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Technical Report 3

SOIL SURVEY REPORT OF GEITA AND SENGEREMA DISTRICTS

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SOIL SURVEY REPORT
OF
GEITA AND SENGEREMA DISTRICTS

Report prepared for the
Government of the United Republic of Tanzania
by
The Food and Agriculture Organization of the
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based on the work of
E. De Pauw Soil Survey Officer

UNITED NATIONS DEVELOPMENT PROGRAMME
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TABLE OF CONTENTS

LIST OF TABLES

ABSTRACT

This report describes a reconnaissance soil survey and land suitability study of Geita and Sengerema Districts, Mwanza Region, which cover an area of 9,800 sq.km. The survey and land suitability study were carried out to assist the Tanzania Cotton Authority in planning the expansion of cotton, as well as maize, the staple food of the region. Soils and land suitability maps for cotton and maize were prepared at a scale of I:250,000.

A close correlation between kinds of soils, parent materials and landforms was observed in the area. Major soils on granitic upland plains and hills include well drained, shallow to deep, sands, loamy sands, sandy loams and sandy clay loams, whereas Nyanzian uplands are mainly covered by well drained clays, sometimes with ironstone layers at the surface. Soil reaction of all upland soils ranges from slightly to moderately acid. Imperfectly to poorly drained clayey soils, often calcareous or sodic, predominate on lowland plains; soil reaction varies from neutral to strongly alkaline.

The soils and major environmental factors of the area, mainly physiography and climate, were assessed in terms of land suitability for relevant land use types : smallholder rainfed arable farming, in particular cotton, maize and rice, and large-scale mechanized rainfed farming.

Most of the upland plains, hill-footslope associations and rolling hills, which occupy approximately 70% of the surveyed area, are moderately suitable for cotton grown under a smallholder system, moderately to highly suitable for drought-resistant crops such as millet and sorghum. Only the western part (40%) of the area is moderately suitable for smallholder maize; owing to imbalanced water supply during the growing season, the risk of crop failure in the eastern part is severe. The lowland and lacustrine plains, which cover about 20% of the area, are as a whole marginally suitable or unsuitable for both smallholder and mechanized rainfed farming, mainly because of poor drainage; moderately suitable for dry-season grazing and partly moderately suitable for paddy rice, depending on water availability. About 40% of the area, particularly the upland plains, is suitable for large-scale mechanized farming; the remaining land is either marginally suitable or unsuitable because of steep slopes and rockiness mainly.
Owing to the severe risk of soil erosion by water, the hilly areas (about 24% of the area) are currently considered as marginally suitable or unsuitable for crop production. The less steep areas can be used, however, for rainfed upland crops under smallholder system, provided certain soil conservation practices are adopted.

Major physical constraints for increasing crop production are low soil fertility and inadequate moisture availability. The hills and lowland plains are in general more fertile than the upland plains, which are often poor in exchangeable bases and available phosphorus. Inadequate moisture supply for plant growth is a common limitation over most upland areas and is mainly due to high rainfall variability, rather than poor soil moisture retention capacity. This limitation is more severe for maize than for cotton and is more pronounced in the eastern part of the surveyed area.

ABSTRACT

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Chapter I

INTRODUCTION

1.1. BACKGROUND AND IMPLEMENTATION

This report deals with the soil survey of Geita and Sengerema districts, totalling 9803 sq.km, islands included. This soil survey was undertaken by the National Soil Service in co-operation with the Geita Cotton Project, a daughter-organization of the Tanzania Cotton Authority sponsored by the World Bank. The objectives of the survey were:

1) to prepare a soils map and soils inventory of this important cotton growing area and to evaluate its suitability for the major cash and food crops.

2) to identify constraints for increased crop production from the land resources aspect.

The fieldwork began in December 1976 and was completed by August 1977. Apart from field observations and soil analytical data, existing aerial photographs, topographic maps, geological reports and climatic records have greatly assisted to achieve the outlined objectives. Also satellite imagery was interpreted. Due to various constraints, mainly manpower shortage, the completion of the report was considerably delayed.

The following staff worked on the fieldwork, imagery and photo-interpretation and report preparation:

E.F. De Pauw, FAO, Soil survey officer (fieldwork, imagery interpretation, report preparation)
E.J. Espinosa, FAO, Project Manager URT/73/006 (photo-interpretation)
K.L. Haule, NSS, A.R.O. (fieldwork)
Z.A. Mmari, NSS, A.F.O. (fieldwork, soil correlation)
S. Mgogo, NSS, ARO (fieldwork, soil correlation)
A. Kiwelu, NSS, A.F.A. (fieldwork, data complitation)
A. Kulugutu, NSS, Recorder (fieldwork, map drawing)

Chemical analyses of selected profiles were carried out under the direction of Dr. R. Menon, FAO Soil Chemist. The base maps were drawn by E. De Pauw and final fair drawing was done by Messrs. Hamisi and Lunkombe.
The report was reviewed by Mr. E.J. Espinosa, Project Manager.

For the purposes of this survey the mapping units shown on the soils map are based on more or less uniform physiographic features and soil patterns. At the scale of this map (1 : 250,000) it was not possible to differentiate individual soils. Instead the mapping units are characterized by soil associations, which include one or more main soils occuring in a specified geographical pattern with certain proportions.

The report has following format : first the physical environment of the two districts is described, then the mapping units and the soils, followed by considerations on agricultural potential and recommendations (Chapters 2, 3 and 4 respectively). This is followed by a conglomerate of appendices which elaborate on various technical aspects of the work. The main part of the report is constituted by the first four chapters. They concern particularly the information of immediate value for land planners, extension staff and agriculturalists and have therefore been written as much as possible in non-technical language. With the exception of the last one (Appendix 5), the technical appendices are destined for soil specialists. Appendix 5 (Description of individual soil units) may also be of particular interest for agronomists and extension workers and contain numerous soil analytical data.

1.2. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

1. Ten major soil types have been identified in Geita-Sengerema districts. These soil types and their general distribution are chiefly determined by the parent material and the topography.

On granitic uplands well drained, sandy or loamy soils predominate. Dark skeletal loams (G1-soils) occupy rocky hilltops and eroded upper slopes of granite uplands and are always associated with rock outcrops (Gr) and very shallow, undifferentiated soils (Gs).

These soils are fertile but are usually not cultivated because of their rockiness or shallowness.

Gritty, reddish or brown loams (G2-soils) are the most common soils or granite. They occupy upper and middle slopes of granite uplands. The fertility status of these soils is rather low but they retain moisture quite well and are therefore the most preferred soils for crop production.

Pale brown sands (G3-soils) are the second most important soils on granite and usually occupy middle or lower slopes of granite landforms. Their fertility is low and water storing properties are poor. Yet these soils are extensively used for cultivation of non-exacting crops like cassava, and more and more also for exacting crops like cotton.

On uplands with either Nyanzian or Kavirondian substratum well drained, friable clays predominate with superficial or shallow ironstone as a secondary formation.

Friable red or brown clays (Z1-soils) are the most common soils on Nyanzian substratum. These soils are usually not cultivated, probably because they are strenuous to work by hand methods. These soils have some important fertility limitations, particularly in respect of nutrient retention capacity, and tend to be droughty under low moisture conditions.

Apart from these constraints they appear valuable soils, particularly for mechanized agriculture.

Friable yellowish clays (Z2-soils) are not very extensive soils and occur always in association with shallow ironstone. These soils are usually not cultivated and in view of their limited extent not important for agriculture.

In lowlands clayey soils occur, with deficient drainage. Five soil types have been recognized within the lowlands. The first three (L1, L2, L3) are soils that form part of a soil-topography association (or catena) and are thus a continuation of the upland soils. The last two (L4, L5) are soils that are apparently derived from sediments deposited in the Victoria lake.

Sandy (clay) loams and sandy clays with hardpan at shallow depth (L1-soils) occur at the transition of the sandy lower slopes of granitic uplands and the clayey bottomlands. They are of limited importance for agriculture, in view of their small extent and unfavourable physical properties.

Greyish mottled sandy (clay) loams and sandy clays (L2-soils) are the most extensive lowland soils. They occur on the edges of wide lowland plains or the valley bottoms in dissected granite country. These soils have favourable physical properties for rice growing and a moderate fertility status but the water supply from seepage is often too unreliable for sustained high rice productivity.

Dark cracking clays (L3-soils) are quite extensive and cover the deepest parts of the bottomlands that are subject to flooding. These soils are important for grazing and they are usually not cultivated. The adverse physical properties and extremes of drought and flooding make them unsuitable for subsistence level agriculture. Nevertheless they are very fertile and offer a good potential for agriculture under adapted soil and water management.

Compact, sodic sandy (clay) loams (L4-soils) are confined to flat depression lands around the lake Victoria and are apparently derived from lake bottom sediments. These soils are not utilized except for extensive grazing. They are unsuitable for most crops.

Dark sands (L5-soils) occur also in depression lands bordering the Victoria lake. These soils are quite fertile and high groundwater tables make up for poor water storing properties. Where the soils are not waterlogged, they are intensively cultivated.

Within areas with a common geological substratum and landform, soil variability is mainly determined by topography. This is particularly the case in granitic areas, where different soils are arranged in a pattern that is most clearly related to their topographical position. From hilltop or upland plain summit to bottomland following soil types succeed each other : G1 - G2 - G3 - L1 - L2 - L3. The hardpan soils (L1) are not always part of the catena. Along the slope one soil type is gradually transformed into the next and the soil types described in this report are therefore individual members of a rather continuous series.

2. The main landforms recognized in the survey are are:

1) Hills
2) Hill-footslope associations
3) Upland plains
4) Lowland ('mbuga') plains
5) Lacustrine plains

These broad landforms were subdivided into 19 physiographic units, primarily on the basis of the parent rock, and secondly the slope class. These physiographic units were further subdivided into 39 soil associations which are the basic mapping units as they appear on the Soils Map.

3. The land suitability classification refers to three major agricultural land utilization types, that appear most relevant to the socio-economic conditions prevailing in the survey area :

1) Smallholder rainfed arable farming, intermediate technology
2) Smallholder rainfed paddy rice, intermediate technology
3) Large scale mechanized rainfed agriculture

These land utilization types have been split up according to relevant crops.

4. The main physical constraints for increased crop productivity in the surveyed area are low soil fertility and inadequate moisture availability. Other important limitations are erosion hazard and poor possibilities for mechanization.

Soil fertility is low in most upland areas. Upland soils are usually poor in available phosphorus and in exchangeable bases. General patterns of soil fertility are related to physiography, the hills being in general more fertile than the upland plains. The lowland areas have in general a better fertility status than the uplands.

Poor moisture availability is a very common limitation in most upland areas that depend exclusively on rainfall for their moisture supply. In general this limitation is mainly caused by unreliable rainfall, rather than by poor moisture storage properties. Except for the G3-sands, shallow and gravelly soils, most soils have fairly good water retention properties. The limitation is more severe for maize than for cotton and is most pronounced in the eastern part of the survey area.

Erosion is a great risk in all sloping areas, particularly in the hills and hill-footslope associations. Most soils of the area have a low inherent erodibility and the erosion risk is chiefly determined by the slope class of the landform concerned.

Constraints against mechanization are considerable, both in the hilly areas and in the lowlands. In the former areas the limitation is mainly caused by rockiness, in the latter by deficient drainage or flooding.

Drainage limitations in most parts of the 'mbugas' and lacustrine plains are important enough to preclude cultivation of most upland crops unless the most tolerant to waterlogging.

5. Geita-Sengerema districts have a moderate potential for agriculture. Except for the rocky hills and the permanent swamps most of the survey area can be cultivated for one crop or another.

For general smallholder rainfed cultivation the best areas are located on the upland plains and hill-footslope associations. Although they contain a higher proportion of better soils, the hill areas are currently less suitable because of the erosion hazard. However with better soil conservation practices, many of the less steep hills can also be considered as suitable.

For mechanized rainfed agriculture the hills and most of the hill-footslope associations are unsuitable or marginally suitable, mainly because of rockiness. In such areas it appears that the smallholder arable farming system can make better use of agricultural resources if erosion control is practised. The lowland areas are less suitable both for smallholder as for mechanized rainfed farming because of drainage limitations. They are in part suitable for smallholder paddy rice.

As regards suitability for individual crops, the survey area is in general best suited for drought resistant crops such as cassava, sweet potatoes, sorghum etc. In about 70% of the area most of the land is in general moderately suited for cotton. For more exacting crops, particularly maize, the area is less suited: only in about 40% of the area most of the land is moderately suitable for maize.

6. Following management practices are recommended to overcome current physical constraints :

1) maintenance and enhancement of soil fertility
2) cultivation of drought tolerant or drought evading crops and adoption of timely planting
3) control of soil erosion
4) 'mbuga' development

Chapter 2

ENVIRONMENT

2.1. LOCATION, POPULATION AND COMMUNICATIONS

The surveyed area comprises Geita and Sengerema districts in Mwanza Region, Tanzania and lies approximately between parallels 2°15'S and 3°30'S and longitudes 31°45'E and 33°00'E. Both districts lie south of lake Victoria. They adjoin Biharamulo district in the West, Kahama district in the south, and are separated from Kwimba and Mwanza district in the east by the Mwanza Gulf.

The surveyed area covers about 9,067 sq. km, not including the islands Rubondo, Maisome and Kome. Altitude ranges between 1136 m at lake Victoria level and 1590 m at the Geita hills.

The total population of the two districts as per the 1970 census is 390,000. The population density average is about 43 persons per sq.km. Population density is highly variable, being 50-100 persons near the Mwanza Gulf, and 15-30 in the west and southwest.

Roads are the most important means of communication. An allweather non-metalled road from Mwanza to Bukoba links the two district headquarters. The district headquarters are linked to the villages and cotton ginneries by dry-weather roads. Moreover two dry-weather roads connect Geita with Kahama. As a whole the total number of roads, although fairly dense by country standards, is insufficient to serve all the villages and its distribution is rather inadequate. The hilly interior of the Buhindi peninsula, for example, is virtually inaccessible. A number of roads are no longer operational, mainly because of lack of maintenance. During the rainy season many villages are thus cut off by poor road conditions or by floods. At present a network of new roads is being constructed and maintained by the Geita Cotton Project to facilitate the marketing of cotton.

Other means of communications include two airstrips, one at Geita which used to serve the abandoned Geita Gold Mine but is at present not operational, and the airstrip at Rwamagasa which is operational but only serves the gold mine there. There are also telephone and telegraphs services at the district headquarters.

2.2. CLIMATE

The main characteristics of the climate in the surveyed area are uniform, high temperatures, a seasonal rainfall pattern with more than 90% of the annual rainfall concentrated in the rain season, a high rainfall variability during the rainy season and high evaporation rates.

The most important climatic elements will be discussed in following paragraphs.

2.2.1. Temperature

Temperature data are not available for the surveyed area. The nearest stations for which temperature records are available are listed in tables 1-3 and located on figures 2-16. These tables give average temperatures for these stations, together with standard deviation and coefficients of variation.

From these tables it is inferred that :

1) monthly temperature variations between the stations are minimal. Coefficients of variation have a maximum value of 4.2 percent.

2) seasonal temperature variations are also very low. The range between the warmest month (September or October) and coolest month (generally July) is maximally 3.7°C for the maximum temperature.

3) the range between maximum and minimum temperature values is 10-12°C.
Although the stations are not located in the surveyed area, these temperature data are considered as representative because temperature remains fairly constant over large areas where no orographic anomalies exist. Owing to the low variability from month to month and from station to station, it appears justified to represent temperature in the area by the average from the selected stations. Thus mean annual maximum temperature is estimated at 28.5°C, mean annual minimum temperature at 17.7°C and the mean annual temperature as 23.1°C.

2.2.2. Rainfall

The location of various rainfall stations is given in table 4 and fig. 1-15. A few stations outside the surveyed area are also included in order to make a more reliable interpretation of available climatic data.

The following aspects of the rainfall pattern are discussed:

a) average rainfall amounts (annual and monthly)
b) rainfall variability
c) rainfall intensity, duration and frequency

a) Average rainfall

Annual rainfall data for 25 stations are summarized in table 4. Besides averages the data include standard deviations, coefficients of variation, 80% and 90% probability minimum rainfall amounts.

From this table it appears that the range in annual rainfall between the wettest and driest station is about 600 mm (800-1400 mm), which is rather high. However, it should be noted that for several stations the estimate of the average is not very reliable due to the high variability especially for those stations with less than 10 years of records. This is also evidenced by the fact that if one compares only those rainfall stations with more than 20 years records, the range is barely 200 mm (830-1030 mm).

Fig.1 shows the geographical distribution of the average rainfall. This map was derived from Tomsett's rainfall maps of Tanzania (Tomsett, 1969), and indicates an average annual rainfall of 1000 - 1200 mm in the north and west of the survey area, and 800 - 1000 mm in the remainder (*)

Table 1. Mean monthly and annual maximum temperatures

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Range
Mwanza Agric. Office	28.7	28.6	28.7	28.3	28.4	28.9	28.6	28.9	29.5	29.6	29.0	28.3	28.8	1.3
Nyegezi Mission	28.3	28.3	28.4	27.7	27.8	28.4	28.4	28.8	29.1	28.8	28.1	27.4	28.3	1.7
Mwanza Airfield Met. Stat.	27.1	27.3	27.5	27.2	27.5	27.9	27.8	27.9	28.3	28.0	27.4	26.7	27.5	1.6
Ukiriguru Agric. Res. Stat.	28.1	28.4	28.4	27.7	27.8	28.5	28.7	29.2	30.2	20.1	28.5	27.8	28.6	2.5
Kijima Mission	28.5	29.1	28.6	28.0	27.9	28.6	28.8	29.5	30.6	31.5	30.1	28.2	29.1	3.7
mean	28.1	28.3	28.3	27.8	27.9	28.5	28.5	28.9	29.5	29.6	28.6	27.7	28.5	
stand. deviation	0.6	0.7	0.5	0.4	0.3	0.4	0.4	0.6	0.9	1.3	1.0	0.7	0.6	
Coeff. of variation	2.1	2.5	1.8	1.4	1.1	1.4	1.4	2.1	3.1	4.4	3.5	2.5	2.1	

Table 2. Mean monthly and annual minimum temperatures

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Range
Mwanza Agric. Office	18.1	17.8	18.3	18.2	17.9	17.0	16.0	16.8	17.9	18.8	18.7	18.3	17.8	2.8
Nyegezi Mission	18.2	18.3	18.3	18.1	17.7	16.6	15.9	16.9	18.4	19.1	18.8	18.4	17.9	3.2
Mwanza Airfield Met. Stat.	18.3	18.3	18.4	18.3	17.9	16.3	15.3	16.4	17.8	18.4	18.5	18.3	17.7	3.2
Ukiriguru Agric. Res. Stat.	17.9	18.0	18.0	18.0	17.4	16.4	15.3	15.4	17.2	18.5	18.5	18.1	17.4	3.2
Kijima Mission	18.4	18.4	18.4	18.1	17.7	16.2	15.8	17.0	17.3	18.2	19.3	18.8	17.8	3.5
mean	18.2	18.2	18.3	18.1	17.7	16.4	15.7	16.5	17.7	18.6	18.8	18.4	17.7	
Standard deviation	0.3	0.3	0.2	0.1	0.2	0.4	0.3	0.7	0.5	0.4	0.3	0.3	0.2	
coeffic. of variation	1.6	1.6	1.1	0.6	1.2	2.4	1.9	4.2	2.8	2.2	1.6	1.6	1.1	

Table 3. Mean monthly and annual temperatures

Station	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	Range
Mwanza Agric. Office	24.4	23.2	23.5	23.3	23.2	23.0	22.4	22.9	23.7	24.2	23.9	23.3	23.3	1.8
Nyegezi Mission	23.3	23.3	23.4	22.9	22.8	22.5	22.2	22.9	23.8	24.0	23.5	22.9	23.1	1.8
Mwanza Airfield Met. Stat.	22.7	22.8	23.0	22.8	22.7	22.1	21.6	22.2	23.1	23.2	23.0	22.5	22.6	1.6
Ukiriguru Agric. Res. Stat.	23.0	23.2	23.2	22.9	22.6	22.3	22.0	22.3	23.7	24.3	23.5	23.0	23.0	2.3
Kijima Mission	23.5	23.8	23.5	23.1	22.8	22.4	22.3	23.3	24.0	24.9	24.7	23.5	23.5	2.6
mean	23.2	23.3	23.3	23.0	22.8	22.5	22.1	22.7	23.7	24.1	23.7	23.0	23.1	
standard deviation	0.3	0.3	0.2	0.2	0.2	0.4	0.3	0.4	0.3	0.6	0.6	0.4	0.3	
coeffic. of variation	1.3	1.3	0.9	0.9	0.9	1.8	1.4	1.8	1.3	2.5	2.5	1.7	1.3	

Source: E.A. Met. Dept (1970). Temperature Data for stations in East Africa. Part II: Tanzania

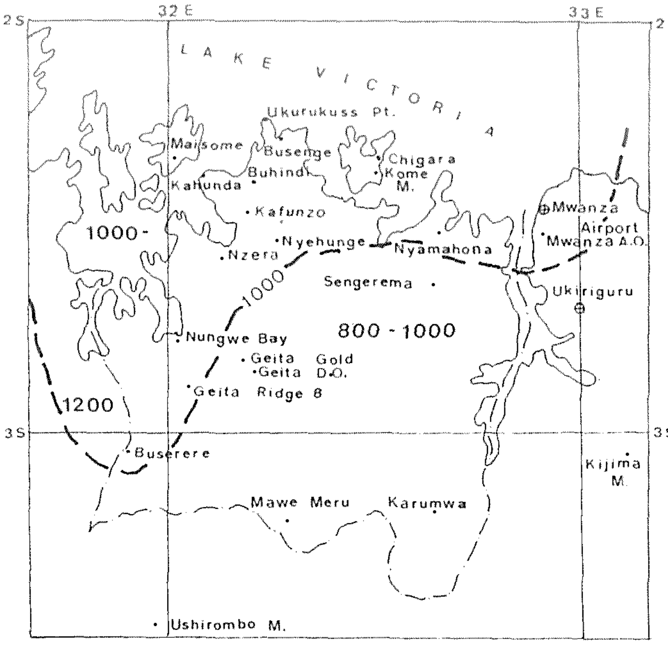


Fig.1. Distribution of average annual rainfall. (After Tomsett 1969).

