	4.72	2.90	1.32	0.30	-	4.52	238.2	31.9	6.6	192.1	-	2.7	-	-	1.40	2.86
2- 15	57.7	6.65	7.76	0.49	0.80	2.95	0.20	3.95	2.10	1.22	1.06	-	4.38	298.3	25.5	26.0	200.4	51.6	8.7	-	3.8	0.20	1.66
15- 50	74.2	7.90	8.15	1.08	1.10	7.65	0.09	8.84	4.50	1.50	3.24	-	9.24	336.4	13.3	49.4	260.9	47.8	14.6	0.8	3.9	-	1.12
50- 70	87.5	7.84	8.10	1.00	0.70	7.21	0.05	7.69	4.30	1.19	2.33	-	7.82	341.8	12.6	71.1	254.5	47.9	20.8	1.8	3.8	-	0.62
70-100	66.5	7.94	7.65	1.50	0.90	10.26	0.14	11.30	4.20	1.44	2.65	2.5	10.79	340.7	13.1	73.4	232.3	51.2	21.5	0.8	4.0	-	0.36
>100	64.9	8.04	7.79	1.30	1.00	8.69	0.07	9.76	3.75	1.54	1.16	4.0	10.45	319.0	11.7	69.6	213.2	64.0	21.8	4.0	30.6	-	0.12
D36: BANAGI 5																							
0- 10	26.8	6.34	7.01	0.28	1.60	0.36	0.75	2.71	1.50	0.91	-	-	2.41	128.8	17.5	1.9	95.4	27.4	1.4	-	10.0	-	1.18
10- 30	30.2	6.28	6.89	0.31	1.45	0.60	0.62	2.67	1.00	0.88	0.90	-	2.78	123.3	15.8	1.2	95.4	11.7	0.9	-	7.8	-	0.92
30- 60	33.8	6.45	7.10	0.31	1.75	0.84	0.26	2.85	1.40	0.50	0.42	-	2.32	156.6	11.7	2.9	140.0	8.0	1.8	-	8.9	-	0.65
>60	41.5	6.95	7.58	0.50	3.61	1.08	0.16	4.85	2.20	0.62	0.21	2.0	5.03	183.8	9.3	2.9	184.5	17.1	1.5	0.3	8.6	-	0.53

Depth (cm)	SP (g/100g)	pH_p	pH_e	EC_e ($mS\ cm^{-1}$)	Ionic equivalents (mmol/l) $\frac{1}{2}Ca^{2+}$ + $\frac{1}{2}Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $\frac{1}{2}CO_3^{2-}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	(mmol/kg) CEC	K^+ exch.	Na^+ exch.	$\frac{1}{2}Ca^{2+}$ exch.	$\frac{1}{2}Mg^{2+}$ exch.	ESP	Lime (g/100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/100g)
D37: TOGORO 1																							
0- 20	33.42	5.52	7.20	0.31	1.85	0.52	1.07	3.43	2.18	0.34	0.50	-	3.02	98.2	2.6	3.6	106.2	-	3.6	-	4.3	0.70	1.66
20- 40	41.47	5.58	6.50	0.24	1.50	0.46	0.84	2.80	1.90	0.17	0.35	-	2.25	124.5	3.1	3.3	102.8	3.15	2.8	-	4.0	0.15	1.05
40- 84	41.41	5.65	7.50	0.35	1.85	0.97	0.81	3.63	2.40	-	0.40	-	2.80	162.5	4.6	3.8	141.4	33.6	2.4	-	4.6	-	0.66
84-134	50.05	6.50	7.19	0.23	0.80	1.13	0.43	2.36	2.20	-	0.40	-	2.60	228.2	6.0	4.3	183.2	32.4	2.4	-	4.1	-	0.40
D38: TOGORO 2																							
0- 10	60.53	5.85	7.57	0.40	2.60	0.48	0.78	3.86	1.90	0.17	1.16	-	3.23	302.4	5.8	2.5	247.5	71.2	0.8	-	3.6	1.85	1.72
10- 60	75.15	6.32	7.65	0.33	1.90	1.18	0.24	3.32	3.00	-	0.40	-	3.40	293.6	3.7	5.4	241.1	43.2	2.2	-	4.0	0.15	1.12
60- 80	61.76	7.57	7.74	0.34	1.75	1.34	0.10	3.19	2.20	-	0.30	-	2.50	309.7	18.7	16.3	302.2	10.3	5.0	-	4.2	-	0.91
80-120	58.42	7.78	8.08	0.37	2.05	1.34	0.08	3.47	1.80	0.85	0.30	0.7	3.65	315.2	2.6	5.9	276.4	79.8	2.2	4.8	32.8	-	0.90
D39: TOGORO 3																							
0- 20	28.8	6.30	7.24	0.33	1.69	0.67	0.65	3.01	2.44	0.74	0.19	-	3.37	152.9	14.3	17.6	96.0	17.4	11.5	-	3.8	.	1.40
20- 50	38.8	6.40	7.16	0.23	1.34	0.69	0.30	2.33	1.48	0.53	-	-	2.01	180.1	12.4	10.5	144.0	13.5	5.8	-	1.7	.	0.99
50- 85	37.9	6.45	7.26	0.29	1.89	0.79	0.06	2.74	0.85	0.80	0.19	1.0	2.84	207.3	4.7	16.0	179.3	22.3	7.7	-	5.5	.	0.74
D40: TOGORO 4																							
0- 30	27.8	5.80	7.00	0.23	1.19	0.35	0.59	2.13	1.48	0.70	-	-	2.18	125.0	9.5	6.2	82.9	19.4	4.9	-	0.4	.	1.48
30- 55	29.8	5.38	7.33	0.14	0.49	0.52	0.19	1.20	0.53	0.53	-	-	1.06	119.5	8.1	2.0	76.5	13.4	1.6	-	0.1	.	0.89
55- 80	27.8	5.27	7.56	0.25	0.44	1.56	0.29	2.29	0.42	0.28	1.88	-	2.58	117.6	7.8	7.8	76.5	13.4	6.6	-	0.5	.	0.57
80-100	35.4	5.82	7.57	0.27	0.49	1.80	0.26	2.55	0.63	0.99	0.64	-	2.26	169.2	9.0	13.8	121.6	10.7	8.1	-	0.6	.	0.42
D41: TOGORO 5																							
0- 20	58.0	7.20	7.99	0.90	2.49	7.82	0.13	10.44	7.80	0.74	0.64	-	9.18	309.7	6.6	30.4	248.7	45.8	9.8	1.2	0.7	.	1.76
20- 60	70.5	7.85	8.60	1.11	1.74	10.13	0.08	12.94	10.31	0.90	0.59	-	11.80	312.5	3.5	54.3	232.7	20.8	17.3	3.8	1.3	.	1.08
60-100	45.6	7.86	8.66	1.00	0.69	9.21	0.04	9.94	6.63	1.36	1.19	-	9.18	298.9	3.5	64.6	230.5	21.5	21.6	4.3	7.6	.	0.33
D42: BOLOLEDI 1																							
0- 5	31.3	6.62	7.50	0.46	2.80	0.67	1.69	5.16	4.58	-	0.87	-	5.45	100.5	14.6	-	68.7	18.8	0	-	1.7	3.60	1.41
5- 30	24.1	6.35	7.37	0.24	1.00	0.46	1.24	2.70	1.70	0.73	0.38	-	2.81	88.5	18.9	-	50.0	31.2	0	-	2.5	0.25	0.59
>30	27.8	6.06	7.16	0.29	1.80	0.86	0.71	3.37	1.91	0.90	0.38	-	3.19	102.1	15.8	-	59.3	28.2	0	-	1.4	0.15	0.62