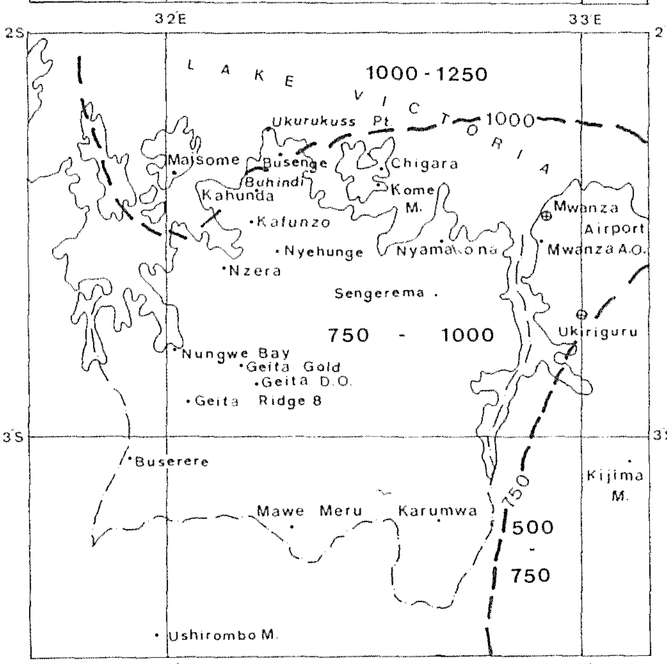


Fig.2. Distribution of the 90% probability minimum annual rainfall. (after E.A.Met. Dept.1961).

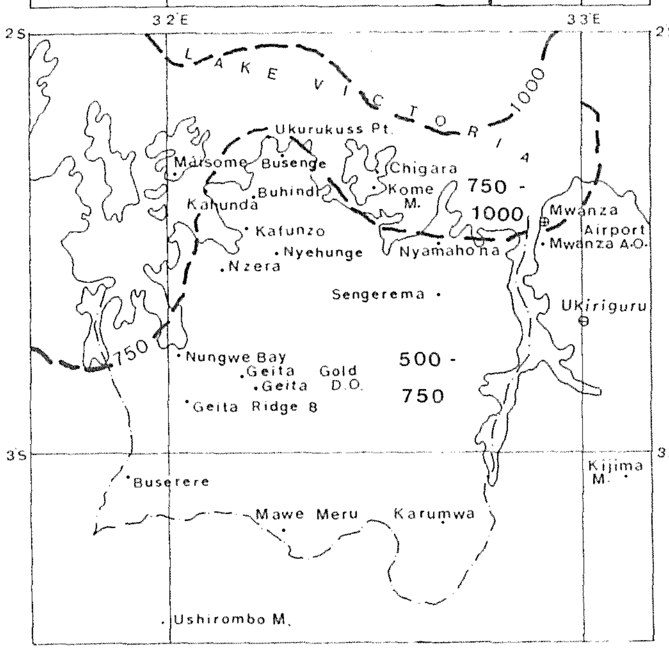


Fig.3. Distribution of the 90% probability minimum annual rainfall. (After E.A. Met. Dept.1961).

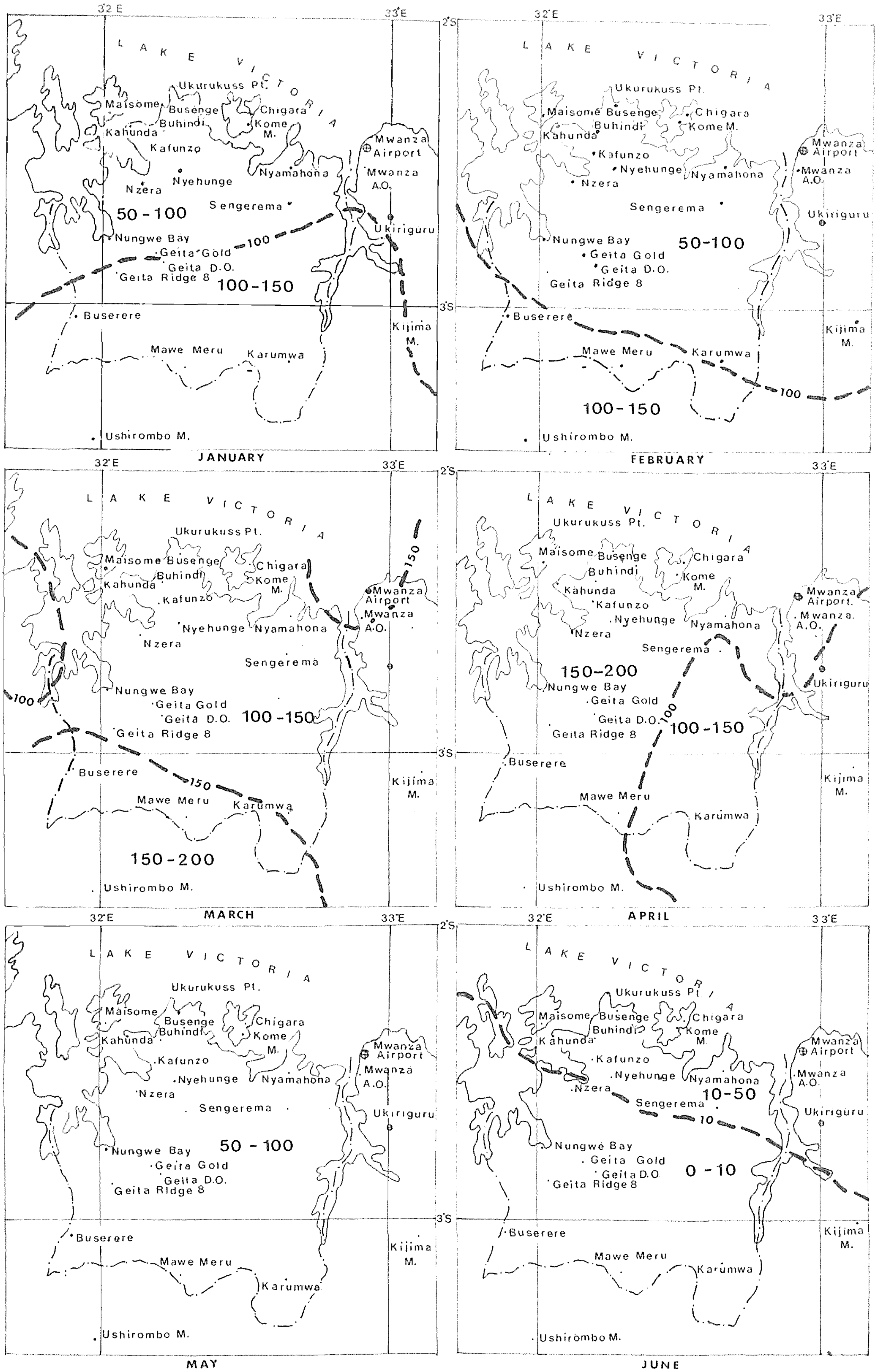


Fig.5–11 Mean Monthly Rainfall (January– June) based on Tomsett (1969)

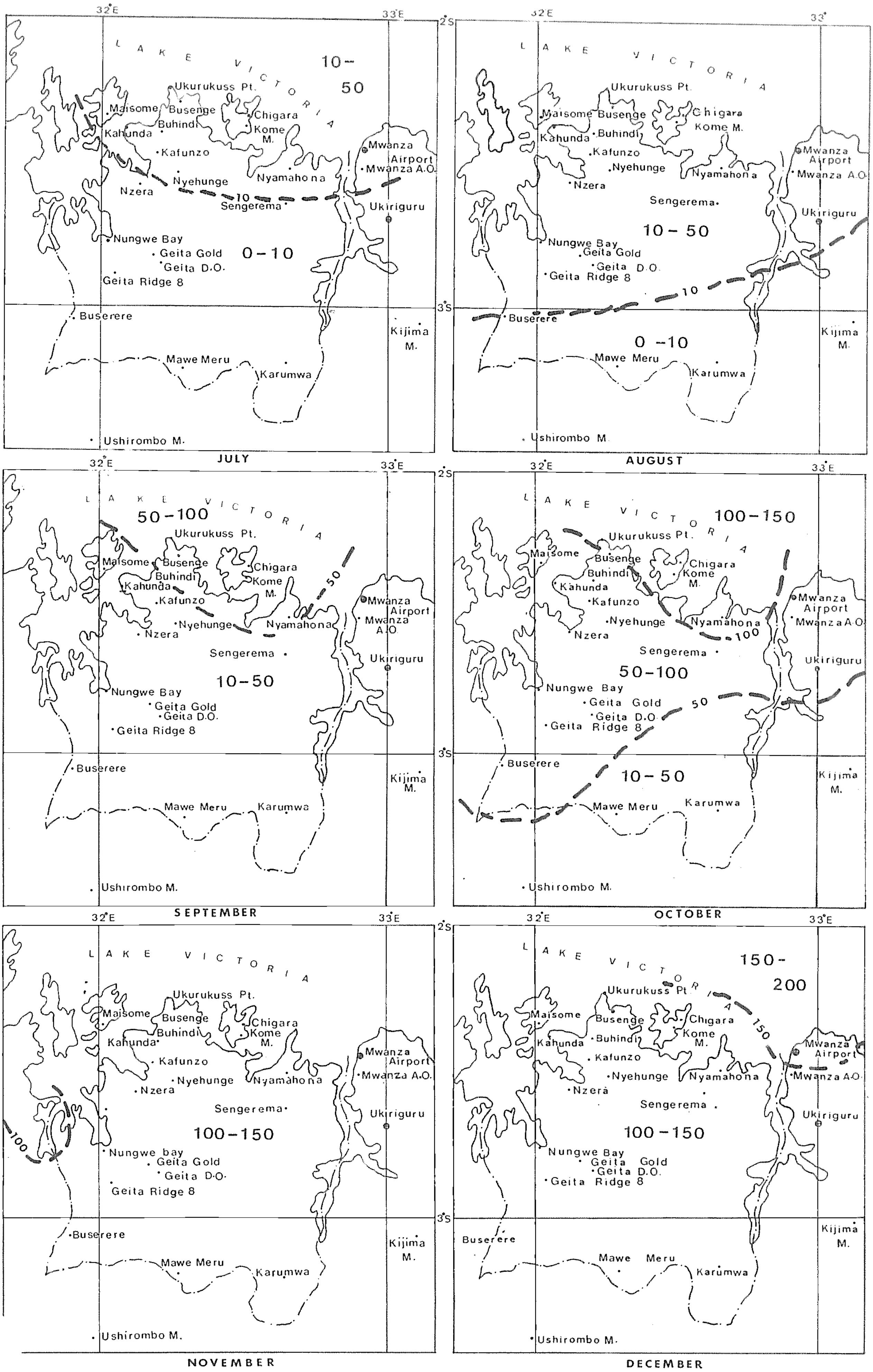


Fig. 11-16 Mean Monthly Rainfall (July-December) based on Tomsett (1969)

Monthly rainfall data for 11 rainfall stations are summarized in table 5. At all stations the rainfall shows a typical seasonal distribution, with more than 90% of the rain falling between October and May, and very little from June to September.

Two rainfall maxima occur, one in November-December and another one in March-April. January and February usually receive less rain.

A generalized picture of the geographical distribution of the mean monthly rainfall can be obtained from Tomsett's maps (1969), which are reproduced in fig. 4-15. The maps indicate that from January to March the southern part of the survey area receives more rain than the northern part. In April more rain falls in the west than in the east. From May to October the dominant trend is one of increasing rainfall towards the north. In November and December the mean rainfall is more or less uniformily distributed over the whole area.

b) Rainfall variability

Rainfall may vary considerably from year to year. Coefficients of variation listed in table 4 indicate that the annual rainfall can easily be 25% off the average. On a monthly basis the rainfall variability is even higher. Table 5 lists coefficients of variation of 40-70% from October to February, and of 30-60% in the more reliable rainy months of March and April.

The annual rainfall pattern in Geita and Sengerema districts, as in most of Tanzania, is characterized by a positive skewness (Niewolt, 1973). There is a higher probability that the annual rainfall amounts will be below the average than above, but that the lower values will deviate less from the average than the higher values.

From these facts it can be concluded that average rainfall data are likely to provide an overoptimistic picture of water availability and should be supplemented with an indicator that expresses what rainfall can reasonably be expected over a given return period, the reliable rainfall.

Frequently used indicators for the reliable rainfall are the 80% and 90% probability minimum rainfall. These are the minimum rainfall amounts that can be expected in 4 years out of 5, and 9 years out of 10 respectively, or alternatively the rainfall amounts that will not be exceeded in 1 year out of 5, and 1 year out of 10 respectively. A more correct formulation is that 80%, and 90% respectively of a series of years exceed these rainfall amounts.

Reliable rainfall data provide a much safer instrument for agricultural planning than averages. As a rule of thumb it is accepted that rainfall of at least 750 mm per year permits profitable maize growing. A rainfall of 500 mm or over would allow sorghum to perform well.

(*) Available maps of mean annual rainfall are somewhat in disagreement for the survey area.

The map of Mean Annual Rainfall in Atlas of Tanzania (1976) indicates for the whole survey area an average annual rainfall of 800-1000 mm. Tomsett's map of Annual Rainfall indicates for the north and west of the surveyed area an average rainfall of 1,000 - 1,200 mm and for the remainder 800 - 1,000 mm. Tomsett's map has been adopted here because it agrees better with the data of table 4.

Table 4. Annual Rainfall Data.

Station	Reference number	Location			No.	Annual Rainfall				
		Lat. (° .')	Long. (°.')	Altit. (m)	years record	mean	stand. deviat.	Coeff. variat.	80% P	90% P
Buhindi Forest Stat.	92.3215	not recorded			14	1318	136	10	1204	1147
Busenge	92.3218	2.18	32.18	1219	10	1419	282	20	1182	1064
Buserere	93.3104	3.04	31.53	1219	4	1207	*	*	*	*
Chigara (Kome isl.)	92.3220	2.20	32.51	1143	11	1254	364	29	948	795
Geita District Office	92.3210	2.52	32.15	1280	26	980	251	26	769	664
Geita Gold Mine	92.3203	2.52	32.10	1292	22	1018	233	23	322	724
Kafunzo Prim. School	92.3229	2.27	32.11	1182	7	907	*	*	*	*
Kahunda Hydromet. Station	92.32027	2.24	32.04	1145	7	1161	*	*	*	*
Karumwa N.A. School	93.3202	3.12	32.39	1158	6	797	*	*	*	*
Kome Mission	92.3201	2.21	32.29	1134	15	1017	256	25	802	694
Maisome	92.32019	2.21	32.00	1158	13	1175	286	24	935	815
Mawe Meru Mine	93.3201	3.07	32.13	1306	11	981	225	23	792	698
Mwanza Agric. Office	92.3200	2.31	32.54	1131	34	1025	227	22	834	739
Mwanza I.D & W.D.	92.3216	not recorded			13	1089	158	15	956	890
Mwanza Met. Station	92.3209	2.28	32.55	1140	27	1020	227	22	829	734
Nungwe Bay	92.3204	2.47	32.01	1134	15	864	295	34	616	492
Nyamahona	92.3206	2.31	32.38	1158	29	977	224	23	789	695
Nyegezi Mission	92.3208	2.38	32.52	1158	25	977	225	23	788	694
Nyehunge Prim. School	92.3228	2.32	32.18	1200	4	1065	*	*	*	*
Nzera	92.3223	2.34	32.08	1164	4	1093	*	*	*	*
Sengerema Agric. Office	92.3222	2.39	32.39	1210	6	1002	*	*	*	*
Ukiriguru Agric. Res. Stat.	92.3304	2.42	33.01	1199	27	827	209	25	661	574
Ukurukuss Point Buyindi	92.3211	2.15	32.13	1134	14	1200	368	31	891	736
Ushirombo Mission	93.3101	3.30	31.58	1189	17	972	311	32	711	580
Geita Ridge 8 Mine	92.3205	2.53	32.01	1303	14	1010	192	19	849	768

Notes: 80%P and 90% P: 80%, and 90% probability minimum rainfall respectively.
80%P had been calculated as: mean - 0.84 stand. deviat.; 90%P as : mean - 1.26 stand. deviat.
*: data not calculated because available records are insufficient for a reliable estimate.

Sources data: 1) Records from Meteorological Department, Dar es Salaam
2) Summaries of Rainfall (Yearbooks E. Afr. Met. Dept., years 1942-44, 1946-64, 1967, 1969, 1970)

Table 5. Monthly rainfall data

Station	Statistic	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Buhindi	X	65	130	182	200	84				76	101	194	164
	S	66	62	91	88	57				63	56	113	54
	V	69	48	50	44	68				83	55	59	33
	P	40	78	106	126	36				23	54	99	119
	N	15	16	15	16	16				16	16	16	15
Busenge	X	73	139	160	220	87				66	161	215	193
	S	58	108	104	109	65				37	90	76	137
	V	79	78	65	50	75				56	56	35	71
	P	24	13	73	128	32				35	85	151	78
	N	13	14	13	13	12				11	12	12	12
Geita D.O	X	98	60	124	155	78	9	6	11	43	79	139	145
	S	54	58	63	69	52	13	15	13	40	60	96	90
	V	55	54	51	45	67	44	250	118	93	76	69	62
	P	53	26	71	97	34	0	0	0	9	29	58	96
	N	26	26	26	26	26	25	26	27	27	27	27	27
Kome	X	81	50	133	165	64	18	23	43	73	115	109	112
	S	45	68	69	95	49					47	75	91
	V	56	31	52	58	77					41	69	81
	P	43	17	75	85	23					76	46	36
	N	18	18	18	18	17	17	17	17	17	17	18	17
Maisome	X	96	71	130	211	117				50	132	181	129
	S	77	68	77	110	86				41	94	86	77
	V	80	44	59	52	75				82	71	48	60
	P	31	14	65	119	42				16	53	109	64
	N	14	14	16	15	15				16	16	15	15
Mawe Meru	X	116	69	145	171	80	7	5	16	25	63	104	134
	S	51	62	63	66	64					49	44	81
	V	44	53	43	39	80					78	42	60
	P	73	48	92	116	26					22	67	66
	N	12	12	12	12	12	16	16	16	16	13	12	11
Mwanza Agr.Office	X	100	95	148	193	81	11	14	27	39	72	121	136
	S	60	45	82	68	45				47	62	85	86
	V	60	47	55	35	56				121	86	70	63
	P	50	57	79	136	43				48	20	50	64
	N	35	35	35	35	35				35	35	34	35
Nungwe Bay	X	75	84	131	181	72				54	68	137	142
	S	34	61	59	75	48				28	55	96	56
	V	45	73	45	41	67				52	81	70	39
	P	46	33	81	118	32				30	13	56	95
	N	23	24	25	25	22				17	18	19	16
Nyamahona	X	84	88	124	166	71	15	8	22	46	85	131	138
	S	43	58	73	73	55	24	21	26	34	57	103	76
	V	51	61	59	44	77	160	263	118	74	67	79	55
	P	48	43	62	105	25	0	0	0	17	37	44	74
	N	35	33	34	34	34	31	30	30	30	34	34	34
Ukiriguru	X	93	84	105	142	69	9	1	12	24	58	103	124
	S	51	44	58	62	43					41	74	64
	V	61	52	55	44	62					71	74	52
	P	50	47	56	90	33					24	41	70
	N	28	29	29	29	29	26	26	26	26	29	29	28
Ukurukuss	X	85	99	134	188	105	16	14	41	78	94	148	121
	S	79	63	69	89	82	26	27	34	71	57	112	52
	V	93	64	51	47	78	163	193	83	91	61	76	43
	P	19	46	76	113	36	6	9	12	18	46	54	77
	N	21	22	22	22	20	22	22	20	20	20	19	17

Notes: X: mean monthly rainfall (in mm); S: standard deviation (in mm); V: coefficient of variation (in %); P: 80% probability minimum rainfall; N: number of months with records

An 80% or 90% probability minimum rainfall of less than 750 mm would thus indicate a serious risk of maize crop failure in 1 year out of 5, 1 year out of 10 respectively.

80% and 90% probability annual rainfall data are listed in table 4 for those stations with sufficient records. From these figures it appears that the 80% reliable rainfall is about 20% below the average, while the 90% reliable rainfall is about 30% below the average.

80% probability monthly data are given in table 5. Concurring with the higher variability on a monthly basis, the 80% probability rainfall in the rainy season is about 40-60% below the average. In the dry months from June to September reliable rainfall is virtually nil.

The geographical distribution of the reliable annual rainfall is featured in figs. 3 and 4. Fig. 3 indicates that most of the survey area would have an 80% probability minimum rainfall of 750-1000 mm, with the exception of Maisome island, east Rubondo and the northwest tip of the Buhindi peninsula. These areas would receive 1000-1200 mm at the least in 4 years out of 5.

Fig.4 indicates that most of the survey area would receive at least 500-750 mm in 9 years out of 10, while Rubondo, Maisome and Kome islands and the Buhama peninsula would receive 750-1000 mm (*)

c) Rainfall intensity, duration and frequency

These rainfall characteristics are of great importance to assess both soil erosion and effective rainfall, which is the rainfall that enters the soil and remains within the root range.

Data on intensity, frequency and duration of individual rainstorms are not available for the surveyed area. From information from other areas with similar rainfall patterns it can be assumed that the rainfall intensity is high, and that a large proportion of the rain pours down in thunder-storms with an intensity that exceeds the threshold level at which rainfall becomes erosive (Hudson, 1971).

Moreover it can also be expected that large storms of high intensity will result in considerable water losses by surface runoff and by deep percolation beyond the rooting zone, thus reducing the effective rainfall.

(*) The rainfall Probability Map in Atlas of Tanzania (1976) gives higher estimates of the 90% probability minimum annual rainfall for the central part of the survey area. (750-1000 mm). The map of the E.A. Met. Dept. (1961) was adopted because it agrees better with the data of table 4.

Some data related to rainfall intensity and frequency are given in table 6 for Mwanza and Ukiriguru.

Table 6. Rainfall intensity and thunderstorm frequency data

Station	Rainfall characteristic	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Year
Mwanza (1950-70)	Maximum 24 h rainfall	63	146	112	151	65	32	52	99	54	118	72	130	151
	Number of days with thunder	14	13	13	15	8	4	3	5	8	15	15	17	130
Ukiriguru (1963-70)	Maximum 24 h rainfall	41	65	58	77	25	24	18	35	52	26	83	49	83

Source: E.A. Met. Dept. (1964)

Maximum 24 hour intensity values are higher for Mwanza than for Ukiriguru. This should not merely be attributed to significant differences in intensity but also to the fact that different return periods are compared (21 years for Mwanza, 8 years for Ukiriguru).

It should also be noted that, in relation to total annual rainfall and compared with other areas, the observed intensities are not particularly high. Nevertheless, in order to assess rainfall erosivity in a reliable way intensities during shorter observation periods (ex.g. one hour or one half hour) would be required but these are not available.

2.2.3. Evapotranspiration

To determine the agricultural potential of an area from the climatic viewpoint, rainfall data are not sufficient. The water gains from rainfall have to be related to the water losses by surface evaporation, plant transpiration, surface runoff and deep percolation beyond the root zone.

While surface runoff and deep percolation are difficult to assess, the combined action of evaporation and transpiration known as evapotranspiration can be estimated by different methods of which the Penman method is widely considered as the most reliable.

The Penman method refers to the estimation of the potential or reference evapotranspiration (hereafter denoted as ETo), which is defined as "the rate of evapotranspiration from an extensive surface of 8 to 15 cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water" (Doorenbos & Pruitt, 1974). Expressed in another way, it is the quantity of water required for optimal grass growth under a given climate.

The climatic data required to compute Penman evapotranspiration (temperature, humidity, windspeed, sunshine and radiation data) are not available for the stations of the surveyed area. Since the average potential evapotranspiration is rather uniform over large areas, the ETo-values from the two nearest meteorological stations (Mwanza Airport, and ARI Ukiriguru) have been applied to the surveyed area.

Table 7. Potential evapotranspiration according to Penman, Pan-evaporation and Blaney-Griddle methods (*)

Station	Method	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Mwanza Airport Met. Station	mm/day (Penman)	4.9	4.9	5.0	4.8	4.9	5.5	6.3	6.4	6.9	6.1	5.1	4.8	
	mm/day (Pan-evaporation)	4.4	4.4	4.4	4.2	4.2	4.4	4.1	5.0	4.5	4.5	4.7	4.4	
	mm/day (Blaney-Griddle)	4.0	4.0	4.1	3.8	3.8	3.7	4.2	4.2	4.3	4.6	4.5	4.0	
	mm/month (Penman)	152	138	195	144	152	165	195	198	207	189	153	149	1998
	mm/month (Pan-evaporat.)	137	124	137	127	134	133	127	155	135	141	141	137	1628
	mm/month (Blaney-Criddle)	124	113	127	114	118	111	130	130	129	143	135	124	1498
Ukiriguru Agric. Research Inst.	mm/day (Penman)	4.4	4.2	4.0	3.8	4.1	4.4	5.0	5.5	5.7	5.7	4.3	4.1	
	mm/day (Pan-evaporation)	4.4	4.1	4.1	3.9	4.1	4.5	5.1	5.4	5.4	5.0	4.7	4.2	
	mm/day (Blaney-Criddle)	3.7	3.0	3.0	3.4	3.8	5.1	5.0	5.1	5.2	5.7	3.4	4.1	
	mm/month (Penman)	136	119	124	114	127	132	156	171	171	177	129	127	1681
	mm/month (Pan-evaporat.)	135	116	127	116	127	134	159	166	163	154	140	129	1666
	mm/month (Blaney-Criddle)	115	85	93	102	118	153	155	158	156	177	102	127	1541

(*) Calculations of potential evapotranspiration are based on procedures in Doorenbos & Pruitt (1974)

Source data: E.A.Met.Dept. (1975). Climatological Statistics for East Africa. Part III. Tanzania.

The data from Ukiriguru are considered relevant for most of the surveyed area. The Mwanza data are considered representative for the lake shores where higher windspeeds prevail.

Penman potential evapotranspiration data for Mwanza and Ukiriguru are listed in table 7. For comparison are also given the ETo-values according to the Blaney-Criddle method and for the Pan-evaporation method, all computed following the procedures described in Doorenbos & Pruitt (174).

From this table it follows that:

1° the potential evapotranspiration values are high, watever the method of estimation. This is a characteristic common to all low and medium altitude tropical areas.

2° the seasonal differences in potential evapotranspiration are not very high due to the small variations in solar radiation throughout the year, and merely related to variations in cloud cover, windspeed, humidity and sun altitude. The relative difference between the highest and lowest Penman-value over the year is about 30%, and about 15% over the rainy season.

3° ETo-data for Mwanza are on the average about 15% higher than Ukiriguru-data, reflecting higher windspeeds around the lake shore.

4° The Penman method gives the highest ETo-values. It would therefore appear that the use of another method for ETo-estimation than the Penman may risk to considerably underestimate the actual water needs and alternatively, to overestimate the the climatic potential for agriculture.

As pointed out earlier, potential evapotranspiration (ETo) represents the effect of climate on water needs and refers exclusively to a grass cover. Crop evapotranspiration (ETm) represents the water needs for optimum growth of a particular crop and is therefore also defined as the crop water requirement. It is a more suitable indicator of individual crop water needs than the potential evapotranspiration. In early growth stages ETm is usually smaller than ETo but in later stages ETm may exceed ETo.

The ratio between the water requirement of a crop at a particular growth stage and the reference evapotranspiration is the crop coefficient (kc). Crop coefficients depend mainly on crop characteristics but also on planting periods. Reference evapotranspiration, crop water requirements and crop coefficients of cotton and maize are compared for two planting periods (October and January) in table 8 for the climatic conditions prevailing at Ukiriguru.

2.2.4. Evapotranspiration in relation to rainfall

The comparison of available water from rainfall with the water demand for evapotranspiration can be done through simple water-balance studies of the kind used by Sansom (1954).

An example of such simplified water balances based on average monthly rainfall and evapotranspiration data, is given for Ukiriguru in Table 9 and illustrated in Fig.17.

Table 8 Comparison of potential evapotranspiration, crop water requirements and crop coefficients for Cotton and maize, planted in October and January at ARI Ukiriguru

	J	A	S	O	N	D	J	F	M	A	M	J	TOTAL
Potential evapotranspiration Penman	156	171	171	177	129	127	136	119	124	114	127	132	1681
Cotton (6-month var.)													
Crop coefficients (*)				.29	.79	1.11	1.2	1.14	.83				
Crop water requirements (*)				110	102	141	163	136	103				755
Crop coefficients (o)							.80	.92	1.13	1.2	1.14	.83	
Crop water requirements (o)							109	109	140	137	145	110	750
Maize (5-month var.)													
Crop coefficients (*)				.63	.85	1.12	1.15	.87					
Crop water requirements (*)				112	110	142	156	104					624
Crop coefficients (o)							.81	.96	1.13	1.15	.87		
Crop water requirements (o)							110	114	140	131	110		605

(*) Crop planted in October

(o) Crop planted in January

Table 9. Average waterbalance for Ukiriguru

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo	136	119	124	114	127	132	155	171	171	177	129	127
R	93	84	105	142	69	9	1	12	24	58	103	124
Sc	0	0	0	+28	-28	0	0	0	0	0	0	0
Sa	0	0	0	28	0	0	0	0	0	0	0	0
ET	93	84	105	114	97	9	1	12	24	58	103	124
D	43	35	19	0	30	123	154	159	147	119	26	3
S	0	0	0	0	0	0	0	0	0	0	0	0

Table 10. Waterbalance for Mwanza, average year (1969)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo	152	138	155	144	152	165	195	198	207	189	153	149
R	172	222	110	47	89	0	0	0	29	78	140	204
Sc	+20	+75	-45	-97	- 8	0	0	0	0	0	0	+55
Sa	75	150	105	8	0	0	0	0	0	0	0	55
ETa	152	138	155	144	97	0	0	0	29	78	140	149
D	0	0	0	0	55	165	195	198	178	111	13	0
S	0	9	0	0	0	0	0	0	0	0	0	0

Table 11. Waterbalance for Mwanza, dry year (1949)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
ETo	152	138	155	144	152	165	195	198	207	189	153	149
R	29	40	5	201	25	13	1	29	23	25	57	314
Sc	-123	-27	0	+57	-57	0	0	0	0	0	0	+150
Sa	27	0	0	57	0	0	0	0	0	0	0	150
ETa	152	67	5	144	82	13	1	29	23	25	57	149
D	0	71	150	0	70	152	194	169	184	164	96	0
S	0	0	0	0	0	0	0	0	0	0	0	15

Explanation of symbols

ETo : average potential evapotranspiration (Penman)
R : rainfall
Sc : moisture storage change
Sa : Soil moisture storage
ETa : actual evapotranspiration
D : deficit
S : surplus

All terms of the waterbalance are expressed in mm.
Terminology is based on Sansom (1954).
Maximum moisture storage 150mm.

From this example it can be concluded that during II months the potential evapotranspiration exceeds rainfall and only during one month (April) rainfall exceeds evapotranspiration. Only in April the actual evapotranspiration equals the potential evapotranspiration. In the other months it equals rainfall plus soil moisture storage, if any. Soil moisture recharge would be confined to April, and this moisture would be fully utilized in May and possibly June. Thus it would appear that for most of the year the water available from rainfall would be less than the water needed for plant growth, even during the rainy season.

It should be noted that this would provide a misleading picture of seasonal water availability. The use of average rainfall data, and to a lesser extent of average evapotranspiration data, tends to mask a much more complicated pattern.

This is illustrated by the comparison of the waterbalance for Mwanza in an average year (fig.18, table 10) with the waterbalance for a dry year (fig. 19, table 11), From this example it is evidenced that due to the high rainfall variability the soil moisture recharge and utilization periods can vary considerably. In a normal rainfall year a crop could draw from the soil moisture reserve to overcome the dry spell in January but in a dry year a crop may fail because a period with considerable water deficit would separate the periods with rainfall maxima and soil moisture recharge.

In chapter 4 and Technical Appendix 3 it is discussed how the effects of rainfall variability on the climatic suitability for individual crops are assessed by means of a more sophisticated waterbance approach.

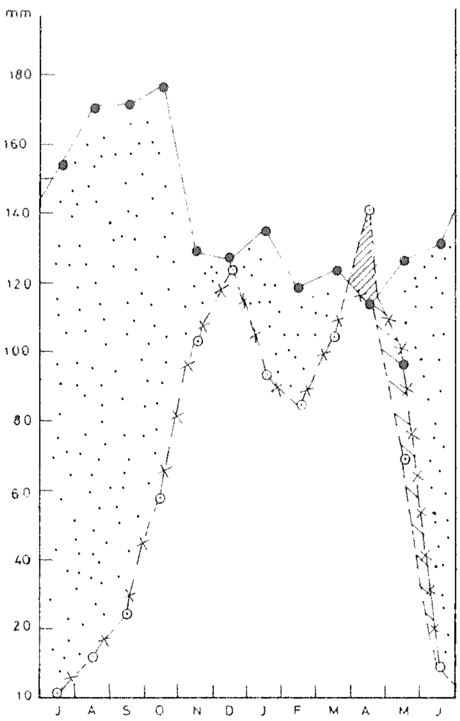
2.3. GEOLOGY

The rocks of the survey area form part of the Central Nyanza Shield, a rigid crystalline part of the earth crust composed of very old Precambrian rocks.

The oldest rocks belong to the Nyanzian system. This system is made up of basic, intermediate and acid volcanic rocks and interbedded sediments that have undergone slight metamorphism as a result of intense folding and subsequent granitic batholite intrusions. The age of these rocks is estimated at 2,600-3,000 million years. The Nyanzian rocks occur in steep hills aligned along parallel ridges with approximate W-E trend. They fall apart in two lithological subgroups :

Banded ironstones and quartzites

These rocks are characterized by a distinct banding of quartz and iron ore, being very hard and resistant to weathering. These have undergone gold mineralization and the main gold mines in the area are exploiting the ore in the banded ironstones and their weathering products.



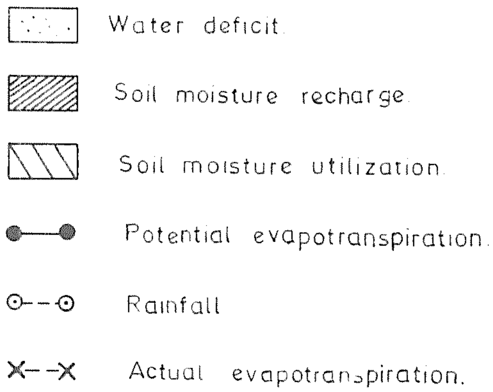


Fig.16
Average Waterbalance,
ARI Ukiriguru

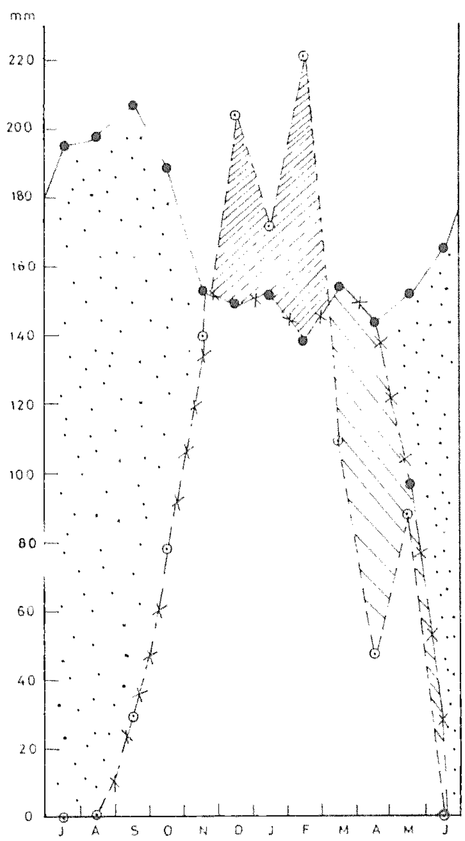


Fig.17
Waterbalance for Mwanza
Average year (1969)

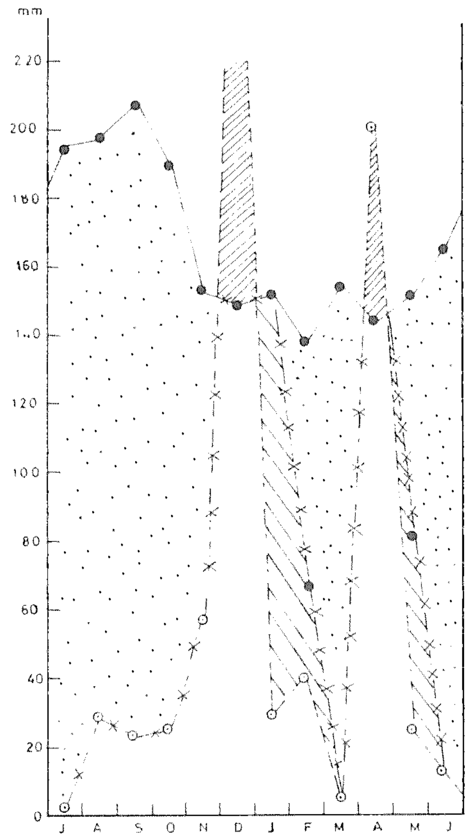


Fig.18
Waterbalance for Mwanza
Dry year (1949)

Greenstones

These rocks are a complex of different metamorphic rocks such as amphibole schists and basic metamorphosed volcanics. Fresh rocks have a green lustre, hence the name. These rocks weather more easily than the banded ironstones.