Depth (cm)	SP (g/ 100g)	pH_p	pH_e	EC_e ($mS\,cm^{-1}$)	Ionic equivalents (mmol/l) $\frac{1}{2}Ca^{2+}$ + $\frac{1}{2}Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $\frac{1}{2}CO_3^{2-}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	(mmol/kg) CEC	K^+ exch.	Na^+ exch.	$\frac{1}{2}Ca^{2+}$ exch.	$\frac{1}{2}Mg^{2+}$ exch.	ESP	Lime (g/ 100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/ 100g)
D43: BOLOLEDI 2																							
0- 20	26.4	6.22	7.29	0.36	2.20	0.64	1.20	4.04	2.82	0.86	0.38	-	4.06	96.7	18.0	-	68.7	28.1	0	-	0.5	0.20	1.19
20- 30	29.4	6.16	7.24	0.26	1.40	0.60	0.90	2.60	1.91	0.69	0.29	-	2.89	93.2	19.3	1.2	78.1	9.4	1.2	-	1.3	-	0.80
30- 60	35.4	6.40	7.29	0.20	1.50	0.53	0.71	2.74	1.27	0.82	0.29	-	2.38	111.1	22.2	1.8	68.7	28.1	1.6	-	0.4	-	0.66
60-100	39.7	6.60	7.58	0.34	1.70	1.22	0.44	3.36	1.06	0.84	1.74	-	2.80	136.6	16.7	3.3	106.2	21.9	2.4	-	0.8	-	0.37
>100	43.1	7.09	7.87	0.27	1.80	1.06	0.19	3.05	1.17	0.69	0.43	-	2.29	148.6	12.8	5.0	125.0	31.2	3.3	-	3.7	-	0.35
D44: BOLOLEDI 3																							
0- 20	27.6	6.07	7.98	0.38	2.05	0.72	1.20	3.97	1.75	0.73	1.35	-	3.83	101.0	16.3	1.2	37.5	50.0	1.1	-	0.3	0.20	1.23
20- 40	27.1	5.79	7.86	0.23	1.40	0.58	0.61	2.59	1.43	0.34	0.33	-	2.10	95.6	15.6	2.3	53.1	40.6	2.4	-	0.2	0.10	0.81
40- 70	31.7	5.98	7.78	0.19	1.00	0.45	0.46	1.91	0.74	0.47	0.29	-	1.50	95.6	19.0	2.0	53.1	37.5	2.0	-	0.2	-	0.51
70-100	37.6	6.36	7.81	0.22	1.15	0.93	0.36	2.44	0.74	1.47	0.62	-	2.83	133.6	19.5	8.7	90.6	34.4	6.5	-	0.4	-	0.35
D45: BOLOLEDI 4																							
0- 13	25.0	6.02	8.90	0.29	1.60	1.13	0.70	3.43	1.38	0.97	0.58	-	2.93	146.5	16.2	2.1	68.7	56.3	1.4	-	0.5	0.15	1.23
13- 33	69.0	6.65	8.05	0.70	1.80	4.34	0.44	6.58	3.41	-	2.99	-	6.40	320.6	35.0	29.6	109.2	143.8	9.2	-	-	-	0.82
33- 56	63.0	8.03	8.55	0.80	1.60	5.39	0.39	7.38	4.26	-	0.96	2.0	7.22	293.4	31.3	30.1	137.5	131.2	10.2	0.7	0.8	-	0.50
56- 90	60.7	8.31	8.76	1.08	1.40	8.69	0.45	10.54	5.22	-	2.27	3.5	10.99	299.0	33.0	50.1	112.5	140.6	16.7	6.5	18.8	-	0.30
D46: RHINO 2																							
0- 15	40.7	6.00	7.49	0.54	3.95	0.44	1.11	5.50	3.75	1.46	1.07	-	6.28	141.7	10.3	-	115.6		0	0.5	3.7	1.45	2.50
15- 30	42.8	6.20	7.42	0.65	4.65	0.69	1.38	6.72	4.58	1.32	0.73	-	6.63	157.6	15.3	-	121.8		0	-	3.7	0.60	1.51
D47: RHINO 3 (termite ridge)																							
0- 5	36.8	5.92	7.24	0.43	3.10	0.81	0.40	4.31	2.08	1.46	0.58	1.0	5.12	163.5	5.7	2.2	131.2	25.0	1.34	-	3.7	1.10	1.47
5- 25	39.9	6.02	7.58	0.57	3.00	3.39	0.08	6.47	4.58	1.37	0.83	-	6.78	155.9	2.4	7.0	128.1	12.5	4.49	-	3.6	-	0.91
30- 50	46.8	6.37	7.95	0.56	2.30	4.08	0.05	6.43	4.27	1.78	0.68	-	6.73	205.6	2.7	11.0	181.2	31.3	5.35	-	3.9	-	0.63
57- 75	52.1	7.45	8.00	1.00	3.90	6.60	0.06	10.56	5.83	1.92	0.78	2.0	10.53	233.6	3.2	15.3	218.7	6.3	6.54	0.8	3.9	-	0.52
80- 95	52.1	7.51	8.15	1.25	5.50	7.65	0.08	13.23	7.50	2.47	0.78	1.5	12.28	244.5	3.7	17.0	221.8	21.9	6.95	1.3	32.7	-	0.63
D48: RHINO 4																							
0- 18	31.8	5.35	6.80	0.43	3.00	0.95	0.76	4.71	2.91	1.09	0.63	-	4.63	119.5	5.8	2.2	93.7	15.6	1.84	-	4.4	1.20	1.55
18- 56	52.1	5.65	7.34	0.45	1.65	2.78	0.27	4.70	2.91	1.05	0.34	-	4.30	189.8	8.1	8.0	137.5	46.8	4.21	-	4.2	-	0.73
56- 75	52.3	7.28	8.00	0.80	2.80	5.56	0.37	8.73	7.29	1.14	0.39	-	8.82	206.1	8.5	12.9	151.2	43.8	6.25	-	4.9	-	0.41