Next, but not widely separated in age, are the rocks of the Kavirondian system. In the surveyed area these rocks outcrop only on Maisome Island, where they are described as phyllites, with a few fine-grained sandstones (Geological Survey, Quarter Degree Sheet 20).

The Nyanzian and Kavirondian rocks are folded together along W-E fold axes and probably, together with the large associated granitic intrusions, they represent different stages of one complex Precambrian orogeny.

The most important rocks in the area are granites and granodiorites. They represent batholithic intrusions of post-Nyanzian and post-Kavirondian age, but emplaced before the end of the Precambrian. According to the time of formation with reference to the main orogenic movements, they are genetically subdivided in synorogenic and late-orogenic granites. The lithological differences between these genetic rock types are minor. So are the differences between the lithological subgroups, granite and granodiorite. The main mineralogical difference is a higher proportion of Ca-rich feldspars in the latter. These rocks are rather coarse-grained and have similar weathering behaviour.

They weather more easily than the banded ironstones.
No deposits are preserved that are younger than the Precambria to bear evidence of geological events that predate the Tertiary.

Throughout the Tertiary the area was subject to weathering and peneplanation. The only deposits that probably data back to this epoch are the Neogene Terrestrial (or Superficial) Deposits. They form a superficial, more or less thick cover over the Precambrian basement rocks, covering at present the slopes of hills and upland plains (see chapter on Geomorphology). They are subdivided in two lithological subgroups :

Superficial deposits derived from granitic rocks, which are in general clayey and include ironstone layers.

It should be noted that these deposits are not sediments in the true sense of the word, but the weathering products of the end-Tertiary peneplain. At the end of the Tertiary this peneplain was uplifted and warped, followed by stripping of an originally thicker weathering mantle (the regolith) and are from the gemorphological evidence dated as Neogene.

Effects of continuing earth movements and fluctuating lake levels in the Quaternary are reflected in the Lowland Superficial Deposits. These deposits occur in the lowest parts of the survey are and are lithologically and genetically complex. They include lake terrace and raised beach deposits of varying lithology, swamps and poorly drained alluvial deposits, often of considerable thickness, occurring in an extensive network of flat 'mbuga' bottomlands.

The various geological substrata are indicated in the legend of the generalized map of geology and geomorphology. (Map 1).

2.4. GEOMORPHOLOGY

A good correlation can be found in the surveyed area between the main relief features and the structural trends and lithological characteristics of the geological substratum.

The main physiographic zones recognized in the survey are are:-

1. Hills
2. Upland plains
3. Hill - Footslope associations
4. Lowland 'mbuga' plains
5. Lacustrine plains

2.4.1. Hills

On the basis of geological substratum the hills can be separated into:

Hills formed on granitic rocks

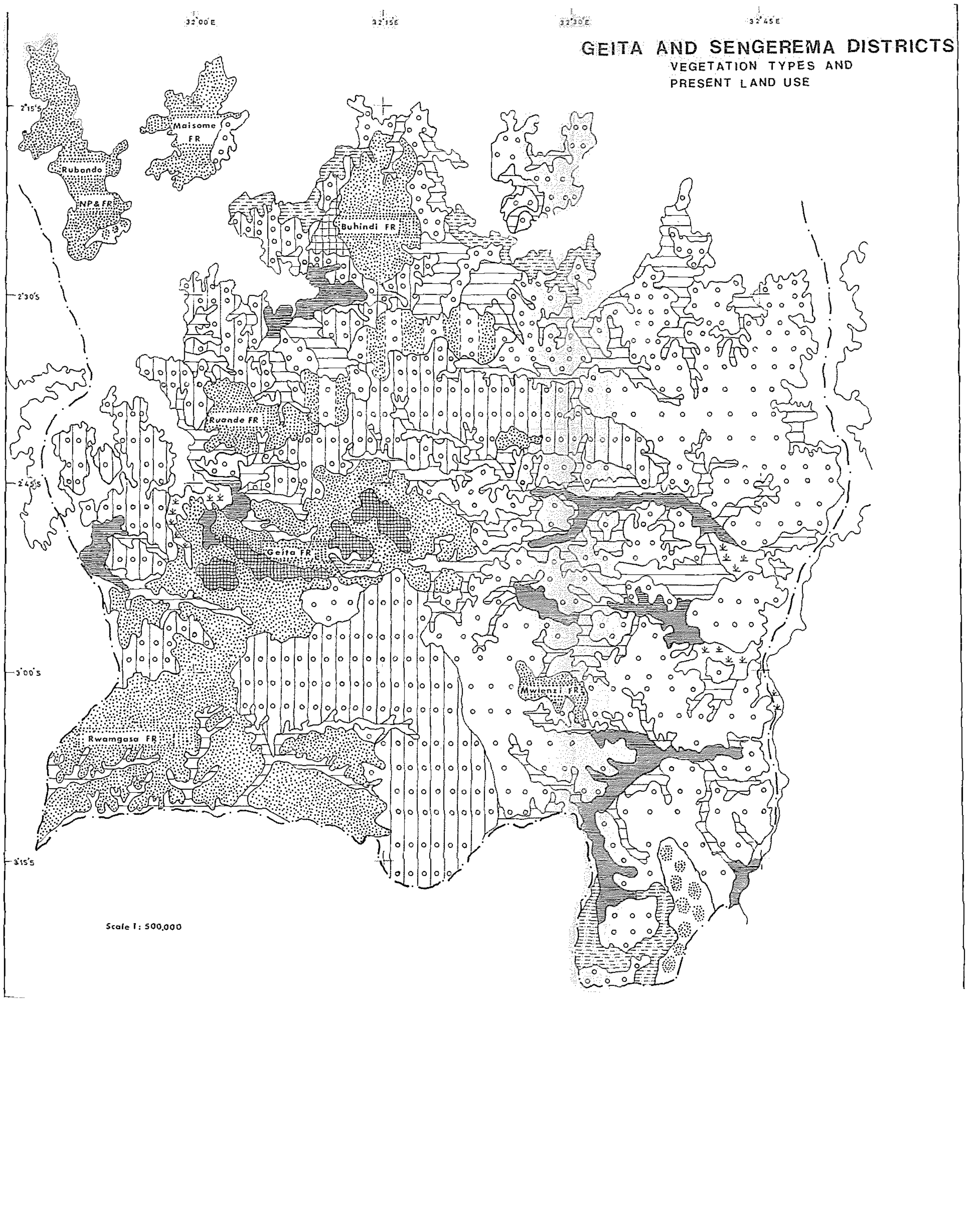
These hills are low (maximum 200 m above the intervening valleys) and rolling but distinctly dissected by drainage lines. They are characterized by tor-like exposures of rounded boulders or by whaleback type outcrops on the crests and summits. The slopes are formed by a piedmont zone of rather thin, sandy or loamy regolith in which soils have developed. Where these hills occur in groups, the summits are concordant at levels of 1300-1400 m above sea level. Where isolated, they are usually more strongly eroded and lower in attitude especially along the lake shores.

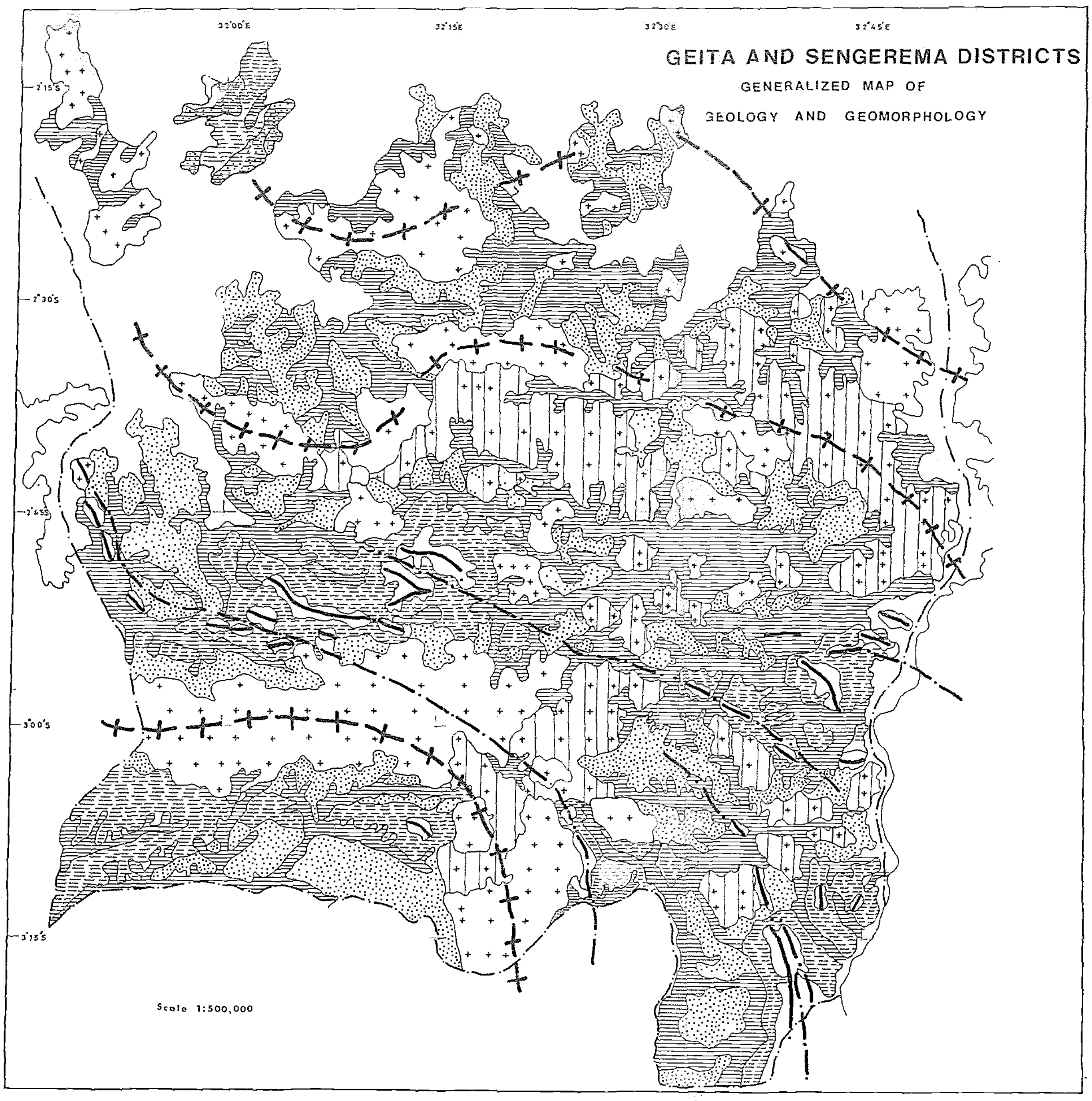
Hills formed on Kavirondian rocks

These hills are low and rounded and have bare tops. Their average altitude is about 1250 m above sea level. These hills occur only on Maisome island.

Hills formed on banded ironstones and associated rocks

These hills are high, steep and aligned along parallel ridges that can be several kilometers long. They are usually surrounded by a distinct piedmont zone. The summit levels are concordant at about 1450-1550 m above sea level in the west of the survey area, and 1400-1450 m in the southeast, and rise up to 300-400 m above the intervening valleys.

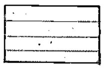
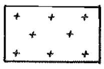
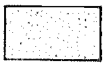
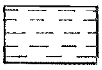
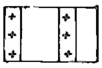

GEITA AND SENGEREMA DISTRICTS
VEGETATION TYPES AND
PRESENT LAND USE
32°00'E
32°15'E
32°30'E
32°45'E
2°15'S
2°30'S
2°45'S
3°00'S
3°15'S
Maisome FR
Rubondo
NP&FR
Buhindi FR
Ruande FR
Geita FR
Mwienzi FR
Rwamgasa FR
Scale 1: 500,000



GEITA AND SENGEREMA DISTRICTS
GENERALIZED MAP OF
GEOLOGY AND GEOMORPHOLOGY
32°00'E
32°15'E
32°30'E
32°45'E
2°15'S
2°30'S
2°45'S
3°00'S
3°15'S
Scale 1:500,000

GENERALIZED MAP OF GEOLOGY AND GEOMORPHOLOGY

LEGEND

GEOMORPHOLOGY		GEOLOGY
	*High steep hills on Nyanzian rocks*	*NYANZIAN SYSTEM* *Outcrops of banded ironstones and basic metamorphosed volcanics. No or very thin regolith.*
	*Low, rolling hills on Kavirondian rocks*	*KAVIRONDIAN SYSTEM* *Outcrops of sandstones and phyllites.* *No or very thin regolith.*
	*Low, rolling hills on granitic rocks.*	*SYNOROGENIC AND LATE-OROGENIC GRANITES.* *Outcrops of granites and granodiorites* *Generally thin sandy or loamy regolith.*
	*Undulating and rolling upland plains on granite substratum*	*NEOGENE UPLAND SUPERFICIAL DEPOSITS.* *Thick regolith cover, generally sandy or loamy.*
	*Undulating and rolling upland plains on Nyanzian and Kavirondian substratum*	*NEOGENE UPLAND SUPERFICIAL DEPOSITS.* *Thick regolith cover, generally clayey, with ironstone layers.*
	*Hill - upland plain associations*	*GRANITES AND SUPERFICIAL DEPOSITS.* *Granite and granodiorite rock outcrops, separated by thick sandy or loamy regolith cover.*
	*Flat lowland "Mbuga" plains, lake terraces, raised beaches, swamps, aggradational valleys*	*QUATERNARY LOWLAND SUPERFICIAL DEPOSITS.* *Sands and poorly drained sandy clays and clays.*

+ + + *Inferred trend lines of granitic hills and hill - plain associations*

—·—·— *Inferred trend lines of Nyanzian hills*

In view of the considerable erosion below these levels, Grantham (1945) assumed that these summits represent the remains of an old peneplain of early-Tertiary age or older. Similarly the concordant summits of the granite hills are considered to be the remains of the same old peneplain, but at a lower level because weathering proceeded more easily in the granite than in the highly resistant banded ironstone.

This old peneplain is tentatively correlated with the African planation surface.

2.4.2. Upland Plains

The upland plains are undulating or rolling low-relief features. They are covered by a usually thicker regolith than the hills.

According to morphological characteristics they can be subdivided into:

Piedmont plains around hills, with a concave profile. This type of plains is very common around the banded ironstone hills.

Upland plains without significant rock outcrop, with convex profile. This type of plains predominates in granite country.

According to the lithology of the geological substratum the upland plains can be subdivided into upland plains on granitic substratums; and upland plains on Nyanzian or Kavirondian substratum. The former are covered by a sandy to loamy regolith; the latter by a clayey regolith and ironstone layers.

The upland plains envelop a surface with approximate altitudes of 1180-1250 m. This surface is much less dissected than the older African surface and is representative for the Central Plateau of Tanzania. It is considered by Grantham (1945) as a younger peneplain, presumably of Miocene age and can be correlated with the late-Tertiary planation surface in other parts of Africa.

2.4.3. The Hill-Footslope Associations

These areas are rather extensive, flat or undulating piedmont surfaces covered by a usually thick regolith, with a central bouldery or castellated rock outcrop. In the survey area they are almost exclusively confined to granitic country. The summit levels of the central rock outcrops are usually lower than those of the hills zones, but generally between 1250-1300 m; the levels of the surrounding upland plains are also between 1180-1250 m. The size of the central rock outcrop is usually much smaller than that of a hill.

Clearly the hill-upland plain associations represent a more advanced stage of erosion of the old African peneplain. The central rock outcrops are the strongly eroded remains of the African surface, while the plains already form part of the late-Tertiary surface.

2.4.4. The lowland ('mbuga') plains

The lowland ('mbuga') plains cover the lowest parts of the surveyed area. They contain valley bottoms of varying width with very low relief intensity and poor drainage, and merge gradually into the upland plains. They occur at altitudes between 1180 and 1140 m above sealevel.

These bottomlands form part of the youngest (Quaternary) peneplain that is at present still expanding at the expense of the older surfaces. The main geomorphic process is aggradation, in contrast with the previous physiographic zones where degradation and erosion predominate.

2.4.5. The lacustrine plains

This physiographic zone refers to flat depression lands around the shores of lake Victoria that are apparently related to oscillating lake levels such as lake terraces, raised beaches and swamps. They occur at altitudes between 1160 and 1140 m.

The lacustrine plains are the youngest part of the Quaternary peneplain.

The generalized map of geology and geomorphology shows that the direction of the main physiographic zones is approximately W-E, which coincides with the alignment of the Nyanzian rocks. It is thought that this pattern is related to ancient tectonic lines and zones of weakness in the Precambrian substratum. In zones with strongly folded, crushed and sheared Nyanzian rocks erosion has most naturally etched out these zones of weakness. This explains why the best developed part of the Quaternary peneplain occurs in the eastern part of the survey area (between lat. 2°45'E), in a zone where one would normally expect the continuation of the Nyanzian system and its weathering materials. On the other hand in granitic rocks the weathering pattern and resulting scenery largely depends on the nature of the jointing. In the granites forming the present-day hills the density of the joints must have been lower than in those forming the present-day upland plains.

2.5. DRAINAGE AND WATER RESOURCES

Most rivers in the surveyed area flow north and east towares lake Victoria. In the southwest the rivers flow south and west towards the Malagarassi swamps, and eventually to lake Tanganyika.

The watershed between these two drainage basins is formed by the granite hill range in the southwest corner of the survey area, and approximately bordered by lat. 3°00'S and long 32°30'E.

The drainage basin of lake Victoria is characterized by a mature topography with broad, flat valley bottoms, grading smoothly into upland plains.

The valleys have little gradient and contain many swamps. Most rivers lack a perennial flow, banks and a wide channel. As a result they are not able to cantain the stormwaters in the rainy season, which spread out over the adjoining lowlands and keep them flooded or waterlogged for several months.

The river pattern is generally dendritic with tributaries converging to the main streams. It shows no relationship to the underlying rock structure. An exception is formed by the granitic hills of the Buhindi peninsula, where the drainage lines follow a clear rectangular pattern, with tributaries joining at right angles.

In contrast, the drainage towards lake Tanganyika appears more youthful, which can be attributed to the lower base level of the Malagarassi swamps. Valley bottoms are narrow and sandy lower hillslopes extend down to the edge of the 'mbugas'. There is also more structural control in this basin. The trend of the streams is predominantly SW or NW, which is attributed by Grantham (1945) to directions of major jointing or shearing in the granite.

Also more rivers with permanent flow seem to occur in this basin.

The supply of surface water varies according to the season: the rivers dry up in the dry season and overflow the bottomlands in the rainy season. To conserve the wet-season water several dams with hafirs have been constructed and these form now the major source of dry-season water in many villages.