Depth (cm)	SP (g/100g)	pH_p	pH_e	EC_e ($mS\ cm^{-1}$)	Ionic equivalents (mmol/l): $\frac{1}{2}Ca^{2+}$ + $\frac{1}{2}Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $\frac{1}{2}CO_3^{2-}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	(mmol/kg): CEC	K^+ exch.	Na^+ exch.	$\frac{1}{2}Ca^{2+}$ exch.	$\frac{1}{2}Mg^{2+}$ exch.	ESP	Lime (g/100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/100g)
D49: RHINO 5																							
0- 18	23.0	6.75	7.78	0.40	2.20	0.51	1.19	3.90	2.91	1.14	0.34	-	4.39	45.8	4.7	2.3	46.8	6.3	5.0	-	5.0	0.90	0.77
18- 50	22.3	6.02	7.15	0.32	2.70	0.82	0.28	3.80	2.18	1.05	0.39	-	3.62	36.6	1.7	2.8	18.7	21.8	7.6	-	5.4	0.15	0.41
50- 80	22.9	5.49	5.72	0.21	1.85	0.57	0.09	2.51	1.19	0.50	0.19	-	1.83	37.5	1.2	1.3	25.0	12.5	3.4	-	6.7	-	0.37
D50: RHINO 6																							
0- 15	27.3	5.98	6.94	0.21	0.90	0.30	0.99	2.19	1.83	-	0.34	-	2.17	68.4	7.8	18.2	50.0	12.5	26.6	-	5.7	1.60	1.36
D51: RHINO 7																							
0- 10	29.1	6.04	7.60	0.52	3.00	2.17	0.20	5.37	3.33	1.22	0.68	-	5.23	97.2	3.8	2.6	90.6	21.9	5.4	-	3.6	0.45	1.32
10- 55	48.7	5.58	7.33	0.41	1.15	2.86	0.08	4.09	2.18	0.64	0.39	-	3.21	189.6	4.4	12.2	150.0	18.7	6.4	-	4.1	-	0.82
55- 75	44.9	7.35	8.18	0.82	2.05	6.52	0.10	8.67	7.85	0.60	0.58	-	9.03	182.2	4.9	16.6	156.2	25.0	9.1	-	3.9	-	0.47
75-100	50.0	7.57	8.30	0.79	1.50	7.39	-	8.89	6.09	0.85	0.53	-	7.47	214.8	5.6	24.2	171.8	9.4	11.2	1.2	4.5	-	0.36
>100	51.4	7.63	8.18	0.82	1.90	6.86	0.08	8.84	7.30	0.72	0.34	-	8.36	236.5	6.3	32.9	208.1	15.7	13.9	3.5	31.1	-	0.27
D52: MBALI PALI 2																							
0- 15	30.11	5.91	6.61	0.43	1.80	0.76	1.92	4.48	3.28	0.62	0.48	-	4.38	110.5	11.0	-	65.7	10.8	-	0.10	-	1.10	1.85
15- 30	29.84	5.40	7.48	0.41	1.24	1.53	1.23	4.00	2.00	0.41	1.38	-	3.79	105.1	14.1	6.5	70.1	10.6	6.1	0.07	0.46	0.20	1.12
30- 45	49.80	5.89	7.50	0.54	1.34	3.13	1.19	5.66	2.56	0.50	1.96	-	5.02	154.0	24.2	5.4	121.1	15.5	3.5	-	0.75	0.05	0.73
45- 60	47.91	6.73	7.80	0.84	2.28	5.21	1.19	8.68	4.93	0.25	2.62	-	7.80	219.2	25.2	12.5	146.6	27.3	5.7	-	0.41	-	0.59
60-100	51.94	7.85	8.34	0.78	1.80	5.04	0.96	7.80	4.23	0.37	2.51	-	7.11	224.7	26.1	18.4	184.9	26.3	8.1	1.20	-	-	0.40
D53: MBALI PALI 3																							
0- 15	50.4	6.89	7.82	0.75	4.62	1.47	1.15	7.24	5.37	0.41	1.05	-	6.83	230.1	20.4	3.2	159.4	23.8	1.3	0.10	0.95	1.05	1.17
15- 30	47.0	7.73	7.40	1.20	5.20	4.78	1.23	11.21	3.83	0.62	6.26	-	10.71	209.7	21.8	24.8	166.9	31.1	11.8	0.36	1.19	-	0.83
30- 45	43.0	7.84	7.63	1.36	5.16	6.60	1.65	13.41	3.83	0.66	5.82	3.0	13.31	204.3	22.1	18.9	173.2	24.8	9.2	0.42	-	-	0.73
45- 60	51.9	7.64	7.35	1.60	6.90	7.30	1.69	15.89	3.28	1.29	3.52	6.0	14.09	242.3	25.2	30.3	185.8	36.9	12.5	0.24	-	-	0.65
60-100	56.0	7.46	7.90	2.40	11.77	9.39	2.15	23.31	2.52	2.08	2.69	6.0	23.29	242.3	24.2	28.1	173.2	37.1	11.5	0.48	-	-	0.58
D54: MBALI PALI 4																							
0- 25	39.8	5.24	5.90	0.40	2.65	2.01	0.18	4.84	3.50	0.50	0.48	-	4.48	136.1	3.3	8.5	94.5	26.4	6.2	-	0.35	0.80	2.69
25- 45	62.7	5.57	7.24	0.37	1.24	2.55	0.12	3.91	3.12	-	0.39	-	3.51	217.6	4.5	11.3	173.2	25.2	5.1	-	1.09	-	0.99
45- 85	54.1	7.22	8.18	0.80	2.35	5.34	0.31	8.00	7.01	0.16	0.30	-	7.91	236.6	5.7	6.4	179.5	43.7	2.7	0.45	3.02	-	0.60
85-100	47.1	7.56	7.63	0.65	1.30	5.61	0.15	7.06	3.83	0.83	0.35	1.5	6.51	190.4	4.5	16.7	160.6	31.6	8.7	0.11	17.54	-	0.13
D55: LAMAI 1																							
0- 15	38.9	5.87	7.38	0.32	2.20	0.73	0.50	3.43	2.64	0.29	0.30	-	3.23	130.7	8.4	8.0	66.1	30.0	6.1	-	8.93	1.20	1.89

Depth (cm)	SP (g/ 100g)	pH_p	pH_e	EC_e ($mS\,cm^{-1}$)	Ionic equivalents (mmol/l) $\frac{1}{2}Ca^{2+}$ + $\frac{1}{2}Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $\frac{1}{2}CO_3^{2-}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	(mmol/kg) CEC	K^+ exch.	Na^+ exch.	$\frac{1}{2}Ca^{2+}$ exch.	$\frac{1}{2}Mg^{2+}$ exch.	ESP	Lime (g/ 100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/ 100g)
D56: LAMAI 2																							
0- 5	53.1	6.36	7.79	0.45	1.55	2.76	0.40	4.71	3.28	0.62	0.35	-	4.25	223.0	11.3	17.8	129.1	38.3	7.9	0.28	7.97	0.05	3.28
5- 20	71.2	5.90	7.61	0.51	1.09	4.08	0.16	5.33	4.50	0.33	0.57	-	5.40	304.6	12.0	37.3	192.1	59.0	12.2	-	2.11	-	2.29
20- 50	92.2	7.25	8.00	0.82	1.40	6.95	0.15	8.50	7.70	0.50	0.30	-	8.50	407.8	15.1	36.8	267.7	82.7	9.0	0.13	2.51	-	1.69
50- 85	103.7	8.01	7.95	0.51	0.50	4.39	0.12	5.01	4.24	0.50	0.22	-	4.96	440.4	25.9	61.3	311.8	53.7	13.9	17.97	54.4	-	0.22
D57: SRI-1																							
0- 9	34.8	6.40	7.00	0.60	4.55	0.34	1.23	6.12	4.85	-	0.95	-	5.80	166.3	19.5	15.7	118.1	28.1	9.4	-	13.3	0.85	1.61
9- 30	61.0	6.08	7.48	0.31	1.85	0.30	1.46	3.61	2.98	-	0.20	-	3.18	172.8	19.8	10.8	137.5	18.7	6.2	0.7	12.1	0.10	1.15
30- 80	49.2	6.57	7.59	0.24	1.60	0.42	0.07	2.09	2.32	-	0.20	-	2.52	217.3	5.8	30.9	156.8	40.7	14.2	-	10.9	0.05	0.78
D58: SRI-2																							
0- 9	36.5	7.02	8.49	0.90	0.80	5.82	0.16	6.78	5.06	-	2.50	-	7.56	213.2	5.6	62.4	120.6	46.2	29.2	-	15.0	0.15	1.08
9- 19	63.1	8.00	8.69	1.03	0.90	7.91	0.06	8.89	8.52	-	1.55	-	10.07	256.1	4.1	70.1	177.5	37.5	27.3	0.7	7.2	0.10	0.85
10- 33	64.6	8.20	8.85	1.40	1.00	11.47	0.07	12.54	8.16	3.75	2.15	-	14.06	275.7	5.8	78.8	183.7	43.8	28.5	2.5	5.1	-	0.65
33- 80	58.3	8.13	8.89	1.63	1.30	15.30	0.10	16.70	8.57	5.42	2.88	-	16.87	292.0	9.2	92.3	177.5	56.2	31.6	1.5	6.9	-	0.46
>80	55.7	8.05	8.59	2.03	1.00	16.34	0.11	17.45	5.78	7.78	4.95	-	18.51	313.2	13.0	117.1	171.2	62.5	37.3	1.2	21.1	-	0.17
D59: SRI-3																							
0- 6	48.9	6.66	7.73	0.60	1.68	3.91	0.53	5.63	5.63	-	0.58	-	6.21	235.8	3.1	14.1	134.2	93.9	5.9	-	4.2	2.15	2.13
6- 42	79.1	6.88	7.65	0.60	1.47	5.02	0.06	6.55	5.78	-	0.50	-	6.28	301.0	1.6	20.6	207.4	78.5	6.8	-	5.0	0.25	0.95
42- 67	79.4	7.75	7.75	0.83	1.64	8.00	0.03	9.67	7.69	-	0.38	-	8.07	306.5	0.9	39.1	244.0	68.5	12.7	0.5	6.0	-	0.81
67- 87	71.8	7.90	7.90	0.90	1.00	8.86	0.03	9.89	5.86	3.24	0.38	-	9.48	317.3	1.1	50.5	225.7	93.0	15.9	2.5	6.5	-	0.56
>87	58.5	7.90	7.90	0.80	0.69	8.17	0.03	8.89	5.33	2.49	0.38	-	8.20	295.6	1.0	45.6	201.3	98.7	15.4	2.2	14.5	-	0.40
D60: LARALE 1																							
0- 15	41.8	6.76	7.73	0.58	3.70	1.33	1.70	6.73	5.49	-	0.62	-	6.11	229.7	7.3	12.8	152.5	38.1	5.5	-	1.0	2.60	1.19
15- 50	39.0	7.33	8.28	0.45	2.83	1.69	1.03	5.55	4.21	0.51	0.58	-	5.30	240.6	6.4	13.9	164.7	41.5	5.7	0.3	2.1	0.25	0.62
50- 90	43.6	8.06	8.54	0.39	1.14	2.11	1.42	4.67	3.41	0.34	0.38	-	4.13	229.7	11.4	18.8	173.8	57.4	8.1	4.0	1.6	0.15	0.41
90-100	41.7	8.88	9.17	1.56	2.13	10.78	3.00	15.91	10.82	2.02	2.75	-	15.59	251.5	25.2	91.0	85.4	27.1	36.1	8.5	3.2	-	0.20
100-135	39.6	9.52	9.74	2.64	2.73	26.26	4.00	32.99	21.89	4.50	2.37	0.5	29.26	261.4	28.1	137.5	62.3	6.4	52.6	9.0	18.7	-	0.10
D61: LARALE 2																							
0- 14	43.8	7.34	8.47	0.82	1.10	7.30	0.35	8.75	6.92	-	1.25		8.17	294.0	5.7	20.6	222.6	27.4	7.0	0.3	0.7	3.05	1.16
14- 30	71.6	8.41	8.68	1.00	0.90	11.21	0.70	12.81	8.67	1.24	2.08		11.99	315.7	3.8	132.6	186.0	32.7	12.5	10.7	0.6	0.25	0.70
30- 70	55.8	9.30	9.41	5.12	0.99	51.30	0.55	52.84	15.67	18.60	15.29		49.56	294.0	3.7	282.6	71.8	21.9	>6.5	17.5	1.7	-	0.35
70-100	64.1	9.80	9.99	13.40	0.44	44.34	0.52	145.30	42.77	81.98	21.53	0.5	46.60	275.0	5.1	332.8	57.9	1.4	>7.5	22.5	1.0	-	0.08
>100	75.8	9.90	9.97	13.40	0.34	28.69	0.68	129.71	34.15	75.96	21.53	2.0	33.64	329.3	18.8	393.9	50.0	15.6	>7.5	9.2	0.9	-	0.03