Shallow groundwater is present but the reserves are limited. In granite country many small springs are frequently found at the junction of the sandy lower hillslopes and the clayey bottomlands. At this junction waterholes are frequently dug. Banded ironstone country is virtually devoid of shallow groundwater. Deeper groundwater reserves in the weathered granite are most probably considerable but remain at present untapped. As a matter of fact, the number of boreholes in the survey area is surprisigly small.

Although at present no serious water shortages exist in the survey area, it can be expected that population and cattle increase will put more pressure on the available water resources.

2.6. VEGETATION

In this report the vegetation of the survey area has been described on the basis of physiognomy, a classification by gross appearance, following the methodology and terminology given by Pratt, Greenway and Gwynne (1966). A classification on the basis of floristic composition, however useful, is not within the scope of this study.

The main physiognomic vegetation types that occur in the survey area are:

Woodland: a stand of trees, up to 18 m in height, with open or continuous but not thickly interlaced canopy, and a canopy cover of more than 20%.

Bushed woodland refers to woodland with 20-40% shrub cover.

Bushland: an assemblage of woody plants, mostly of shrubby habit, with a shrub canopy of less than 6 m in height and a canopy cover of more than 20%.

Wooded bushland: refers to bushland with 20-40% tree cover.

Grassland: land dominated by grasses, sometimes with widely scattered or grouped trees and shrubs, the canopy cover of which does not exceed 2%. If the canopy cover exceeds 2%, the appropriate terms are wooded grassland (2-20% tree cover) and bushed grassland (2-20% shrub cover).

The distribution and general characteristics of these vegetation types in the survey area is discussed in following paragraphs. Their distribution in relation to present land use is featured in map 2.

Before most of the natural vegetation was cleared by immigrants from Sukumaland at the beginning of this century, the survey area was covered by woodland. At present woodland is concentrated in the west and southwest, in the forest reserves of Geita, Ruande, Rwamagasa, Mwienzi and Buhindi, as well as the islands Rubondo and Maisome.

This woodland is currently described as 'miombo', referring to an association of broad-leaved, generally decidous trees, usually of the genera Brachystegia and Julbernardia, that is very widespread throughout southern Africa and covers about two-thirds of Tanzania. The trees have relatively slender trunks and much branched, light canopies and feathery foliage. They are very resistant to fire and have the peculiarity to flush into leaf before the onset of the rains.

In the agricultural areas outside these forest reserves 'miombo' woodland is steadily disappearing and only preserved on hilltops and upper slopes that are too rocky for cultivation.

The east of the survey area is dominated by bushland, mainly of the genera Combretum and Acacia. The poorly drained lowlands that are subjected to regular floods are invariable covered by grasslands. Other less common vegetation types are the Borassus palm grasslands on sandy soils with mobile groundwater near the lake Victoria shore and the permanent swamps in sheltered bays of the lake shore.

It appears that the distribution of the various vegetation types is largely determined by interactions between rainfall, soils and drainage conditions.

The western areas with good rainfall, deep, well drained soils with good water storing capacity carry a well developed 'miombo' woodland. Where soils are less well drained, bushland predominates. Very shallow soils on ironstone carry grassland, sometimes with interspersed stunted Combretum trees.

The eastern areas with somewhat less rainfall and either excessively drained sands or poorly drained heavy soils carry a more shrublike, often xerophytic vegetation.

It is also likely that human activities have played a major role in the distribution of the vegetation types. The intensive colonization of eastern Geita-Sengerema with its associated cultivation, overstocking and burning has apparently triggered the degradation of the original 'miombo' woodland into a drier secondary bushland. This is suggested by following observations:

1° the eastern boundary of the 'miombo' woodland coincides approximately with the boundaries of highest population and cattle density. It is not an ecological boundary.

2° the minimum rainfall necessary to support 'miombo' woodland (approximately 700-800 mm) is exceeded in the east (fig.1).

3° the scattered trees and shrubs that occur sporadically in the uplands of the east on sites that escaped clearing and invasion by more drought adapted species are 'miombo' species.

Map 2 features the general distribution of the main vegetation types in Geita and Sengerema districts in relation to present land use patterns. Following mapping units have been differentiated:

1) Dense 'miombo' woodland

This type of woodland is characterized by overlapping and interlacing tree canopies and gives from the distance the impression of a dense forest. There is little undergrowth. It occupies the banded ironstone hills around Geita. Widlife is present, especially baboons, and antilopes and occasionally some elephants.

Although this unit belongs to the Geita forest reserve, felling occurs at considerable scale, especially near to Geita town. Some parts of the steep slopes have been degraded to secondary bush and grassland by severe burning and felling without replanting, and are now used as grazing land.

2) Open 'miombo' woodland

This type of woodland is characterized by open and continuous but not thickly interlaced canopies. There is an important grass undergrowth. It occupies the forest reserves of Geita, Rwamagasa, Ruande, Buhindi, Mwienzi, Maisome and Rubondo.

The forest reserves are little grazed and well preserved but under increasing pressure from the adjoining agricultural areas for wood and land resources. Especially part of the Rwamagasa forest reserve is at present being cleared for agricultural development.

3) Derived bushland and grassland

This vegetation types is apparently derived from an original woodland by burning and overgrazing. It is confined to the slopes and hilltops of the banded ironstone hills near Bukwimba and the southern shore of Rubondo island.

4) Open 'miombo' woodland on hilltops and upper slopes

This vegetation type occurs in hilly country northwest of the Ruande forest reserve. It is similar to the open 'miombo' woodland, but is confined to the hilltops and upper slopes; while the lower slopes are cultivated.

It is a well preserved woodland with an important grassy undergrowth.

Narrow lints of gallery forest occur along the waterways.

The lower slopes are fully occupied for rainfed cultivation and produce the common upland crops.

5) Scattered remnants of 'miombo' woodland

In this mapping unit agriculture occupies most of the available land and has replaced the original 'miombo' woodland except on the rocky hilltops where cultivation is unfeasible. The main trees in these areas are 'miombo' species.

6) Scattered remnants of (secondary) bushland

As in the previous mapping unit the natural vegetation is only preserved on the non-cultivated rocky hilltops, with all the remaining land being cultivated. The trees associated with this vegetation are generally of a drier type, such as Combretum and Acacia genera, but typical 'miombo' trees may be encountered.

7) Vegetation of the seasonally waterlogged lands

The lowlands that are liable to waterlogging in the rainy season are in general covered by bushed or wooded grassland. Acacia bushland or bushed grassland predominates on the dark cracking clays, while decidous bush occurs on lowland soils with higher sand content. These areas form good grazing grounds and are frequently used for rice cultivation.

8) Floodplain vegetation

The deepest parts of the bottomlands that are frequently subjected to prolonged flooding are covered by edaphic grasslands. Edaphic grasslands derive their features from soil and drainage conditions, in contrast with derived or secondary grassland, which have probably formed from woodland as a result of burning, grazing or felling. Trees or shrubs are absent except on anthills.

These areas support a rich pasture and are valuable dry season grazing grounds. In the wet season they are not very suitble for grazing due to the extensive open water surfaces.

9) Edaphic grassland remants

In this lowland area with heavy clays most of the natural grasslands have been cleared for rice cultivation.

10) Permanent swamp vegetation

This vegetation type occurs near the lake shores in sheltered bays and may extend inland where it merges with the floodplain of the main rivers. It is composed mainly of papyrus, reeds and water grasses.

11) Anthropic forest

This mapping unit refers to a planted pine forest west of the Buhindi forest reserve.

MAP OF VEGETATION TYPES AND PRESENT LAND USE
LEGEND

VEGETATION TYPE	LAND USE
1. Dense "Miombo" woodland. Dense deciduous hill woodland. Often degraded to secondary bush and grassland	FOREST RESERVE Grazing of degraded areas. Wildlife refuge
2. Open "Miombo" woodland. Open, deciduous hill and upland woodland, well preserve	FOREST RESERVE Sparse grazing, wildlife refuge
3. Derived bushland and grassland	Grazing
4. Open "Miombo" woodland on hilltops and upper slopes	CULTIVATION Grazing
5. Scattered remains of "Miombo" woodland on tor-type granite hilltops	Cultivation of upland crops
6. Scattered secondary bushland on tor-type granite hilltops	
7. Vegetation of the seasonally waterlogged lands Grasses, decidous and thorny bush.	GRAZING Scattered rice cultivation
8. Floodplain vegetation Edaphic grasslands	Grazing
9. Edaphic grassland remains	Cultivation, mainly rice
10. Permanent swamp vegetation Mainly papyrus, reeds and water grasses	No land use
11. Anthropic forest Planted pine forest	Softwood resource

Abbreviations

NP National Park
FR Forest Reserve

From the map and the preceding descriptions it can be concluded that agriculture and natural vegetation are mutually exclusive. This is attributed to the fact that land-use in the area is by local standards very intensive. Except for the robust pastures of the floodplain areas, occupation of the land has nearly always caused massive deforestation and degradation of the natural vegetation, especially in eastern Geita and Sengerema. Here clearing of the natural vegetation has proceeded to such degree that the term "cultural steppe" has often been used.

In only one instance a significant woodland area, the Mwienzi forest reserve, has been preserved inside an agricultural area, probably because of poor sandy soils.

The main reason behind this intensive land use may be population pressure due to natural increase and continuing immigration from across the Mwanza Gulf, combined with a reluctance to open the big woodland areas of the West, where tse-tse infestation until recently was very high.

2.7. PRESENT LAND USE

The surveyed area is one of the leading cotton producing areas in the country and essentially agrarian in character. Agriculture is characterized by an overwhelming predominance of small farmsteads and by an important cattle raising component which, however, is usually not integrated with the arable farming and contributes little to the farmer's cash income.

The main forms of land utilization in the surveyed area are:

1. Agriculture

The main crops produced in the area are cotton, maize, sorghum, cassava, finger millet, sweet potatoes, groundnuts, rice, bananas and pineapples. Practically all of these crops are grown under a traditional smallholder system with the use of handtools and are labour intensive.

Cotton is the most important cash crop and contributes over 80% of total crop income. Cassava is the most important marketed food crop. All crops, except rice, are grown rainfed on the rolling uplands and lower hillslopes in rather sandy, easily workable soils.

Rice is the main lowland crop and is grown under controlled flooding on very small plots, scattered over the seasonally waterlogged lands. Rice is an important cash crop in the southermost part of Geita district, around Nyaghorongo, where it is grown on heavy clay soils with use of oxen.

Fertilizer, pesticide and insecticide inputs by smallholders are very low and confined to cotton and maize crops only. Fallowing is still the most widely used means to restore the natural fertility, but due to pressure on the land fallow periods nowadays are usually kept below optimal length (5-10 years). The fertilizer situation is improving in those villages that are incorporated in the Geita Cotton Project but there inputs are confined to cotton and maize.

Mechanized farming is very limited but more block farms are being established within the Geita Cotton Project area. The total area of these partly mechanized farms is a few thousand ha.

2. Livestock raising

According to estimates by the FAO census of Livestock in 1965, about 300,000 heads of cattle existed in the area. Figures on present cattle population are not available but are probably much higher.

Cattle raising is most intens in the eastern part, which corresponds with a higher population density and eradication of the tse-tse fly. The cattle population mainly consists of zebu-type cows, goats and sheep. It forms an important asset to the smallholder agriculture with the potential to substantially increase the farmer's income. However the cattle is to a very large degree maintained for its intrinsic social value and contributes little wealth to the monetary economy. Moreover livestock raising is not integrated with the arable farming system: grazing and cultivation in most cases occur on different land and the manure is generally not collected to fertilizer farmer's fields.

All rangeland is natural. There are no improved pastures and no ranches. The grazing lands are communally held and concentrated in the seasonally waterlogged or flooded lowland areas, which under traditional farming systems agricultural potential. Sometimes fallow fields are made available for communal grazing, while around Geita and the southern banded ironstone hills around Bukwimba grazing occurs on the steep hill slopes, where the original woodland vegetation has been replaced by secondary grasslands.

Overstocking does not appear a very serious problem at present, but the competition between cash crop growing and cattle raising will undoubtedly increase pressure on the land, in the near future. Soil erosion is already evident in certain areas of high cattle density.

3. Forestry

Although forest reserves occupy a major portion of the surveyed area, they have not been exploited so far on a modern, industrial scale. The main reason is probably that most of the forest trees are suitable only for firewood or charcoal but not for timber. Charcoal is therefore the major product from the forest areas and some of it finds its way to Mwanza and even Biharamulo. The main timber tree is 'Mninga' (Pterocarpus angolensis). All hardwood is processed locally and serves local demand. A pine plantation west of the Buhindi forest reserve serves as a softwood resource for Mwanza.

4. Wildlife preservation

Rubondo island, which is completely covered by 'miombo' woodland, has recently been declared a National Park.

Other forest reserves contain numerous wild animals, notably wild pigs, antilopes, baboons, elephants, buffaloes and many bird species.

5. Urban land

Urban land includes towns and villages, gold mines with their waste disposals, and quarries for rock, gravel or brick earth. It does not cover more than 1% of the area but is expanding, especially around Geita, Sengerema and the Rwamagasa gold mine.

Chapter 3

SOILS

This chapter includes a general account of the soils of Geita and Sengerema districts, a description of the mapping units and Soils Map.

Section 3.1 explains the legend of the Soils Map and discusses the main features of the Map.

Section 3.2. gives a broad outline of the soils of the surveyed area. In view of the importance of the parent rock in soil formation, the soils are grouped on the basis of the parent material from which they are derived. The soil descriptions summarize relevant profile and environmental characteristics, their distribution, extent and potential. Detailed technical descriptions of soil types together with analytical data are given in appendix 5 of this report.

Section 3.3. describes the mapping units that are shown on the Soils Map in terms of physiography, parent material, drainage conditions and soil associations.

3.1. THE SOIL MAP LEGEND

The legend of the Soils Map is included as a separate sheet at the back of this report. It is composed of two distinct parts:

The first part, covering the left-hand side of the sheet, lists the different physiographic units, mapping units and soil associations.

The second half of the sheet lists the different soils units, gives a summary of their characteristics and classifies each soil unit in terms of the FAO/UNESCO World Soil Map legend (1974) and the USDA Soil Taxonomy (1975).

The physiographic units are determined by physiography, parent rock and slope class e.g. steep hills on granite, 16-30% slope. A given physiographic unit usually comprises different soil units that may occur in varying or fixed proportions.

The mapping units are the basic units of the Soils Map. They refer to areas with a fair homogeneity of physiography, parent material, slope class and are characterized by a particular soil association.

A soil association is a group of defined soil units, that are regularly associated in a geographical pattern with certain proportions. The composition of a soil association is expressed by the relative proportions of the included soil units. The dominant soils are those that are most specific for the given soil association. In general they occupy more than 50% of the mapping units. Associated soils are also important and occupy on the average 20-50% of the mapping unit area.

Table 12. Areal extent of the mapping units and proportions of the soil units in the mapping units

Mapping unit	Areal extent (sq.km)	Dominant soil		Associated soil(s)		Inclusions	
		Symbol	Proport. (%)	Symbol	Proport. (%)	Symbol	Proport. (%)
Hl-g/1	907	G2	50-80	Gr,Gs,Gl	20-50	G3	0-20
Hl-g/2	12	Gr	>50	Gs	20-50	-	-
Hl-g	142	UNDIFFERENTIATED					
Ho-g/1	697	G2	50-90	G3	5-30	Gr,Gs,Gl	0-20
						L2	0-5
Ho-g/2	407	G2	79-100	-	-	G3	0-20
						Gr,Gs,Gl	0-10
Ho-g/3	13	G3	40-60	G2	30-50	Gr,Gs,Gl	5-15
Ho-g	34	UNDIFFERENTIATED					
H2-z	184	Zr	>50	Zs	20-50	-	-
Hl-z	59						
Ho-z	23						
Ho-k	67	Kr	>50	Ks	20-50	-	-
HlPl-g/1	96	G2	50-75	G3	20-45	Gr,Gs,Gl	5-15
						L2	0-5
HlPl-g/2	120	G3	50-80	G2	20-50	Gr,Gs,Gl	0-10
HoPl-g/1	890	G2	50-75	G3	20-45	Gr,Gs,Gl	5-15
						L2	0-5
HoPl-g/2	325	G3	50-80	G2	20-50	Gr,Gs,Gl	0-10
HoPo-g/1	21	G2	50-75	G3	20-45	Gr,Gs,Gl	5-15
						L2	0-5
HoPo-g/2	18	G3	50-80	G2	20-50	Gr,Gs,Gl	0-10
HoPl-z	19	Zl	80-90	Zr	10-20	Zi	0-5
Ul-g/1	640	G2	50-90	G3	10-50	Gr,Gs,Gl	0-10
						L2	0-10
Ul-g/2	162	G3	80-100	-	-	Gr,Gs,Gl	0-5
						G2	0-20
Ul-g/3	335	G3	50-90	G2	10-50	Gr,Gs,Gl	0-20
						L2,L3	0-5
Ul-g/4	68	G2	80-100	-	-	Gr,Gs,Gl	0-5
						G3	0-20
Ul-g	17	UNDIFFERENTIATED					
Uo-g/1	543	G3	50-90	G2	10-50	L2	0-5
Uo-g/2	267	G3	50-90	G2	10-50	L1,L2,L3	0-10
Uo-g/3	149	G3	50-90	G2	10-50	-	-
				L1,L2,L3	10-30		
Uo-g	75	UNDIFFERENTIATED					
Ul-z	705	Zl	70-90	-	-	Zl,Z2	10-20
Uo-z	512	Zl	70-90	-	-	Zi,Z2	10-20
Mw/1	450	L2	90-100	-	-	G3	0-10
Mw/2	351	L2	50-90	L3	10-50	G3	0-10
Mw/3	361	L3	50-80	L2	20-50	L1,G3	0-20
Mw	47	UNDIFFERENTIATED					
Mf/1	372	L2	50-90	L3	10-50	G3,G2	0-10
Mf/2	336	L3	80-100	-	-	L2	0-20
Mf	5	UNDIFFERENTIATED					
Lt	87	G3	50-80	L4	20-50	L2,L3,L5	0-20
Lb	95	G3	50-80	L5	20-50	L4,L2	0-20
Lp	192	-	-	-	-		

Inclusions are minor soils that occupy less than 20% of a mapping unit. More precise estimations of the relative importance of the individual soils units in each mapping unit are given in table 12.

The soil units are the basic soil bodies recognized during the survey. They are described in detail in Section 3.2. and Technical Appendix 5. The mapping units are described in Section 3.3. of this chapter.

Each mapping unit is identified on the Soils Map by a mapping symbol, for which the following code system has been used: first symbol (capital letter) refers to the physiographic zone :

H : Hills
HP : Hill-footslope associations
U : Upland plains
M : Lowland ("mbuga") plains
L : Lacustrine plains

Second symbol (number or small letter)

If a number, it refers to the slope class of the physiographic zone considered : e.g.

Ho : rolling hills, 8-16% slope
HI : steep hills, 16-30% slope
UI : undulating uplands, 2-8% slope

If a small letter, it refers to the particular subdivision of the physiographic zone: e.g.

Mw : seasonally waterlogged ("mbuga") lowland plains.
Mf : ("mbuga") floodplains

third symbol (small letter, if present) refers to the parent rock ex.g.

g : granitic rocks
Z : Nyanzian rocks
k : Kavirondian rocks

fourth symbol (number) refers to the specific soil association ex.g.

UI-g/1 : undulating upland plains on granitic rocks, characterized by the soil association in which G2 occurs as dominant soil, G3 as associated soil and Gr, Gs, G1 and L2 as inclusions.

3.2 GENERAL DESCRIPTION OF THE SOILS

The soil types and their general distribution in the surveyed area are chiefly determined by the parent material and the topography.

On granitic uplands well drained, sandy or loamy soils predominate. On uplands with Nyanzian or Kavirondian substratum well drained, friable clays predominate with surface or shallow ironstone as secondary formations. In lowlands clayey soils occur, with deficient drainage.

In this section the soils of the survey area will be discussed in relation to the main soil forming factors, parent material and topography.

In relation to parent material and topography three main soils groups can be differentiated:

1) Upland soils on granitic rocks
2) Upland soils on Nyanzian (and Kavirondian) rocks
3) Lowland soils

3.2.1. Upland soils on granitic rocks

The main soil units differentiated on granitic substratum are the following:

3.2.1.1. G1-Soils: Dark skeletal loams

GI-Soils comprise mainly well drained, shallow, very dark colored sandy loams, with high organic matter content, high base supply and good structure.

They occupy the rocky hilltops and eroded upper slopes of the granite uplands and occur always in association with rock outcrops (Gr) and very shallow, undifferentiated soils (G_s). These soils are not very widespread. They are most extensive in the granite hills, where in conjunction with the rock outcrops and shallow soils, they occupy about 10-33% of the terrain. They are less extensive on the upland plain areas where, in association with the rock outcrops, they occupy 0-5% of the land.

The natural vegetation is usually 'miombo' woodland, in some places secondary bush. Although very fertile, these soils are usually left under natural woodland because they are too shallow to cultivate.

GI is the symbol used for these soils in the legend of the Soils Map. A detailed description of these soils and analytical data are given in technical appendix 5.

3.2.1.2. G2-soils: Gritty reddish or brown loams

G2-soils comprise well drained, yellowish red or brown, deep, friable, gravelly sandy loams and sandy clay loams, with weak structural development. They are slightly acid, have a low to moderate base supply and low to moderate organic matter content.

These soils occur on the upper and middle slopes of the granite hills as well as on the summits and convex upper parts of the upland plains. They are the most common soils on granite, covering 40-73% of granite territory. They are most extensive in the hill areas where they occupy 56-90% of the terrain, and least extensive on the upland plains, where they cover only 23-60% of the land.

The natural vegetation is 'miombo' woodland, but usually these soils are brought under intensive cultivation of the common food and cash crops. The fertility is rather low but they retain moisture quite well, especially in the subsoil. Nevertheless unreliable rainfall in some parts of the surveyed area is a major limitation for agriculture.

The soil symbol on the legend of the Soils Map is G2. These soils are described in detail in Appendix 5.

3.2.1.3. G3-soils: Pale brown sands

G3-soils comprise deep, moderately well to somewhat excessively drained, brownish (loamy) sands. These soils are usually structureless and become progressively paler with depth. They are slightly to medium acid, have a low base supply and usually a low organic matter content.

These soils usually occur on the middle or lower slopes of granite landforms and are more or less influenced by mobile groundwater. They are the second most important soils on granite, with an estimated extent of 23-56% of the granite country. They are most extensive on the upland plains, on which they cover most of the slopes (39-86%). They are least extensive in the hills, where they cover only small parts of the lower slopes (3-26%).

The natural vegetation is 'miombo' woodland, bushland or wooded grassland, but most has been cleared for cultivation. The main crops grown on G3-soils are drought reistant crops (cassava, sweet potatoes) and to a leaser extent exacting crops like cotton and maize.

The fertility of these soils is definitely low, their water storing properties are poor but crops may benefit from seepage additions. The agricultural potential is very limited and fertilizer or manure use is required for sustained crop production.

The soil symbol used in the legend of the Soils Map is G3. A more detailed description of these soils, with analytical data, is given in Technical Appendix 5.

3.2.1.4. Gs-soils: Undifferentiated shallow soils on granitic rocks

Gs-soils comprise somewhat excessively or well drained, very shallow and gravelly, black or greyish sandy loams. At the scale of the survey they have not been differentiated further.

These soils occur mainly on the eroded upper slopes and rocky summits of granitic hills or hill-footslope associations and are intimately associated with G1-soils and granitic rock outcrops (Gr). They are usually covered by 'miombo' woodland or by secondary bush.

These soils are too shallow for cultivation and are left under protective woodland or bush.

The soil symbol in the legend of the Soils Map is Gs.

3.2.1.5. Gr: Granitic rock outcrops

Granitic rock outcrops comprise a variety of coarse-grained rock types with minor lithological or mineralogical differences but similar weathering behaviour. Most outcrops of granitic rocks have rounded, bouldery shapes.

Granitic rock outcrops occur mainly in hills and hill-footslope associations and to a much lesser extent in upland plains, usually as tor-type exposures of rounded boulders on the crests and summits. They are always left under natural 'miombo' woodland or under secondary bushland.

The symbol in the Legend of the Soils Map is Gr.

3.2.2. Upland soils on Nyanzian (and Kavirondian) rocks

The soils described in following paragraphs were identified on Nyanzian substratum. Kavirondian outcrops only occur on Maisome Island, where no field work was undertaken. On the basis of existing geological reports and maps it was assumed that areas with Kavirondian rocks are covered by similar soils as the ones differentiated on Nyanzian rocks.

The main soil units distinguished on Nyanzian and Kavirondian substratum are the following:

3.2.2.1 ZI-soils : Friable, red or brown clays

ZI-soils include well drained, reddish or brownish, deep, friable clays. These soils are porous and permeable and have a weak or moderate structure. They are slightly acid, have a moderate to high organic matter content and a very low base supply.

These soils are the most common soils on Nyanzian rocks. They occupy the major part of the upland plains and of the footslopes that surround the Nyanzian hills.

The natural vegetation is 'miombo' woodland and is usually well preserved. These soils are usually not cultivated, probably because the high clay content makes them too heavy for cultivation by hand methods. Yet they have favourable properties for plant growth, although they tend to be droughty by their high permeability and clay content. Moreover fertility limitations also exist in view of the very low nutrient retention capacity. Nevertheless these soils should respond well to fertilizers and to manure.

The soil symbol on the legend of the Soils Map is ZI. Detailed descriptions of these soils with analytical data, are given in Appendix 5.

3.2.2.2. Z2-soils: Friable, yellowish clays

This second soil type on Nyanzian rocks refers to similar soils as the ZI-soils, but modified by deficient drainage due to continous ironstone at shallow depth. Z2-soils include moderately well drained, yellowish friable clays, shallow or moderately deep, with weak or moderate structure. They are slightly acid and have a very low base content and a moderate organic matter content.

These soils have many characteristics in common with the Z1-soils but differ by somewhat deficient drainage and shallowness due to continous ironstone in the subsoil.

These soils are of very limited extent. They occupy less than 7% of the banded ironstone country. They occur on almost flat parts of lower or middle slopes, surrounding the Nyanzian hills or upland plains.

The natural vegetation is wooded grassland. These soils are usually not cultivated and in view of their limited extent not very important for agriculture.

The soil symbol in the legend of the Soils Map is Z2. Analytical data for this soil are given in Appendix 5.

3.2.2.3. Zs-(Ks-) soils : Undifferentiated shallow soils on Nyanzian (Kavirondian) rocks)

Zs- (Ks-) soils comprise somewhat excessively or well drained, very shallow and gravelly, dark reddish brown clay loams and loams. They occur in intimate association with Nyanzian (Kavirondian) rock outcrops. At the scale of the survey they have not been differentiated further.

These soils occur on the slopes of Nyanzian (Kavirondian) hills and are covered mainly by 'miombo' woodland, to a lesser extent by secondary bushland or grassland. Due to their shallowness and steep slopes they have no potential for cultivation, and are usually left under protective woodland.

The soil symbol in the legend of the Soils Map is Zs for shallow soils on Nyanzian rocks and Ks for shallow soils on Kavirondian rocks.

3.2.2.4. Zi : ironstone caps

Extensive areas of these uplands are covered by ironstone caps. The thickness of these caps in variable but on the average about 1 m. The ironstone caps are very conspicuous in the landscape because they are covered by sparse short grasses, which contrast markedly with the surrounding 'miombo' woodland on the deeper soils. The extent of these ironstone caps is estimated at 10-20% of the banded ironstone country. The areas with surface ironstone have no agricultural use, except for some sparse grazing.

The ironstone caps are denoted in the legend of the Soils Map by the symbol Zi.

3.2.2.5 Zr (Kr) : Nyanzian (Kavirondian) rock outcrops

According to lithology the Nyanzian rocks are separated into banded ironstones, quartzites and greenstones. The banded ironstones are characterized by a distinct banding of quartz and ironstone. They are very hard and resistant to weathering. The greenstones are a complex of different metamorphosed rocks.

Fresh rocks have a green lustre, hence the name. Greenstones weather more easily than banded ironstones. Most outcrops of Nyanzian rocks have angular, bricklike shapes.

Kavirondian rocks are described in the geological reports as phyllites and fine-grained sandstones. It is assumed that these rocks weather fairly easily and produce similar soils as the Nyanzian rocks.

Nyanzian rocks outcrops occur almost exclusively in hills. Hills on banded ironstones form the highest and steepest parts of the surveyed area. Hills on greenstones and Kavirondian rocks are lower and have less steep slopes. Areas covered by Nyanzian and Kavirondian rock outcrops have no agricultural potential and usually left under protective woodland.

The symbol in the Legend of the Soils Map is Zr for Nyanzian rocks, and Kr for Kavirondian rocks.

3.2.3. Lowland soils

The lowland soils are characterized by more clayey textures and more deficient drainage than the upland soils. They are all formed on surfaces on which accumulation is (or was) the dominant geomorphic process.

Two kinds of lowland soils can be distinguished. The first kind comprises soils that form part of a soil-topography association (or catena) and are thus a continuation of the upland soils. The second kind comprises soils that are apparently derived from Victoria lake sediments.

Within the first kind, three major lowland soil types can be distinguished :

3.2.3.I. LI-soils: Hardpan sandy (clay) loams and sandy clays

These lowland soils include moderately well or imperfectly drained, grey or brown sandy loams to sandy clays, with a hardpan horizon within 50 cm. Typically in wet weather they are oversaturated in the topsoil, but dry in the subsoil. These soils have slightly acid to neutral topsoils and moderately to strongly alkaline subsoils. They are often calcareous, slightly to moderately sodic and have a moderate to high base supply.

These soils occur at the transition between the sandy lower slopes of the granitic uplands (G3-soils) and the clayey bottomlands. They are not extensive and appear to be confined to the eastern part of the survey area.

Their natural vegetation is very short grassland with low bush. These soils are normally used as extensive grazing grounds, sometimes for rice cultivation where seepage water can easily be captured. The stock carrying capacity for grazing is however very low because of the scattered grass cover.

The soil symbol on the Soils Map legend is LI. More details on these soils, including analytical data, are given in Appendix 5.

3.2.3.2. L2-soils : Greyish mottled sandy (clay) loams and sandy clays

These lowland soils include deep, imperfectly drained, grey or dark brown sandy loams to sandy clays without hardpan. These soils have a quite sandy and dark grey surface horizon, but become progressively more clayey and strongly mottled in the subsoil. The soil reaction is slightly to strongly acid and there is usually no calcium carbonate accumulation in depth. These soils have a rather low base content and a moderate organic matter content. Although quite clayey in depth, they usually do not develop cracks.

These soils occupy the edges of wide lowland plains or the valley bottoms in dissected granite country, and are waterlogged in the rainy seasons. These soils are the most extensive ones in the lowland plains, covering 38-61% of the area.

The natural vegetation is bushland or bushed grassland. They are valuable grazing grounds but sensitive to overgrazing. Although the soils have favourable physical properties for rice growing and a moderate fertility status, only areas with a reliable water supply from seepage or runoff offer a moderate potential.

The symbol in the legend of the Soils Map for these soils is L2. Soil body descriptions and analytical data are given in Appendix 5.

3.2.3.3. L3-soils : Dark cracking clays

These lowland soils include imperfectly to poorly drained dark grey (brown) or black sandy clays and clays. These soils are deep and characterized by deep and wide cracking in dry weather, but are impervious and flooded in the rainy season. They are slightly acid or neutral on top to alkaline in the subsoils and usually contain calcium carbonate concretions at variable depth. The soil matrix may be calcoreous or not. The base supply is high, but the organic matter content is rather low, notwithstanding the dark colors.

These soils cover the lowest parts of the bottomlands, are subject to regular flooding, and cover 24-43% of the lowland plains.

The natural vegetation is either dense grassland or gall Acacia bushland. These soils form valuable dry-season grazing grounds, which appear very resistant to overgrazing. They are usually not cultivated. Their adverse physical properties and extremes of drought and flooding make them unsuitable for subsistence level agriculture. Nevertheless, they are very fertile and offer a good potential for various crops under careful and adapted soil and water management.

The soil symbol in the legend of the Soils Map is L3. A more detailed description of these soils, with analytical data, is provided in Appendix 5.

Within the second group of lowland soils, presumed to be derived from old Victoria lake sediments, two main soil types have been distinguished.

3.2.3.4. L4-soils : Compact, sodic sandy (clay)

These soils include imperfectly drained, very compact sandy (clay) loams with a shallow cover of (loamy) sand or sandy loam. In wet weather the sandy top is usually supersaturated, the subsoil impervious. These soils are neutral or slightly alkaline, moderately or strongly sodic. They have a moderate or high base supply especially in the compact subsoil.

These soils occupy depression lands around lake Victoria, apparently former shallow lake bottoms between 1140 and 1160 m altitude. They are of limited extent.

The natural vegetation is very short grassland with scattered Acacia trees. These soils are not utilized. Their susceptibility to extremes of drought and flooding make them unsuitable for cultivation.

The symbol for these soils on the legend of the Soils Map is L4. Detailed descriptions and analytical data for these soils are given in Appendix 5.

3.2.3.5. L5-soils : Dark sands

These lowland soils comprise well to imperfectly drained; very dark coarse sands. These sands are slightly acid to neutral, have a high organic matter content throughout the profile, and moderate base supply.

These soils are not very extensive. They occur in depressions bordering the Victoria lake that are most likely former lake beaches. A permanent groundwater table is present at variable depths.

The natural vegetation is either swampy grassland in the lowest sites or Borassus palm grasslands on higher ground. Where the soils are not waterlogged, they are intensively cultivated. They are moderately fertile and the usually high groundwatertable makes up for the poor water storing properties.

The symbol on the Soils Map for these soils is L5. Analytical data for this soil type are given in Appendix 5.

3.2.4. Soil distribution in relation to physiography.

The choice of physiography units characterised by particular soil associations as mapping units is sensible because of the clear relationships between soil distribution and physiography. These relationships are illustrated in the cross-sections at the base of the Soils Map.

These relationships are well marked in granite areas where the presence of particular soils can be adequately predicted from their position along the slope.

Such a succession of soil types in relation to topography is termed a 'catena' or 'soil-topography association'.

In granitic areas the distribution of soils in relation to topography is in general as follow:

from granite hilltop or upland plain summit to bottomland following soil types succeed each other: G1 - G2 - G3 - L1 - L2 - L3.

It should be noted that this sequence represents a hypothetical case where all members of the catena are present along the slope. This is not always the case. G1-soils may be absent on upland plains and L3-soils may be absent in narrow bottomlands. The hardpan soils L1 appear to occur exclusively in the eastern part of the survey area, and their presence seems to depend on climatic factors (see Appendix 4). In granite areas it is also found that the proportions of the various soils are strongly related to the nature of the surrounding physiography. The G2-soils are most common in the hills, together with the G1-Soils. In conjunction with the rock outcrops they cover about 65-100% of the hill country. In hilly areas G3-soils occupy only 3-25% of the land. In areas with a less dissected, more flattened topography the relative importance of the G3-soils increases at the expense of the G2-and G1-soils. Thus in the hill-footslope associations G3-soils occupy 29-56% of the land, and on the uplands plains their extent is maximal (39-86%). At the same time the extent of the G2-soils decreases to 41-67% in the hill-footslope associations and to 23-60% in the upland plains.

The general distribution of soils in granite areas is illustrated by cross-section A-B at the base of the Soils Map.

In areas with Nyanzian rocks there is no evident catenary distribution of soils.

The general distribution of soils in areas with Nyanzian rocks is illustrated by cross-section C-D at the base of the Soils Map.

3.3. DESCRIPTION OF THE MAPPING UNITS

A mapping unit is part of a physiographic unit and is characterized by a particular soil association. In the chapter on geomorphology five major physiographic zones were recognized in the survey area. These are:

1) Hills
2) Hill-footslope associations
3) Upland plains
4) lowland ('Mbuga') plains
5) Lacustrine plains.

The physiographic zones are subdivided into 19 physiographic units on the basis of primarily the parent rock, and secondly the slope class. The 19 physiographic units are further subdivided into 39 mapping units on the basis of soil associations.

This section describes the mapping units in the same order in which they are shown on the Soils Map.

3.3.1. Hills

According to geological substratum the hills can be subdivided into:

1) Hills on granitic rocks
2) Hills on Nyanzian rocks
3) Hills on Kavirondian rocks

3.3.1.1. Hills on granitic rocks

These hills are usually low (summits rise at most 200 m above the intervening valleys) and broad, but distinctly dissected by drainage lines. The crests are characterized by tors or whale-back-type exposures of rounded boulders. The pediment-like slopes are covered by a thin loamy regolith in which soils have developed.

The altitude of the granitic hills depends upon the degree of erosion. Where they are clustered and form an extensive hill-country the summits have concordant levels at 1300-1400 m. Where they occur in isolation, for example along the lake shores, they are less high (1200-1300m.)

The majority of the hill soils are included in the G2-unit. The summits and a large part of the upper hillslopes are usually covered by rock outcrops (Gr) and shallow soils (Gs and GI).

According to slope class the granitic hills are subdivided in steep hills and rolling hills.

1. The steep hills cover an area of 1061 sq.km (10.8% of the surveyed area). Most of the steep hills occur in the NW of the surveyed area on the Buhindi peninsula and along a S-shaped curve running south of the axis Nyehunge-Nzera. In the steep hills following mapping units are recognized:

H1-g/1: Steep hills on granitic rocks (907 sq.km. 9.3% of surveyed area)

Dominant slopes : 16-30%
Soils : G2 is the dominant soil, the complex Gr, Gs, Gl are the associated soils and G3 is the main inclusion.

This mapping unit has high relief intensity and is strongly dissected by drainage lines. This mapping unit is usually not cultivated because of its high degree of rockiness. In some parts, such as the hill areas south of Nyehunge and Katoro, the lower slopes which are relatively free from rocks are brought under rainfed cultivation. Most of this mapping units is kept under natural, and usually protected, woodland or bush. 'Miombo' woodland prevails in the north and west of the survey area, secondary bush in the east. Because of the steep slopes soil erosion is a major risk for agriculture and protective forest appears to be the best land use.

H1-g/2: Steep hills on granitic rocks (12 sq.km; 0.1% of surveyed area)

Dominant slopes: 16-30%
Soils: Gr is dominant, Gs occurs as associated soil.

This mapping unit is entirely rocky. It should be kept under protective natural woodland or bush. Deeper soils usually occur lower down the slope and form part of other mapping units.

Hl-g : Steep hills on granitic rocks (142 sq.km: 1.4% of surveyed area)

Dominant slopes: 16-30%
Soils : Undifferentiated.

This mapping unit occurs mainly on Rubondo Island and is entirely covered by 'miombo' woodland. The soils are probably the same as in previous mapping units but their propo tions have not been estimated.

2. The rolling hills cover an area of 1151 sq.km, 11.7% of the surveyed area. Most of the rolling hills occur in the northern and western parts and surround or link the steep granitic hills. In the east the rolling hills occur usually in small isolated groups.

The rolling hills have lower relief intensity than the steep hills and are more intensively cultivated. The natural vegetation cover is in the north and west 'miombo' woodland and in the east secondary bushland and is in general only preserved on the rocky hilltops.