Depth (cm)	SP (g/100g)	pH_p	pH_e	EC_e ($mS\ cm^{-1}$)	Ionic equivalents (mmol/l)									(mmol/kg)					ESP	Lime (g/100g)	Fraction >1.7 mm (g/100g)	Roots (g/kg)	C (g/100g)
					$\frac{1}{2}Ca^{2+}$ + $\frac{1}{2}Mg^{2+}$	Na^+	K^+	Σ cations	HCO_3^- + $\frac{1}{2}CO_3^{2-}$	$\frac{1}{2}SO_4^{2-}$	Cl^-	NO_3^-	Σ anions	CEC	K^+ exch.	Na^+ exch.	$\frac{1}{2}Ca^{2+}$ exch.	$\frac{1}{2}Mg^{2+}$ exch.					
D62: LARALE 3																							
0- 20	46.4	6.80	8.03	0.68	4.22	2.43	0.96	7.61	6.28	-	1.06	-	7.34	215.2	5.7	14.1	140.3	53.4	6.5	-	3.4	1.30	0.98
20- 50	53.0	7.48	8.44	0.46	1.40	3.04	0.41	4.85	3.78	-	0.48	-	4.26	264.1	5.3	21.7	210.4	22.7	8.2	-	2.5	0.10	0.58
D63: SIMIYU																							
0- 12	44.9	6.12	7.48	0.47	2.78	1.21	1.19	5.18	3.74	0.66	0.54	-	4.94	234.5	31.1	19.2	150.4	44.9	8.1	-	0.7	1.75	2.39
12- 25	48.0	5.82	7.35	0.43	1.84	2.00	0.61	4.45	3.27	0.70	0.49	-	4.46	229.0	28.7	17.1	169.6	28.8	7.4	-	0.4	0.25	1.51
25- 55	74.6	6.80	7.86	0.55	1.09	4.04	0.96	6.09	4.21	0.83	0.99	-	6.03	386.6	35.2	56.2	214.5	91.0	14.5	-	0.1	-	0.96
55- 85	72.7	7.90	7.80	1.60	0.84	13.04	0.27	14.15	4.95	1.79	8.17	-	14.91	408.4	37.6	136.9	185.7	66.3	33.5	0.5	0.6	-	0.76
85-110	70.0	7.89	7.40	3.25	1.99	27.39	0.41	29.79	4.11	7.83	19.13	-	31.07	442.7	37.9	116.5	204.9	66.0	26.3	0.4	1.4	-	0.67
110-130	53.1	7.65	7.93	6.50	7.12	55.04	0.18	62.24	3.05	20.04	42.05	-	65.16	321.4	40.0	124.5	135.4	58.8	38.7	0.4	2.1	-	0.40

APPENDIX E. VARIATIONS IN SOIL MOISTURE FOR 9 SOILS IN THE SERENGETI WOODLANDS

A: total moisture (mm)
B: loss of moisture (mm)
C: rainfall (mm)
D: evapotranspiration + run off (mm)
E: rainfall intensity of relatively high-intensity showers > 8 mm/h (given in mm/min)

1975

	May		June			July			August				September			October		November			December								
	5	13 24	2 4	11	18	6	7 15	25	30 1	2 11	18	30 31	15	24	29 30		7 19		2 12	19	29 2		5 7	8 9	10 11	13	14 15	17 18 20	21 30
SRI-1																													
A147								133												118									
B	2	-	3	8	6	4	-2	-7	5	2	2	-	-4	4	-1	1	3	1	1	1	1	-15	-4	-7	5	-2	-1	2	21
C	15	23	15	-	-	2	7	21	5	7	-	11	25	3	13	2	6	13	-	-	2	23	10	13	-	10	9	12	1
D	17	23	18	8	6	6	5	14	10	9	2	11	21	7	12	3	9	14	1	1	3	8	6	6	5	8	8	14	22
SRI-2																													
A195								198												188									
B	-3	4	-4	2	1	3	-2	-4	5	-	-	-	-2	2	-2	2	3	-1	2	1	-1	-11	-4	-7	7	-4	2	-1	15
C	15	23	15	-	-	2	7	21	5	7	1	11	25	3	13	2	6	13	-	-	2	23	10	13	-	10	9	12	1
D	12	27	11	2	1	5	5	17	10	7	1	11	23	5	11	4	9	12	2	1	1	12	6	6	7	6	11	11	16
E	9	17	10					10					17		8							8		6		7	6	8	
	15	15	30					60					30		60							60		15		15	15	15	

1976

	January				February						March						April					May			June				July			
	4	5 11	12 20	25 27	28 7	11	13	17	18 21	27 28	3	4	8	14	18 23	28 29	3	9	17		23 27	29 7	17	22	2	14	21	22	1	11	12	21
SRI-1																																
A		160						178													134											
B	-8	-34	31	8	2	-1	-6	-52	7	27	-	-12	15	7	1	-10	10	-	-17	14	2	7	-	-2	-3	3	3	-38	24	-32	4	19
C	20	75	2	-	5	3	17	61	21	2	18	51	3	-	13	42	5	17	56	3	17	3	24	9	28	37	-	47	-	74	2	1
D	12	41	33	8	7	2	11	9	28	29	18	39	18	7	14	32	15	17	39	17	19	10	24	7	25	40	3	9	24	42	6	20
SRI-2																																
A		210						214													198											
B	-6	-12	16	4		-	-6	-18	3	12	-1	-3	8	2	-1	-4	2	-	-13	12	-1	6	-	-3	-3	-4	8	-12	10	-12	-	11
C	20	75	2	-		8	17	61	21	2	18	51	3	-	13	42	5	17	56	3	17	3	24	9	28	37	-	47	-	74	2	1
D	14	63	18	4		8	11	43	24	14	17	48	11	2	12	38	7	17	43	15	16	9	24	6	25	33	-	35	10	62	2	12
E	16	24 34				9	8 9	12 13	13		16	48				35		7 11	15	8 10	6	8	16	12	15	15 15		35 12		50 15		
		+				+		+ +											+ +			+		+		+		+		+		
	30	60 30				15	60 15	60 60	15		60	30				30		30 30	15	30 30	15	30	60	30	30	60 60		60 60		30 15		