According to differences in the relative proportions of the recognized soil units the rolling hills are subdivided into the following mapping units:

Ho-g/1 : Rolling hills on granitic rocks (697 sq.km., 7.1% of surveyed area)

Dominant slopes: 8-16%
Soils: G2 is the dominant soil, G3 is the associated soil and L2 and the complex Gr, Gs, Gl occur as inclusions.

This mapping unit occurs mainly in the northern and western part of the surveyed area

Ho-g/2: Rolling hills on granitic rocks (407 sq.km; 4.2% of surveyed area)

Dominant slopes: 8-16%
Soils: G2 is the dominant soil, G3 and the complex Gr, Gs, Gl occur as inclusions.

This mapping unit occurs mainly in the southeast of the surveyed area, east of long. 32°15'E and south of lat. 2°45'S.

Ho-g/3: Rolling hills on granitic rocks (13 sq.km: 0.13% of surveyed area)

Dominant slopes: 8-16%
Soils: G3 is the dominant soil, G2 is associated soil and the complex Gr, Gs, Gl occurs as inclusion.

This mapping unit covers a small isolated area south of Sengerema.

Ho-g: Rolling hills on granitic rocks (34 sq.km: 0.4% of surveyed area)

Dominant slopes: 8-16%
Soils: Undifferentiated.

This mapping unit is confined to Rubondo and Kome Islands. The soils are probably the same as in previous mapping units but their proportions have not been estimated.

3.3.1.2. Hills on Nyanzian rocks

These hills are mainly composed of banded ironstone rock. They are usually steep and rise up to 300-400 m above the intervening valleys. The table-top summits of the larger hills are concordant at levels of 1450-1550 m in the west and 1400-1450 m in the south-east. Smaller hills have usually knife-edge shape and are less steep.

The hills are usually surrounded by extensive footslopes with ZI-soils and ironstone outcrops. The hills themselves are invariably rocky or have a very shallow soil cover. The summits of the most extensive hills are covered by pedogenetic ironstone.

'Miombo' woodland is the main vegetation but in many areas, particularly the southeast of the survey area, it has been degraded to secondary bush or grassland. They are unsuitable for agriculture and should be kept under protective vegetation. Overgrazing of these areas may lead to erosion on the footslopes.

According to slope class, these hills are further subdivided into 3 mapping units:

H2-z : Very steep hills on Nyanzian rocks, dominant slopes > 30%
HI-z : Steep hills on Nyanzian rocks, dominant slopes 16-30%
Ho-z : Rolling hills on Nyanzian rocks, dominant slopes 8-16%.

3.3.1.3. Hills on Kavirondian rocks

These hills occur only on Maisome island. They are low and rounded. Dominant slopes are 8-16%. Their average altitude is about 1250 m above sealevel.

They are covered by Kavirondian rock outcrops and very shallow soils. The summits are bare, the slopes are covered by 'miombo' woodland.

3.3.2. Hill-footslope associations

This physiographic zone comprises extensive, almost flat to undulating piedmont plains that converge towards rocky, tor-type hills. It covers 1470 sq.km (15% of surveyed area). This zone is virtually exclusively confined to granite country. The piemont surfaces cover most of the area, while only about 10% of the land is occupied by rocky hills. The summits of the hills rise generally between 1250-1300 m, whereas the piedmont plains are between 1180 and 1250 m. above sealevel.

In general the hill-footslope associations are dominated by G2-soils, but G3-soils are also important in some areas.

The hill-footslope associations are most common in the eastern part of the surveyed area, especially east of long 32°15'E.

1. On granitic rocks the hill-footslope associations are subdivided according to the degree of dissection and the soil association into following mapping units:

HP1-g/1: Steep hills on granitic rocks with moderately dissected footslope footslopes

(96 sq.km. 1.0% of surveyed area).
Dominant slopes : hills 16-30%, footslopes 2-8%
Soils: G2 is the dominant soil, G3 is associated soil and the complex Gr, Gs, Gl occurs as inclusion.

The mapping unit covers small scattered areas in the northeast, near Buyagu. With exception of the rocky hilltops this land is brought under cultivation. The natural vegetation is secondary bushland, which is only preserved on the hilltops.

HP1-g/2: Steep hills on granitic rocks with moderately dissected (120 sq.km: 1.2% of surveyed area)

Dominant slopes: hills 16-30%, footslopes 2.8%.
Soils: G3 is the dominant Soil, G2 is the associated soil and the complex Gr, Gl, Gl occurs as inclusion.

This mapping unit covers some scattered areas in the southeast, near Karumwa. Land use and vegetation are as in the previous mapping unit.

HoPl-g/1: Rolling hills on granitic rocks with moderately dissected footslopes.

(890 sq.km; 9.1% of surveyed area)
Dominant slopes: hills 8-16%, footslopes 2-8%
Soils: G2 is the dominant soil, G3 is the associated soil and L2 and the complex Gr, Gs, Gl occurs as inclusions.

This mapping unit is the most extensive of the hill-footslope associations. It occurs mainly along West-east line from Mkorani to Busisi. This mapping unit is characterized by intensive culti-vation of upland crops. Virtually all the land has been cleared with the exception of the rocky hilltops. In the west the hilltops are covered by 'miombo' woodland, in the east by secondary bush.

HoPl-g/2: Rolling hills on granitic rocks with moderately dissected footslopes

(325 sq.km; 3.3% of surveyed area)
Dominant slopes: hills 8-16%, footslopes 2-8%
Soils: G3 is the dominant soil, G2 is the associated soil and the complex Gr, Gs, Gl occurs as inclusion.

This mapping unit occurs mainly in the southeast of the surveyed area. Land use and vegetation types and their distribution are similar to unit HoPl-g/1.

HoPo-g/1: Rolling hills on granitic rocks with almost flat footslopes.

(21 sq.km; 0.2% of surveyed area)
Dominant slopes: hills 8-16%, footslopes 0-2%
Soils: G2 is the dominant soil, G3 is the associated soil and L2 and the complex Gr, Gs, Gl occur as inclusions.

HoPo-g/2: Rolling hills on granitic rocks with almost flat footslopes

(18 sq.km; 0.2% of surveyed area)
Dominant slopes: hills (8-16%, footslopes 0.2%.
Soils: G3 is the dominant soil, G2 is the associated soil and L2 and the complex Gr, Gs, Gl occur as inclusions.

Mapping units Ho Po-g/1 and Ho Po - g/2 cover very small areas near the Mwanza Gulf. Land use patterns are similar as in previous units. The rocky hilltops are usually covered by secondary bush.

2. On Nyanzian rocks following footslope association has been distinguished:

Ho-Pl-z: Rolling hills on Nyanzian rocks with moderately dissected footslopes

(19 sq.km, 0.2% of surveyed area).
Dominant slopes: hills 8-16%, footslopes 2.8%,
Soil : Zl is the dominant soil, with associated outcrops of Nyanzian rocks (Zr) and inclusions of pedogenetic ironstone (Zi)

On Nyanzian rocks the hill-footslope associations are barely represented. They cover a few, small, scattered areas in the extreme west and east of the survey area. They are usually not cultivated but utilized for extensive grazing.

3.3.3. Upland plains

This physiographic zone refer to undulating to rolling country with low relief, low degree of dissection, lying at 1180 and 1250 m. above sealevel. Upland plains occur both on granite and on banded ironstone.

In granitic areas the upland plains occur usually as broad, low watersheds. In contrast with the hill-footslope associations, a central tor-type rock outcrop is generally not present.

In banded ironstone country the upland plains either occur as broad, convex watersheds or as piedmont plains with concave profile around the banded-ironstone hills.

The upland plains on granitic substratum are subdivided into 9 mapping units on the basis of degree of dissection and soil association.

Ul-g/1: Undulating, moderately dissected upland plains

(640 sq.km, 6.5% of surveyed area).
Dominant slopes: 2-8%.
Soils: G2 is the dominant soil, G3 is the associated soil and L2 and the complex Gr, Gs, Gl are inclusions.

This mapping unit occurs in the north of the surveyed area. Virtually the whole of this mapping unit has been brought under cultivation.

Ul-g/2: Undulating, moderately dissected upland plains

(162 sq.km, 1.6% of surveyed area)
Dominant slopes: 2-8%.
Soils; G3 is the dominant soil, G2 is the associated soil and the complex Gr, Gs, Gl occurs as inclusion.

This mapping unit occurs in areas scattered along a W-E line passing south of Geita. Between Chibongo and Geita this mapping unit has been brought into cultivation. In the east most of it is covered by the Mwienzi forest reserve.

Ul-g/3 : Undulating, moderately dissected upland plains.

(335 sq.km, 3.4% of surveyed area)
Dominant slopes: 2-8%.
Soils: G3 is the dominant soil, G2 is the associated soil and L2, L3 and the complex Gr, Gs, Gl occur as inclusions.

This mapping unit occurs mainly in the south and east of the surveyed area, in the Rwamagasa Forest Reserve, near Karumwa village and near Sengerema.

Ul-g/4: Undulating, moderately dissected upland plains.

(68 sq. km, 0.7% of the surveyed area).
Dominant slopes: 2-8%
Soils: G2 is the dominant soil, G3 is the associated soil and the complex Gr, Gs, Gl occurs as inclusion.

This mapping unit occupies a small area west of Sengerema and occurs as a piedmont plain around granitic hills. It has been brought entirely under cultivation.

Ul-g: Undulating, moderately dissected upland plains.

(17 sq.km, 0.2% of surveyed area).
Dominant slopes: 2.8%.
Soils: Undifferentiated.

This mapping unit is confined to Rubondo and Kome Islands. The soils are probably the same as in previous mapping units but were not differentiated because their proportions could not be assessed by fieldwork.

U0-g/1: Very gently undulating, slightly dissected upland plains.

(543 sq.km, 5.5% of surveyed area)
Dominant slopes: 0-2%
Soils: G3 is the dominant soil, G2 is the associated soil and L2 is an inclusion.

This mapping unit occurs in the same parts of the surveyed area as units Ul-g/1 and Ul-g/3 and occurs often as a lower, less dissected part of the same upland plain. Virtually the whole of the mapping unit has been brought into cultivation.

Uo-g/2: Very gently undulating, slightly dissected upland plains

(267 sq.km, 2.7% of surveyed area)
Dominant slopes: 0-2%

Soils: G3 is the dominant soil, G2 is the associated soil and L1, L2 and L3 occur as inclusions.

Apart from the fact that this mapping unit includes L1 and L3 as minor soils, it is very similar to mapping unit Uo-g/1. It occurs in the same areas as mapping unit Ul-g/2 and Ul-g/3 and is often a lower lying, less dissected extension of the same upland plain. It is quite extensive in the southeast of the survey area around Karumwa village. Except for some areas located in the Rwamagasa forest reserve, most of this mapping unit is brought under cultivation.

Uo-g/3: Very gently undulating, slightly dissected upland plains. (149 sq.km, 1.5% of surveyed area)

Dominant slopes: 0-2%
Soils : G3 is the dominant soil, G2, L1, L2, and L3 occur as inclusions.

In this mapping unit the bottomoland soils L1, L2, L3 are more extensive than in other upland plain areas. This mapping unit represents therefore poorly differentiated upland areas, that are transitional towards lowland plains. This mapping unit is mainly centered around Bukwimba village in the extreme southeast of the survey area. It is entirely brought into cultivation.

Uo-g: Very gently undulating, slightly dissected upland plains (75 sq.km, 0.8% of surveyed area)

Dominant slopes: 0-2%
Soils: Undifferentiated.

This mapping unit is confined to Rubondo and Kome Islands. The main soils are probably the same as in previous mapping units but they were not differentiated because their proportions could not be assessed by fieldwork.

The upland plains on Nyanzian (and Kavirondian) rocks are all characterized by a uniform distribution of the major soil types. Not much is known about the soils developed on Kavirondian rocks, because their main occurrence is on Maisome island where no field checking was done (see section 3.2.2)

The subdivision into two mapping units is based on differences in slope class only:

Ul-z: Undulating moderately dissected upland plains (705 sq.km, 7.2% of surveyed area)

Dominant slopes: 2-8%
Soils: Z1 is the dominant soil, Za and Zi occur as inclusion.

O-z: Almost flat, slightly dissected upland plains (512 sq.km, 5.2% of surveyed area)

Dominant slopes: 0-2%
Soils: Z1 is the dominant soil, Z2 and Zi occur as inclusions.

These two mapping units occur usually in association, Ul-z as the upper, more dissected and Uo-z as the lower, less dissected part of the same upland plains. The distribution of both mapping units is closely related to the alignment of the Nyanzian rocks, which is approximately W-E in most of the survey area and bends south in the southeast.

Most of these two mapping units are still under natural woodlands, that belong pricipally to the Geita and Rwamagasa forest reserves. In the southeast of the survey area they are brought into cultivation of mainly drought resistant crops.

3.3.4. Lowland ('Mbuga') plains

This physiographic zone refers to the lowest parts of the survey area. It is characterized by very low relief intensity, very little dissection and poor drainage. It occurs at altitudes between 1180 and 1140 m.

The lowland plains can be found throughout the survey area. They are most extensive in the north and northwest where they join lacustrine plains, and in the southeast where they are usually surrounded by low, undulating upland plains. The lowland plains cover in total 1922 sq.km or 19.6% of the survey area.

According to degree of drainage deficiency, the lowland plains are further subdivided into two main types:

1) Seasonally waterlogged lowland plains
2) Floodplains

The seasonally waterlogged lowland plains have normally some relief (0-2% slopes) and although the soils are waterlogged, they are not flooded in the wet months for long periods. They cover 1209 sq.km (12.3%).

The floodplains are the lowest parts of the lowland plains and are aligned along the major drainageways. Virtually without relief (0-1% slope) and without deep channels, they are usually flooded for extensive periods in the wet season. They cover 713 sq.km (7.2%).

Vegetation and land use patterns are strongly influenced by the drainage conditions. Whereas previous physiographic zones were characterized by 'miombo' woodland or secondary bushland, and cultivation of upland crops, the lowlands are in general covered by bushland and grasslands and used for grazing and occasionally for cultivation of lowland rice.

Within the seasonally waterlogged lowland plains following mapping units are differentiated on the basis of soil associations:

Mw/1: Almost flat seasonally waterlogged lowland plains (450 sq.km, 4.6% of surveyed area).

Dominant slopes: 0-2%
Soils: L2 is the dominant soil, G3 is an inclusion.

This mapping unit occurs mainly in the northern part of the surveyed area, north of latitude 2°45'S. Most of this mapping unit is covered by deciduous bushland or bushed grassland and is frequently grazed, and occasionally used for rice cultivation.

Mw/2: Almost flat seasonally waterlogged lowland plains (351 sq.km; 3.6% of surveyed area)

Dominant slopes: 0-2%
Soils: L2 is the dominant soil, L3 is the associated soil and G3 is an inclusion.

This mapping unit occurs mainly in the central and southern part of the survey area and is usually transitional in character towards the floodplain. Soils are in general more clayey than in previous mapping unit and the natural vegetation is often a complex of thornbush, decidous bush and grasslands. This mapping unit is mainly utilized as grazing grounds, rice is cultivated where seepage water can be easily captured.

Mw/3: Almost flat seasonally waterlogged lowland plains (361 sq.km, 3.7% of surveyed area).

Dominant slopes: 0-2%
Soils: L3 is the dominant soil, L2 is the associated soil and L1 and G3 occur as inclusions.

This mapping units occurs mainly in the southeast of the surveyed area and is also transitional to the floodplain. The natural vegetation is dominated by thornbush or grasslands. This mapping unit is mainly utilized for grazing but around Bukwimba it is extensively used for rice cultivation.

Mw/: Almost flat seasonally waterlogged lowland plains (47 sq.km, 0.5% of surveyed area).

Dominant slopes: 0-2%
Soils: Undifferentiated.

This mapping unit occurs mainly on Kome Island. The soils are probably the same as in previous mapping units but were not differentiated because their proportions could not be assessed by fieldwork.

On the basis of soil association the floodplains are subdivided into following two mapping units:

<u>Mf/1</u>: <u>Flat floodplains</u> (372 sq.km; 3.8% of surveyed area)

Dominant slopes: 0.1%
Soils: L2 is the dominant soil, L3 is the associated soil and G3 and G2 are inclusions.

This mapping unit occurs mainly in the north and west of the surveyed area. The natural vegetation is (bushed) grassland and the unit is only utilized for grazing.

<u>Mf/2</u>: <u>Flat floodplain</u> (336 sq.km; 3.4% of surveyed area).

Dominamt slopes: 0-1%.
Soils: L3 is the dominant soil, L2 is an inclusions.

This mapping unit occurs mainly in the east and southeast of the surveyed area. Most of the mapping unit is covered by Acacia thornbush or grassland and is exclusively used for grazing.

<u>Mf</u>: <u>Flat floodplain</u> (5 sq. km, 01% of surveyed area).

Dominant slopes: 0.1%
Soils: Undifferentiated.

This mapping unit occurs exclusively on Kome island. The main soils are probably the same as in previous mapping units but have not been differentiated because their proportions could not be assessed by fieldwork.

<u>3.3.5. Lacustrine plains</u>

This physiographic zone refers to flat depression lands around the Victoria lake shore between 1140 and 1160 m altitude, that appear to have been covered by the lake in the past. Their morphology is one of raised beaches or lake terraces that merge into upland plains. Some specific soil types are confined to these areas (L4 and L5) but usually they are not the major soils and occur in association with sandy colluvium (G3).

The total extent of the lacustrine plains is 374 sq.km (3.8% of the surveyed area) On the basis of landrom and soil types the lacustrine palins are subdivided into following mapping units:

Lt. Lake flats (87 sq.km; 0.9% of surveyed area)

Dominant slopes: 0-1%.
Soils : G3 is the dominant soil, L4 is the associated soil and L2, L3 and L5 are inclusions

This mapping unit covers flat lake depression land, probably a lake terrace, near the lake Victoria shore, north of Sengerema. It is most extensive in the Ngomatimba area north of Kasenye. The natural vegetation is short grassland, often with Acacia bushland. Part of this mapping unit has been brought into cultivation, part is used for grazing.

Lb: Raised bays and beaches (95 sq.km; 1.0% of surveyed area).

Dominant slopes: 0-1%.
Soils: G3 is the dominant soil, L5 is the associated soil and L4, L2 are inclusions.

This mapping unit occurs along several bays of the Victoria lake, especially east of long 32°00'E. Its total extent is 95 sq.km (1%). Mainly covered by well to imperfectly drained sandy soils with mobile groundwater, the land use is largely influenced by the drainage conditions. Where the soils are not waterlogged they are intensively cultivated. The lowest sites are covered by swampy grassland and are not utilized.

Lp: Swamps (192 sq.km; 2.0% of surveyed area)

Dominant slopes: 0-1%.

This mapping unit includes swampy areas near the lake shores, that are characterized by permanent flooding or waterlogging and are therefore covered by aquatic vegetation, mainly papyrus, reeds and water grasses.

It occurs mainly in sheltered bays and may extend inland where it merges with the floodplains of the main drainage ways. This mapping unit is not utilized.

Chapter 4

LAND SUITABILITY EVALUATION

4.1. GENERAL CONSIDERATIONS

In this chapter the practical significance of the soil differences, recognized during the soil survey, together with other important environmental factors such as physiography, drainage, climate etc., are assessed in respect of various productive land-use types.

To develop the land suitability classification the principles and methods given in "A framework for land evaluation" (FAO, 1976) have been followed. The different mapping units of the soils map were evaluated in terms of suitability for specific land use alternatives, which are discussed in section 4.2. The suitability ratings were determined by a number of relevant land qualities such as moisture availability, soil fertility, erosion hazard etc. The meaning of the concept "land quality" and the significance of the land qualities used for the present study is explained in section 4.3. The procedures followed in rating the land qualities are explained in Technical Appendices 2 and 3.