	June	July	August		Sept.	November		December						January				February			March						April					May			June	July		
	1975													1976																								
	4	7	21	30	30	2	20	8	10	14	17	20	30	5	12	20	28	11	18	27	3	8	14	18	23	28	3	9	17	23	29	7	17	22	2	14	21	1
Mukoma 1																																						
A208										236													175														180	
B	15	-15	25	-25	28	8	-60	4	-4	-4	16	33	4	-44	28	15	-5	-34	32	5	2	-	9	-11	-1	7	-	-18	11	8	-	-5	-17	1	15	1	4	
C	6	49	23	99	51	-	76	1	33	33	-	1	15	57	-	-	34	68	3	70	-	4	-	17	12	12	4	77	8	6	25	6	20	18	23	23	9	
D	21	34	48	74	79	8	16	5	29	29	16	34	19	13	28	15	29	34	35	75	2	4	9	6	11	19	4	59	19	14	25	1	3	19	38	24	13	
Mukoma 2																																						
A209										248													192														192	
B	12	-13	10	-13	13	4	-41	4	-15	-	10	33	3	-27	22	7	-1	-48	31	9	11	-2	8	-	-7	2	-1	-13	10	4	1	-3		-7		8	6	
C	6	49	23	99	51	-	76	1	33	33	-	1	15	57	-	-	34	68	3	70	-	4	-	17	12	12	4	77	8	6	25	15		38		46	9	
D	18	36	33	86	64	4	35	5	18	33	10	34	18	30	22	7	33	20	34	79	11	2	8	17	5	14	3	64	18	10	26	12		31		54	15	
Mukoma 3																																						
A223										251													196														197	
B	17	-24	25	-26	23	3	-40	1	-6	-1	7	32	1	-22	17	12	-2	-31	25	8	2	3	3	-7	-			-12	11	3	3	-3	-8	-	5	2	5	
C	6	49	23	99	51	-	76	1	33	33	-	1	15	57	-	-	34	68	3	70	-	4	-	17	12			93	8	6	25	15	20	18	23	23	9	
D	23	25	48	73	74	3	36	2	27	32	7	33	16	35	17	12	32	37	28	78	2	7	3	10	12			81	19	9	28	12	12	18	28	25	14	

	May	June	July		Aug.	Sept.	November		December						January				February			March						April					May			June		
	1975														1976																							
	5	4	6	30	30	24	2	24	8	10	14	17	21	30	5	12	14	27	11	18	27	3	8	14	18	23	28	3	9	17	23	29	7	17	27	2	14	21
Nyara Swiga 2																																						
A110														123											106												108	
B	-2	11	-5	-9	4	6	4	-52	4	-3	-10	17	26	-4	-18	30	7	-1	-55	29	6	-17	26	9	1	-27	22	-10	9	4	3	2	-3	-18	-3	14	4	
C	53	15	22	22	78	33	5	69	-	21	19	1	-	20	56	-	-	14	75	13	10	40	-	2	7	43	-	18	14	3	-	1	14	24	32	8	5	
D	51	26	17	13	82	39	9	17	4	18	9	18	26	16	38	30	7	13	20	42	16	23	26	11	8	16	22	8	23	7	3	3	11	6	29	22	9	
Nyara Swiga 3																																						
A140														142											137												137	
B	-4	7	-4	2	-18	20	3	-20	5	-3	-5	10	7	-2	-6	9	4	-1	-12	6	-	-5	9	1	-	-7	5	-1	-1	5	2	1	-2	-8	4	-2	4	
C	53	15	22	22	78	33	5	69	-	21	19	1	-	20	56	-	-	14	75	13	10	40	-	2	7	43	-	18	14	3	-	1	14	24	32	8	5	
D	49	22	18	24	60	53	8	49	5	18	14	11	7	18	50	9	4	13	63	19	10	35	9	3	7	36	5	17	13	8	2	2	12	16	36	6	9	

1975														
	May	June	July		Aug.	Sept.	November		December					
	3	2	6	30	30	29	2	29	8	10	14	17	21	30
Banagi 4														
A170											193			
B		-8	9	2	3	-11	-	12	-26	7	-11	4	6	13
C		71	13	23	13	79	25	-	63	3	16	-	-	-
D		63	22	25	16	68	25	12	37	10	5	4	6	13
Banagi 5														
A62											72			
B		-5	7	-4	4	-5	2	4	-16	1	2	1	5	4
C		71	13	23	13	79	25	-	63	3	16	-	-	-
D		66	20	19	17	74	27	4	47	4	18	1	5	4

1976																									
	January				February			March						April					May			June			July
	5	12	10	27	11	18	27	3	8	14	18	23	28	3	9	17	23	29	7	12	22	2	14	21	11
Banagi 4																									
A170									182																174
B	1	-22	8	12	1	-22	7	4	-1	6	-	-2	-2	3	-2	2	-2		9	2	-14	-	6	1	1
C	2	50	2	1	13	100	10	16	13	3	-	13	31	10	12	7	-		10	14	72	23	10	9	25
D	3	28	10	13	14	78	17	20	12	9	-	11	29	13	10	9	-		19	16	58	23	16	10	26
Banagi 5																									
A62									68																63
B	-	-12	10	4	-1	-13	8	1	-3	6	1	-2	-1	2	-2	2	3	-1	2	-1	-7	2	3	1	-3
C	2	50	2	1	13	100	10	16	13	3	-	13	31	10	12	7	-	10	-	14	72	23	10	9	25
D	2	38	12	5	12	87	18	17	10	9	1	11	30	12	10	9	3	9	2	13	65	25	13	10	22

	Maximum moisture content (mm)	Minimum moisture content (mm)	Moisture storage (mm)	Total moisture (mm)	Evapo-transpiration (mm/d)
SRI-1 (1975)	180 (0-105 cm)	115	65		
SRI-1 (1976)				< 125	< 1
				125-135	± 1
				135-145	1.5-3.5
				145-165	3.5-4
				165-175	4 -5
SRI-2 (1975)	215 (0-105 cm)	185	30		
SRI-2 (1976)				< 190	< 1
				190-200	± 2
				200-210	± 2.5
				210-215	± 3
Mukoma 1	240 (0- 95 cm)	175	65		
Mukoma 2	250 (0- 95 cm)	195	55		
Mukoma 3	250 (0- 95 cm)	195	55		
Nyara Swiga 2	165 (0- 85 cm)	100	65		
Nyara Swiga 3	160 (0- 85 cm)	135	25		
Banagi 4	195 (0- 75 cm)	165	30		
Banagi 5	75 (0- 65 cm)	60	15		

APPENDIX F. CHEMICAL COMPOSITION SOILS OF THE SERENGETI WOODLANDS (g/100g). Only the non-clay data are

Sample number	Site	Depth (cm)	Total fine earth													Non-clay		
			SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	SiO_2	Al_2O_3	Fe_2O_3
166	Togoro 1	0- 20	75.3	10.5	3.4	0.2	0.1	0.5	2.3	0.6	2.0	0.8	0.3	0.1	2.2	82.2	82.4	1.8
167		20- 40	72.3	11.7	4.2	0.2	0.1	0.6	2.2	0.6	2.2	0.8	0.4	0.1	3.2	81.9	8.3	1.7
168		40- 84	66.7	14.7	6.1	0.2	0.1	1.0	2.2	0.4	2.4	1.0	0.4	0.1	4.9	82.6	7.8	1.4
169		84-135	62.7	15.3	6.9	0.1	0.2	1.4	2.8	0.4	2.4	1.0	0.7	0.1	6.0	68.3	12.5	5.1
170	Rhino 7	0- 10	81.6	8.7	1.3	0.1	-	0.2	0.7	0.4	4.6	0.3	0.1	0.1	1.5	86.7	6.9	0.1
171		10- 55	76.0	10.1	2.8	0.1	-	0.5	1.0	0.3	3.7	0.3	-	0.1	4.1	88.8	5.8	-
172		55- 75	75.5	10.8	3.1	0.2	-	0.4	0.8	0.8	3.7	0.4	-	0.1	4.7	85.9	6.4	0.3
173		75-100	72.8	11.3	3.6	0.1	0.1	0.6	1.9	0.9	3.7	0.6	0.1	0.1	5.3	83.9	6.6	0.2
174		100-150	68.8	11.8	3.7	0.2	0.1	0.7	3.5	0.8	3.6	0.5	0.1	0.1	7.4	78.4	6.9	-
175	Mukoma 3	0- 10	62.0	12.5	6.7	0.2	0.1	1.1	2.0	0.3	2.2	1.3	0.3	0.2	9.8	84.1	3.3	2.1
176		10- 30	61.7	13.1	6.8	0.3	0.2	1.3	3.3	0.3	2.1	1.3	0.3	0.2	11.1	83.8	3.9	1.2
177		30- 60	61.3	13.5	7.2	0.2	0.2	1.4	3.5	0.3	2.2	1.4	0.4	0.2	9.8	81.5	3.8	2.7
178		60- 80	58.9	14.0	7.4	0.1	0.2	1.6	2.8	0.4	2.3	1.5	0.4	0.2	11.1	73.8	6.3	2.8
179		80-100	57.8	13.8	7.5	0.1	0.2	1.6	2.6	0.6	2.5	1.5	0.4	0.2	11.6	68.6	7.1	4.2
180		100-120	59.2	14.0	7.5	0.1	0.3	1.6	3.5	0.8	2.5	1.6	0.4	0.2	7.6	65.7	9.3	4.6
181		120-150	55.7	13.5	7.5	0.2	0.3	1.4	5.2	0.8	2.4	1.6	0.5	0.2	8.5	n.d	n.d	n.d
182		150-160	60.0	14.5	7.5	0.3	0.3	1.3	3.1	0.8	2.6	1.6	0.5	0.2	7.3	63.5	13.0	6.7
183	Bololedi 2	0- 20	74.4	12.3	3.3	0.3	0.1	0.1	1.3	1.1	5.6	0.6	0.2	0.1	2.5	82.3	9.3	1.1
184		20- 30	72.9	13.2	3.4	0.3	0.1	0.1	1.2	1.0	5.3	0.6	0.2	0.1	2.7	84.1	8.6	-
185		30- 60	69.1	14.1	4.0	0.3	0.1	0.1	1.1	0.9	5.0	0.6	0.2	0.1	4.4	81.9	7.9	0.3
186		60-100	67.0	16.6	5.4	0.2	0.1	0.1	1.2	0.8	4.5	0.8	0.1	0.1	4.8	82.0	10.2	1.3
187	Dutwa 1	0- 20	86.6	6.0	2.3	0.1	0.1	0.1	0.6	0.6	1.3	0.4	0.1	0.1	1.8	44.3	2.6	0.8
188		20- 40	82.1	7.9	3.2	0.2	-	-	0.6	0.6	1.3	0.4	0.1	0.1	2.8	102.5	-1.8	0.2
189		40- 80	71.9	11.7	4.9	0.2	0.1	0.1	1.0	0.9	1.8	0.9	0.1	0.1	5.4	85.0	4.0	3.6
190		80-100	69.8	11.2	5.7	0.1	0.1	0.1	2.1	-	2.2	0.9	0.3	0.1	7.4	87.7	1.3	2.2
191	SRI-2	0- 9	70.8	12.9	4.6	0.3	0.1	0.1	2.7	1.0	2.3	1.1	0.3	0.1	3.5	82.3	8.1	1.8
192		9- 19	69.5	14.6	4.9	0.2	0.1	0.1	0.8	0.9	2.1	0.6	0.1	0.1	4.3	84.3	9.0	1.2
193		19- 33	67.9	12.3	4.7	0.2	0.1	0.1	3.8	1.2	2.2	1.3	0.3	0.1	6.8	82.9	3.8	1.0
194		>80	62.4	14.6	6.2	0.2	0.2	0.2	3.3	1.4	2.6	1.3	0.3	0.2	6.6	71.3	10.2	3.7
195	SRI-1	0- 9	69.8	12.0	3.7	0.4	0.1	0.1	3.0	1.6	3.1	1.2	0.6	0.1	6.5	78.9	9.3	2.3
196		9- 30	65.3	13.6	4.4	0.4	0.1	0.1	2.8	1.4	3.2	1.2	0.6	0.2	6.2	76.2	9.3	2.2
197		30- 80	62.0	16.2	5.6	0.2	0.1	0.1	3.0	1.3	2.8	1.2	0.5	0.2	7.1	75.4	9.5	2.3
198	Musabi 1	0- 5	81.9	8.4	2.2	0.2	0.1	0.4	1.3	1.5	2.6	0.6	0.1	0.1	3.5	89.6	6.7	0.8
199		5- 26	69.2	12.7	5.1	0.1	0.1	1.1	1.5	1.2	2.7	0.7	0.2	0.1	6.6	85.3	7.8	1.5
200		26- 72	70.5	12.3	4.9	0.2	0.1	1.2	2.0	1.3	2.8	0.9	0.2	0.1	5.7	80.9	9.2	2.5
201		72-120	69.4	12.0	4.1	0.2	0.1	1.2	1.9	1.3	2.7	1.0	0.2	0.1	5.5	76.9	8.8	2.5
202	SRI-3	0- 6	70.1	9.8	4.1	0.3	0.2	0.7	2.2	1.0	2.3	1.2	0.4	0.1	7.8	83.3	6.0	1.9
203		6- 32	65.5	13.5	5.9	0.2	0.1	1.2	2.1	0.9	2.3	1.0	0.3	0.2	7.6	87.6	4.3	0.6
204		32- 42	67.2	13.3	5.1	0.9	0.2	1.2	2.0	1.0	2.3	0.9	0.3	0.2	7.1	88.9	5.8	-
205		42- 67	66.3	13.0	5.8	0.2	0.2	1.2	3.0	1.0	2.2	1.2	0.3	0.2	7.4	84.9	5.3	1.7
206		67- 87	64.1	12.9	5.8	0.2	0.2	1.3	4.2	1.0	2.3	1.2	0.4	0.2	7.8	79.3	5.9	1.8
207		87-104	64.5	12.8	5.8	0.2	0.2	1.4	4.1	1.0	2.3	1.5	0.3	0.2	7.3	74.9	7.7	2.9
208	Mukoma 1	0- 15	74.7	9.4	3.2	0.3	0.1	0.5	2.1	1.4	2.4	1.1	0.5	0.1	4.1	83.0	7.2	1.7
209		15- 30	65.4	13.2	5.4	0.4	0.1	0.9	3.1	1.3	2.4	1.2	0.4	0.2	7.3	82.6	6.9	1.3
210		30- 45	62.7	12.0	5.0	0.4	0.1	1.1	4.8	1.3	2.2	1.6	0.4	0.2	7.8	75.1	5.4	1.1
211		45- 60	63.3	13.8	6.0	0.4	0.2	1.3	3.5	1.5	2.3	1.3	0.3	0.2	7.2	77.3	7.0	2.0
212		60- 90	65.4	12.8	5.5	0.3	0.2	1.1	3.2	1.5	2.2	1.3	0.3	0.2	6.3	71.6	9.5	3.7
213		90-120	63.5	14.2	6.0	0.6	0.2	1.2	2.5	1.5	2.3	1.4	0.3	0.2	6.7	69.1	11.3	4.3
214		120-150	64.3	13.9	6.3	0.4	0.2	1.1	2.3	1.5	2.3	1.5	0.6	0.2	6.3	67.1	12.8	5.6
215	Nyara Swiga 2	0- 19	67.5	10.2	7.2	1.1	0.1	0.7	2.1	0.9	2.0	1.7	0.3	0.1	5.6	77.0	6.4	5.0
216		19- 62	63.4	12.3	9.1	0.4	0.1	0.8	2.1	0.8	2.0	1.7	0.2	0.1	6.3	77.1	7.0	5.7
217		62- 95	61.3	13.9	10.1	0.4	0.2	1.0	2.6	0.9	2.1	1.8	0.3	0.2	6.4	75.4	8.3	6.3
218		95-150	60.3	14.9	10.5	0.4	0.2	1.1	2.6	0.8	2.0	1.7	0.3	0.1	6.3	73.1	9.2	7.0
219	Mbalageti 1	0- 14	62.1	13.0	6.3	0.3	0.2	1.0	2.0	0.6	3.2	1.5	0.6	0.2	9.5	73.7	8.2	4.6
220		14- 40	62.4	14.5	6.9	0.2	0.2	1.1	1.8	0.6	3.3	1.5	0.5	0.2	8.0	78.8	7.5	4.0
221		40- 70	60.7	16.6	8.2	0.2	0.2	1.3	1.5	0.5	3.3	1.4	0.4	0.2	7.7	79.8	8.4	5.3
222		70-100	58.1	16.4	7.9	0.1	0.2	1.5	1.8	0.5	3.3	1.4	0.4	0.2	7.5	71.3	7.5	4.8
223		100-115	59.7	15.6	7.4	0.1	0.2	1.6	2.5	0.6	3.4	1.4	0.5	0.2	7.6	64.4	12.7	6.4
224	Mbalageti 2	0- 6	69.0	10.4	5.7	0.3	0.2	0.8	2.7	0.8	2.8	1.9	0.7	0.2	6.5	77.2	7.6	4.6
225		6- 20	58.3	15.2	8.0	0.1	0.2	1.3	2.1	0.8	3.1	1.4	0.4	0.2	8.4	69.7	9.5	6.1
226		20- 60	56.4	15.9	7.7	0.4	0.2	1.5	3.6	1.0	3.2	1.4	0.4	0.2	8.8	70.9	7.2	4.4
227		60- 77	58.6	16.1	7.6	0.2	0.2	1.7	3.2	0.9	3.3	1.5	0.5	0.2	7.9	63.2	13.4	6.8
228		77- 92	57.8	16.1	7.7	0.1	0.2	1.6	3.2	1.0	3.4	1.5	0.5	0.2	7.6	63.7	12.6	6.5
229		92-117	56.9	16.5	7.8	0.1	0.2	1.7	3.1	1.2	3.8	1.5	0.4	0.2	7.5	60.9	14.2	6.9

corrected for CO_2.

											Clay												Sample number
FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	BaO	H_2O^+	CO_2	SiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	TiO_2	P_2O_5	H_2O^+	
0.2	0.1	0.4	2.4	0.7	1.8	0.6	0.1	0.1	-	-	48.3	21.4	11.1	0.4	0.3	1.2	0.5	0.1	2.8	1.5	1.3	6.9	166
0.2	0.1	0.3	2.5	0.8	1.9	0.7	0.1	0.2	-	-	48.3	22.9	11.8	0.3	0.3	1.3	0.4	0.1	2.7	1.5	1.1	6.8	167
-	-	0.5	3.0	0.6	2.2	0.7	0.1	0.2	1.3	-	49.4	23.5	12.1	0.3	0.2	1.4	0.3	0.1	2.6	1.3	0.7	6.9	168
-	0.1	1.3	3.0	0.5	2.4	0.9	0.7	0.2	5.5	-	51.6	21.3	10.9	0.3	0.3	1.5	0.7	0.1	2.5	1.2	0.8	7.2	169
0.1	-	-	0.5	0.5	5.0	0.1	-	0.1	-	-	52.7	19.9	9.3	0.2	0.1	1.1	0.2	0.1	2.4	1.2	0.5	7.6	170
0.1	-	-	0.7	0.3	4.5	0.1	-	0.1	-	-	51.1	20.4	10.2	0.1	0.1	1.4	0.4	0.1	2.0	1.0	0.3	8.5	171
0.1	-	-	-	1.1	4.4	0.1	-	0.1	3.0	-	51.2	21.6	9.9	0.3	0.1	1.2	0.3	0.1	1.8	1.0	0.4	8.7	172
0.1	-	0.1	1.9	1.3	4.6	0.4	-	0.1	3.7	-	54.1	19.3	9.5	0.2	0.2	1.5	0.4	0.1	2.1	1.0	0.4	7.9	173
0.1	-	0.2	4.6	1.3	4.6	0.2	-	0.2	6.5	-	55.6	18.7	9.5	0.2	0.2	1.5	0.5	0.1	2.0	1.0	0.4	8.7	174
0.1	0.1	0.3	2.8	0.5	1.8	1.5	0.2	0.3	1.7	0.3	48.1	21.1	11.0	0.4	0.2	1.6	0.4	0.1	2.5	1.2	0.4	10.5	175
0.4	0.1	0.4	5.5	0.5	0.8	1.4	0.3	0.4	8.2	2.0	48.0	20.6	11.2	0.2	0.2	1.8	0.3	0.1	3.0	1.3	0.4	10.0	176
0.4	0.1	0.4	5.9	0.5	1.8	1.5	0.2	0.4	5.4	4.3	49.3	20.9	10.5	0.2	0.2	1.8	0.4	0.1	2.5	1.3	0.5	10.2	177
0.2	0.1	0.7	4.3	0.7	2.1	1.7	0.3	0.4	13.7	2.8	48.2	19.9	11.0	0.1	0.3	1.9	0.5	0.1	2.4	1.3	0.4	9.0	178
0.1	0.2	0.9	3.8	0.8	2.3	1.7	0.3	0.4	12.2	2.1	50.0	20.0	10.6	-	0.3	1.9	0.5	0.1	2.5	1.4	0.5	9.2	179
0.2	0.3	1.4	5.7	1.0	2.5	1.8	0.4	0.4	6.6	1.8	51.3	19.8	11.1	-	0.3	2.0	0.5	0.1	2.4	1.4	0.5	8.9	180
n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	-	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	n.d	181
0.3	0.3	1.2	3.9	1.0	2.7	1.6	0.5	0.2	6.8	3.4	50.9	20.1	10.1	-	0.3	1.8	0.5	0.1	2.2	1.4	0.5	9.4	182
0.4	-	0.1	1.3	1.3	6.4	0.4	-	0.2	-	-	43.8	24.8	12.5	-	0.2	1.0	0.2	0.1	2.0	1.6	1.0	10.7	183
0.4	-	-	1.3	1.4	6.6	0.2	-	0.2	-	-	44.0	26.1	12.4	0.1	0.2	0.9	0.1	0.1	1.9	1.5	0.8	10.9	184
0.4	-	0.1	1.3	1.2	6.5	0.2	-	0.2	0.8	-	43.8	26.5	11.4	-	0.2	0.9	0.1	0.1	1.7	1.3	0.7	11.5	185
0.2	-	0.2	1.4	1.3	6.4	0.6	-	0.2	0.3	-	44.6	26.4	11.7	-	0.1	1.0	0.1	0.1	1.6	1.3	0.5	11.6	186
0.1	-	0.1	0.5	0.6	1.0	0.1	-	0.1	-	-	53.2	23.4	10.0	0.4	0.2	1.3	0.1	0.1	2.4	1.7	0.6	5.8	187
-1.1	-	-	0.5	0.7	0.7	0.3	-	0.1	-	-	50.9	22.7	7.9	2.1	0.1	1.4	0.1	0.1	2.2	1.5	0.4	7.4	188
-1.9	0.1	0.2	1.3	1.1	1.5	0.5	-	0.2	5.4	0.4	53.4	23.1	6.8	3.1	0.1	1.6	0.1	0.1	2.2	1.5	0.2	5.3	189
0.1	0.1	0.3	3.6	1.3	2.3	0.5	0.4	0.3	5.3	-	50.5	22.3	9.6	0.1	0.1	1.5	0.1	0.1	2.1	1.4	0.2	9.7	190
0.2	-	0.2	3.3	1.3	2.4	0.9	0.2	0.2	-	-	46.6	23.2	10.6	0.3	0.2	1.4	0.3	0.1	2.0	1.3	0.5	11.2	191
0.2	0.1	1.7	0.3	1.2	2.2	0.3	-	0.2	-	0.6	47.4	23.2	10.7	0.3	0.1	1.6	0.3	0.1	1.9	1.2	0.5	10.7	192
0.2	0.1	0.1	5.3	1.7	2.4	1.4	0.2	0.2	2.1	2.1	47.5	25.7	10.5	0.2	0.1	1.8	0.2	0.1	1.9	1.2	0.4	11.3	193
0.2	0.2	0.7	4.5	1.9	2.8	1.4	0.2	0.3	4.3	1.0	50.1	21.1	9.9	0.1	0.2	2.6	0.3	0.1	2.2	1.2	0.4	9.9	194
0.4	0.1	0.2	3.2	2.0	3.4	1.2	0.5	0.2	1.5	-	43.4	24.5	10.0	0.5	0.2	1.1	0.7	0.1	2.2	1.2	1.3	13.3	195
0.4	0.1	0.2	3.3	2.0	3.7	1.2	0.4	0.2	1.0	0.5	43.3	25.4	10.4	0.4	0.2	1.1	0.4	0.1	2.0	1.2	0.1	12.3	196
0.1	0.1	0.2	4.1	2.1	3.5	1.3	0.4	0.3	1.7	-	45.7	26.1	10.4	0.4	0.2	1.2	0.4	0.1	1.9	1.2	0.8	11.5	197
0.1	.	0.2	1.2	1.8	2.6	0.4	-	0.1	-	-	49.3	19.9	10.5	0.5	0.2	1.7	0.2	0.1	3.2	1.8	0.7	9.7	198
-	.	0.5	1.4	2.0	2.7	0.3	-	0.2	1.1	-	49.6	20.5	10.8	0.4	0.1	2.0	0.3	0.1	2.9	1.4	0.4	9.8	199
0.1	0.1	0.7	2.0	1.8	2.9	0.6	0.1	0.2	2.3	0.4	51.4	19.7	10.6	0.3	0.2	2.1	0.2	0.1	2.8	1.4	0.3	9.4	200
0.2	0.1	0.8	1.8	1.7	2.6	0.8	0.1	0.1	4.1	0.5	51.8	19.8	10.6	0.2	0.2	2.2	0.2	0.1	3.0	1.4	0.3	8.9	201
0.1	0.2	0.2	2.5	1.4	2.3	1.1	0.3	0.2	1.7	-	47.2	20.8	10.1	0.7	0.2	1.5	0.4	0.1	2.5	1.5	0.8	11.1	202
0.3	0.1	0.2	2.9	1.9	2.3	0.5	0.2	0.3	1.7	-	48.7	22.0	10.7	0.2	0.2	1.7	0.3	0.1	2.3	1.4	0.4	9.8	203
1.7	0.2	0.3	2.5	2.0	2.5	0.5	0.2	0.3	1.0	-	49.0	21.0	10.5	0.2	0.2	1.9	0.4	0.1	2.1	1.4	0.4	10.6	204
0.2	0.1	0.1	4.2	1.8	2.3	1.1	0.3	0.3	2.7	0.5	50.0	21.1	10.2	0.3	0.2	2.0	0.5	0.1	2.1	1.4	0.4	9.5	205
0.2	0.1	0.3	6.5	1.8	2.4	1.1	0.3	0.3	4.5	2.5	50.0	20.6	10.2	0.2	0.2	2.1	0.5	0.1	2.2	1.4	0.4	9.5	206
0.2	0.1	0.5	5.6	1.5	2.4	1.5	0.2	0.3	5.6	1.9	50.4	20.2	9.8	0.1	0.2	2.2	0.5	0.1	2.3	1.3	0.5	9.8	207
0.3	0.1	0.2	2.3	1.7	2.4	1.0	0.5	0.1	0.1	0.3	44.3	21.4	11.2	0.2	0.2	1.4	0.3	0.1	2.5	1.4	0.7	11.8	208
0.6	0.1	0.2	4.5	2.1	2.4	1.4	0.4	0.3	1.8	0.7	46.2	22.0	11.0	0.2	0.2	1.6	0.3	0.1	2.3	1.1	0.5	10.7	209
0.5	0.1	0.3	7.4	2.0	2.2	2.0	0.3	0.3	4.0	7.1	48.8	21.1	10.2	0.1	0.1	2.0	0.5	0.1	2.2	1.2	0.5	10.1	210
0.6	0.2	0.3	5.5	2.4	2.3	1.4	0.2	0.4	4.4	7.4	49.5	20.8	10.1	0.1	0.2	2.1	0.5	0.1	2.2	1.2	0.5	10.1	211
0.3	0.2	0.7	3.5	1.8	2.1	1.3	0.2	0.3	5.0	3.8	50.5	21.0	10.0	0.1	0.2	1.9	0.5	0.1	2.2	1.2	0.5	9.6	212
0.8	0.2	0.8	2.7	1.8	2.3	1.5	0.3	0.3	5.6	1.9	51.1	20.9	10.2	0.1	0.2	1.8	0.3	0.1	2.1	1.3	0.4	9.3	213
0.5	0.2	0.9	2.1	1.5	2.3	1.5	0.5	0.2	5.6	1.0	50.9	20.3	9.8	0.1	0.2	1.7	0.7	0.1	2.1	1.2	0.6	10.0	214
1.4	0.1	0.4	2.6	1.1	2.0	1.8	0.1	0.2	1.4	-	42.7	23.6	15.0	0.2	0.1	1.4	0.1	0.1	2.3	1.4	0.8	11.1	215
0.6	0.2	0.3	2.7	1.3	2.0	1.8	0.1	0.2	-	-	39.4	21.8	15.2	0.1	0.1	1.4	0.1	0.1	2.0	1.4	0.5	17.6	216
0.5	0.2	0.5	3.6	1.5	2.2	1.9	0.2	0.3	1.7	-	43.3	22.4	16.0	0.2	0.1	1.5	0.2	0.1	2.0	1.6	0.4	10.2	217
0.6	0.2	0.5	3.6	1.3	2.1	1.9	0.2	0.3	3.5	-	44.3	22.2	15.1	0.1	0.1	1.6	0.3	0.1	1.9	1.4	0.5	10.0	218
0.3	0.3	0.7	2.4	0.9	2.8	1.6	0.5	0.3	4.4	0.6	47.4	23.4	10.1	0.4	0.1	1.5	0.4	0.1	4.3	1.4	0.8	9.7	219
0.2	0.3	0.6	2.5	1.0	3.0	1.7	0.4	0.3 '	2.3	-	46.0	23.9	10.7	0.2	0.1	1.5	0.3	0.1	3.8	1.4	0.7	10.1	220
0.3	0.2	0.9	2.6	0.9	3.5	1.6	0.3	0.4	3.0	-	46.8	23.4	10.6	0.1	0.1	1.5	0.2	0.1	3.2	1.2	0.5	9.9	221
0.1	0.3	0.9	2.6	1.0	2.9	1.6	0.3	0.4	5.1	-	47.9	23.4	10.3	0.1	0.1	1.7	0.3	0.1	3.5	1.2	0.4	9.5	222
0.1	0.2	1.2	2.7	0.7	3.4	1.5	0.5	0.3	6.8	0.5	49.6	22.2	9.6	0.2	0.2	1.7	0.5	0.1	3.2	1.2	0.5	9.3	223
0.4	0.3	0.5	3.2	0.9	2.4	1.9	0.6	0.3	3.0	-	46.2	21.7	10.5	0.3	0.1	1.4	0.3	0.1	4.3	1.8	0.8	10.2	224
0.1	0.2	1.0	2.9	1.1	3.1	1.7	0.4	0.3	3.7	-	46.5	23.2	10.7	0.2	0.1	1.5	0.1	0.1	3.2	1.2	0.4	10.7	225
0.8	0.3	0.9	7.1	1.7	3.0	1.8	0.5	0.5	4.9	3.3	47.7	22.5	10.2	0.2	0.1	1.7	0.3	0.1	3.3	1.2	0.4	9.7	226
0.2	0.2	1.5	3.8	0.9	3.2	1.6	0.5	0.3	7.0	1.1	49.0	22.3	9.7	0.2	0.2	1.8	0.6	0.1	3.6	1.2	0.5	9.8	227
0.1	0.2	1.4	4.1	1.1	3.2	1.6	0.5	0.3	6.6	1.0	48.5	22.0	9.9	0.2	0.1	1.9	0.5	0.1	3.6	1.2	0.5	9.4	228
0.1	0.2	1.4	3.8	1.3	3.8	1.6	0.5	0.3	6.7	1.3	49.6	22.0	9.8	0.1	0.1	2.0	0.3	0.1	3.6	1.2	0.4	9.1	229

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