The land suitability classfication adopted for Geita-Sengerema districts has some limitations. First, it is a qualitative and physical classification. This means that the suitability of the different land units recognized and mapped during the survey, is assessed on the basis of physical land characteristics and expressed in relative and qualitative terms, without detailed knowledge of economic and social costs and benefits. It is therefore possible (and even plausible) that a given land may be physically suitable for a particular land use but that such land use would be unrealistic within the given socio-economic context ex.g. afforestation of cotton growing areas. Such improbable, but theoretically feasible, land use types have been left out of the land suitability classification.

Secondly, the present land suitability classification refers exclusively to agricultural uses, particularly crop production. Although forests and rangelands will undoubtedly play an important role in the general development of the districts, it was not possible to develop a suitability classification for these land use types in view of the specialized expertise required for this particular work.

Another provision in the present land suitability classification system is that the suitability ratings refer to "current" suitability i.e. the suitability for a defined use of land in its present condition, with allowance for improved management. This means that the suitability ratings refer specifically to properly managed land and assume that, where required, minor land or land use improvements will be carried out. Examples of such improvements are adequate fertilizer use, elementary soil conservation, timely sowing, draught animal power etc. In some instances these improvements are within the financial and technical reach of smallholders but they may not be forthcoming in the near future because of inadequate extension services, limited marketing or credit facilities or poor distribution network. In such cases where the socioeconomic environment is a major constraint, suitability ratings are given with and without improvement.

Major investments on irrigation, land levelling etc. appear impractical within the given socio-economic environment of the survery area.

In view of these limitations the present land suitability classification should be strictly utilized within its own terms of reference, as a base document that will assist land planners to develop balanced land use plans at district, division and possibly village level in which due attention is given to other relevant land use alternatives that could not be considered here.

4.2. RELEVANT LAND USE ALTERNATIVES

Within the present socio-economic context following agricultural land utilization types appear relevant for Geita-Sengerema Districts:

1) Smallholder rainfed arable farming, intermediate technology
2) Smallholder paddy rice, intermediate technology
3) Large scale mechanized rainfed agriculture

Mixed farming systems with integration of livestock and arable farming in individual land holdings are not considered at present. In the area these systems have not yet evolved beyond the stage of demonstration schemes and it may take a long time before they are practised on a significant scale.

Similarly agricultural systems based on the integrated utilization of the 'mbuga' lowlands are not assessed. Nevertheless it is noted that such farming systems in the long run may probably offer the best means to conserve or even ameliorate soil resources and to ensure satisfactory farmer incomes. This matter is discussed further in Section 4.5.

4.2.1. Smallholder rainfed arable farming, intermediate technology

This land utilization types is the most important one in Geita and Sengerema Districts. In this farming system rainfall, occasionally supplemented by seepage water or groundwater, is the sole source of soil moisture for upland crops. Rice grown in the lowlands and relying mainly on floodwater or run-off from higher grounds, is conidered in another land utilization type.

The main crops grown under this farming system are cotton, cassava, maize, sweet potatoes, sorghum, millets, groundnuts. Minor crops are beans, cowpeas, chickpeas, bananas, pine-apples, bambara nuts. The main cash crops are cotton and cassava, to a much lesser extent sweet potatoes, chickpeas, maize and groundnuts. The main food crop is maize, followed by cassava, sweet potatoes, sorghum and millets. Most of these crops are grown on the well drained upland areas, except sorghum and chickpeas which are usually grown at the edges of the 'mbuga' lowlands.

The average size of the holdings is 8-12 ha and supports 6-8 people, who cultivate about one-third to one-half of the area every year. In the east and central parts of the surveyed area most of the cultivable land is already in cultivation and it is expected that in the near future population increases will reduce the average farm size. Opportunities for acreage expansion still exist in the west but these are restricted by the boundaries of vast forest reserves.

The power source of agricultural operations is almost exclusively manpower. Only in the southeast of the survey area, around Bukwimba, is animal traction significant. However there are good prospects for expansion of draught animal power.

The level of technical knowledge is intermediate. Although cultivation is mainly by hand, the standards of husbandry are fairly good. Most crops are grown on broad-based ridges that are aligned across the slope, but do not follow the contour. Cotton is always grown in pure stands, the other crops are grown in both pure stands and as mixtures. Farms are increasingly being enclosed, often with sisal hedges. Most practices recommended by agricultural research and extension are adopted, especially for cotton.

The practice of crop rotations is generally accepted by farmers, although this is somewhat hampered by the old Sukuma notion of specific soil requirements for different crops. Cultivation is abandoned after 4-7 years to a cassava or bush fallow, and new land is opened if declining yields make this worthwhile. In the absence of fertilizers, the fallow periods do not appear adequate to restore natural fertility.

Improved seeds are mainly used for cultivation of cotton, maize and sorghum. The main cotton varieties are UK-varieties with 6-month growth cycle. The main maize varieties are Ukiriguru Composites with 5-month growth cycle and the Katumani-varieties with 3 1/2-month growth cycle. Serena sorghum is a common sorghum variety. Use of fertilizers is limited to cotton and sometimes maize; it largely depends upon availability of credit facilities and efficacy of the distribution network. Insecticides and pesticides are normally not used by smallholders.

The timing of agricultural operations is fairly complex. The agricultural year normally starts in October with land preparation for rice. Maize can be sown as early as September or October and as late as February. To avoid mid-season dry spells early planted maize crops are usually short-maturing Katumani composites. Late planted maize crops (December-February) are longer maturing Ukiriguru composites. The planting of cassava and sweet potatoes may begin in November and the sowing of food crop mixtures can continue from November through February. Rice is usually transplanted in January. There is some late planting of cassava and sweet potatoes in March and early April near the 'mbuga' and swamp edges. The sowing of cotton may begin in November but most of the crop is sown in December and in January. Food crop harvesting begins in April and cotton picking starts in May and continues up to August.

The cultivation pattern is strongly affected by labour and climatic constraints. If the early rains fail, land preparation and sowing are delayed and more emphasis is given to planting famine crops, such as cassava and sweet potatoes. Under these circumstances labour may be critical and cotton is sown late or farmers may shift altogether from cotton to cassava as a cash crop.

Average crop yields are low. Realistic yields per ha targeted by the Geita Cotton Project (1976) are 670 kg for seed cotton, 1450 kg for maize and 700 kg for sorghum.

Farming in Geita-Sengerema districts is generally hampered by poverty of capital. Capital assets of most farmers are limited to elementary farm implements such as hoes, pangas and bowls. Only some prosperous farmers has cattle, oxen, oxploughs or enough cas to purchase seeds, fertilizers, insecticides and to hire labour.

On the other hand labour requirements are high, especially before and during the early parts of the rains. Anthony and Uchendu (1974) estimate the labour requirements for land preparation and sowing alone at 48 mandays/ha for cotton and 60 mandays/ha for foodcrops. Labour shortage is often a constraint in crop production. It limits the total acreage that can be cultivated or causes neglect of husbandry standards. Often competition for labour between food crops and cotton imposes delay of cotton sowing beyond the optimal sowing date, resulting in yield reductions.

4.2.2. Smallholder rainfed paddy rice, intermediate technology

This land utilization type refers to only one crop, lowland rice. In terms of produce and cultivated acreage this land utilization type is at present not very important but offers scope for considerable expansion in the future. The marketed production varies strongly in response to producer prices but is at no time higher than several hundred tons. A highly labour intensive crop, rice is only brought to the market when the price justifies the effort. Geographically, this land utilization type is confined to scattered lake shore areas and seepage areas of 'mbuga' lowlands, especially in the central, southern and eastern parts of the surveyed area.

The farming system is based on the cultivation of local, unimproved rice varieties that are transplanted from nurseries to small plots. The varieties mature in 3 1/2-4 1/2 months (Acland, 1971) The plots are located on suitable soils and sites where seepage water can easily be captured and retained. Usually only the margins of bottomlands are utilized and seepage water is channelled through ditches to the plots. The best rice soils occur however in the deepest parts of the valleys but with present know-how these areas can not be adequately protected from damaging floods and are therefore not utilized.

Because of the dependance on seepage water and inability to harness the floods the farming system indirectly depends on rainfall. To overcome the vagaries of unreliable rainfall, the rice is kept in nurseries in permanently wet soils for several weeks before the onset of the rains, and only then it is transplanted. Land preparation and making of seedbeds normally starts in October, the sowing in the nurseries immediately after. The seedlings are left for 4-7 weeks in the nurseries and usually transplanted in January. Harvesting occurs in June-July.

The level of technical knowledge is intermediate. Although agricultural operations are usually carried out with handtools (except around Bukwimba where oxploughs are utilized) husbandry standards are relatively good. The size of the fields is relatively small (abour 1/10 of a acre) in order to ensure uniform depth of flooding. The fields are protected from floods by bunds. Improved seeds, fertilizers and other agrochemicals are generally not used. It is not known whether crop rotations are practised. Cultivations may be abandoned after some years to bush fallows.

Yield figures are not available but according to Anthony and Uchendu (1974) they are low.

This land utilization type is characterized by low capital intensity and high labour intensity. The only capital assets are the basic handtools and occasionally oxen and oxploughs. Labour requirement figures of 170-270 mandays/ha are mentioned by Acland (1971).

4.2.3. Large-scale mechanized rainfed agriculture

This land utilization type refers to a farming system that relies heavily on expensive capital inputs, modern farming methods and an efficient managerial and maintenance infrastructure to raise crop production by increasing both yields and cultivated acreage.

In the surveyed area this land utilization type is confined to the block or group farms managed by parastatals, cooperatives or Ujamaa villages. These farms concentrate on the cultivation of cash crops, particularly cotton and to a lesser extent maize. The capital inputs are tractors and tractor-drawn ploughs, fertilizers, pesticides and spraying equipment. At present this land utilization type is not very important in acreage but new block farms are being established. The size of these farms is usually 50-100 ha.

It is not possible to give much quantitative information on this land utilization type. It should be noted that the suitability assessment refers exclusively to the physical aptitude of the terrain for mechanization.

4.3. LAND SUITABILITY CLASSES, LAND QUALITIES AND LAND CHARACTERISTICS

Land suitability classification is the appraisal and grouping of land in terms of suitability for specific uses, such as the ones described in section 4.2. The suitability classes which are used in this report are as follows:

Class S1 : Highly suitable land

Land having no significant limitations to sustained application of the considered use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.

Class S2 : Moderately suitable land

Land having limitations which in aggregate are moderately severe for sustained application of the considered use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciable inferior to that in Class S1 land.

Class S3 : Marginally suitable land

Land hving limitation which in aggregate are severe for sustained application of the considered use and will reduce productivity or benefits or increase required inputs, that this expenditure will be only marginally justified.

Class N : Not suitable land

Land having limitations which appear so severe as to preclude any possibilities of succesful sustained use of the land in the given manner; or the limitations may be surmountable in time but cannot be corrected with existing knowledge at currently acceptable cost.

The process of land suitability classification, as recommended by the FAO goes through an intermediate interpretation stage by means of the "land quality" concept.

A land quality is a complex attribute of the land with a distinct and individual influence on the suitability of land for a specific kind of use. Examples of major land qualities are: moisture availability, flooding hazard, erosion hazard. Land qualities can not be measured and are therefore evaluated on the basis of land characteristics.

Land characteristics are attributes of land that can be measured or estimated, such as rainfall, available waterholding capacity, texture, slope etc. The integration of land characteristics into land qualities is done by means of conversion tables. (see Technical Appendix 2).

The suitability assessment of land is made on the basis of those land qualities that are most relevant for the land use types considered. The land qualities that were considered most relevant in the surveyed area are:-

1) moisture availability
2) dependable moisture availability (for maize and cotton only)
3) soil fertility
4) drainage conditions in the growing season
5) workability (for non-mechanized farming systems only)
6) possibilities for mechanization (for mechanized farming systems only)
7) erosion hazard
8) capability to maintain surface water (for paddy rice only)

Other land qualities are also considered relevant, ex.q. "adequacy of topography for gravity irrigation", "drainability for irrigated agriculture", but the available information is too scanty to rate them.

Brief explanations of the meaning of the selected land qualities are given below.

1) Moisture availability

This land quality refers to the availability of moisture for plant growth as determined by water supply (rainfall), water storage capacity of the soil and water outtake by evapotransipiration.

In the assessment of this land quality it is assumed that the climate is homogeneous throughout Geita-Sengerema Districts.

2) Dependable moisture availability

This land quality has been applied to assess land suitability for cotton and maize only.

For other crops the land quality "moisture availability" is used.

Dependable moisture availability refers to the moisture amount available to plants that can reasonably be expected over a long series of growing periods. In contrast with previous land quality it takes into account the variability of the water supply, both in amount as in distribution.

The methodology developed to assess this land quality is fully explained in Technical Appendix 3. Essentially dependable moisture availability is assessed by estimating the probability of crop failure by imbalanced rainfall. These probabilities are crop-specific and area-specific. In the surveyed area three moisture zones were differentiated, which are characterized by different susceptibility to crop failure by imbalanced rainfall, as follows:

Moisture zone A has 0-10% probability of crop failure by imbalanced rainfall.

Moisture zone B has II-20% probability of crop failure.

Moisture zone C has 21-40% probability of crop failure.

The significance of these moisture zones for land suitability classification is that similar land units located in different moisture zones may have substantially different suitability for cotton or maize.

The geographical location and extent of these moisture zones for cotton and maize respectively are indicated in fig. 25 and 26.

3) <u>Soil fertility</u>

This land quality refers to the presence and availability of plant nutrients in the soil, as determined from soil chemical data.

4) <u>Drainage conditions in the growing season</u>

This land quality refers to the drainage condition of a soil, estimated by the frequency and duration of the periods when the soil is saturated with water.

5) <u>Workability</u>

This land quality refers to the ease with which a soil can be worked by handtools or animal drawn ploughs and therefore is only applicable to agricultural systems without mechanization. It is estimated on the basis of stoniness and soil consistence.

6) Possibilities for mechanization

This land quality refers to the physical feasibility of the use of tractors and modern agricultural implements, as estimated from topography, stoniness and soil conditions. It is clearly only applicable to mechanized farming systems.

7) Erosion hazard

This land quality refers to the susceptibility of the soil to water erosion after clearing. The risk of soil erosion by wind appears to be insignificant and is not considered. This land quality is assessed on the basis of actual soil erosion, topography, inherent soil erodibility and rainfall erosivity.

8) Capability for maintaining surface water

This land quality is rated only for paddy rice, which is a crop that needs to be grown in waterlogged or shallowly flooded soils. It is assessed on the basis of topography, drainage and soil texture.

Each land quality is rated as good, moderate, poor or very poor for the land use considered. The code numbers given to these ratings are:-

1: good (no or slight limitation)
2: moderate (moderate limitation)
3: poor (severe limitation)
4: very poor (very severe limitation)

4.4. LAND SUITABILITY CLASSIFICATION OF GEITA-SENGEREMA DISTRICTS

4.4.1 Rating of the land qualities

The rating of the selected land qualities in respect of the different land units established during the survey is given in Table 13. The methodology and technical specifications used for these ratings are given in technical appendix 2 of this report.

By rating the land qualities the major physical constraints for sustained crop production can be identified. Table 13 indicates that the main limitations are soil fertility and (dependable) moisture availability. Other important limitations e erosion hazard and poor possibilities for mechanization.

1) Soil fertility

Soil fertility is a major limitation throughout the area, particularly in the uplands. In general it can be said that in most upland areas the long-term fertility, as estimated by the exchange capacity of the soil is low, while the short-term fertility, as inferred from the organic matter content and pH of the soil is moderate to high, depending on the kind and intensity of land-use.

The main soil fertility problems are the low available phosphorus and low exchangeable base content. pH-levels are generally within acceptable ranges and soil acidity is not a problem. Organic matter contents appear in general adequate, except on sandy G3-soils.

Of the upland soils the G1-soils have the best fertility. The most fertile lowland soils are the L3-soils but they appear deficient in phosphorus. The worst soils in respect of chemical soil fertility are the G3-soils.

The patterns of soil fertility are thus related to the relative proportions of the catenary component soils (see Appendix 4) and to physiography. In granite country the hills are the most fertile areas because they are dominated by G1 and G2-soils. The least fertile areas are probably the upland plains because they are mainly covered by G3-soils. The hill-footslope associations are expected to have intermediate fertility characteristics.

2) Moisture availability and dependable moisture availability

Poor moisture availability for rainfed crops is a common limitation in upland areas as they depend exclusively on rainfall for their moisture supply, particularly in sandy, shallow and gravelly soils. Better soils with moderate water storing properties are G1, G2 and Z1-soils. G3-soils have very low available waterholding capacity.

Dependable moisture availability for cotton is good in most of the survey area (Fig.25). Most of the surveyed area has only 0-10% probability of crop damage by imbalanced rainfall (moisture zone A). In the extreme east a moderate rainfall limitation exists, resulting in a 11-20% probability of crop failure (moisture zone B). Climatologically least suited for cotton growing appear the islands Kome and Maisome, with a 21-40% probability of cotton damage by imbalanced rainfall. (Moisture Zone C).

It should be noted that the given probabilities apply to the most suited planting time. If other planting times are considered, the probabilities of crop failure may be considerbly increased, eppecially for cotton (see appendix 3).

3) Erosion hazard

Erosion is a great risk in all sloping areas, particularly in the hills and hill-footslope associations. The erosion hazard is mainly determined by the slope class of the particular landform, and to a lesser extent by the inherent susceptibility, of the soil to water erosion. Indeed most of the soils in the area have low erodibility.

Table 13. Rating of the land qualities per land unit. Geita-Sengerema districts

Land unit		Land quality										
Mapping Unit	Soil Unit	Moisture availability	Dependable moisture availability by Moisture Zone A	B	C	Soil fertility	Drainage	Workability	Possibilities mechan.	Erosion hazard	Capability maintaining surface water
H1g/1	G2	3-2(b)	1	2	3	3	1	2	4	4	4
	Gr,Gs,Gl	4-2(c)	4-1	4-2	4-3	(1)	1	4	4	4	4
H1-g/2	Gr	n.a.	n.a.	n.a.	n.a.	n.a.	1	4	4	4	4
	Gs	4	4	4	4	n.a.	1	4	4	4	4
Ho-g/(a)	G2	3-2	1	2	3	3	1	1	3	4	4
	G3	4-2(d)	2-1	3-2	4-3(d)	3	1	1	3	3	4
H2-z	Zr	n.a.	n.a.	n.a.	n.a.	n.a.	1	4	4	4	4
	Zs	4	4	4	4	n.a.	1	4	4	4	4
H1-z	Zr	n.a.	n.a.	n.a.	n.a.	n.a.	1	4	4	4	4
	Zs	4	4	4	4	n.a.	1	4	4	4	4
Ho-z	Zr	n.a.	n.a.	n.a.	n.a.	n.a.	1	4	4	4	4
	Zs	4	4	4	4	n.a.	1	4	4	4	4
H1P1-g/(a)	G2	3-2(b)	1	2	3	3	1	1	3	4-3(e)	4
	G3	4-2(d)	2-1	3-2	4-3(d)	3	1	1	2	4-3(e)	4
HoP1-g/(a)	G2	3-2(b)	1	2	3	3	1	1	3	4-3(e)	4
	G3	4-2)d)	2-1	3-2	4-3(d)	3	1	1	2	4-2(e)	4
HoPo-g/(a)	G2	3-2(b)	1	2	3	3	1	1	3	4-2(e)	4
	G3	4-2(d)	2-1	3-2	4-3(d)	3	1	2	3	3-2(e)	4
HoP1-z	Z1	2	1	2	3	3	1	2	3	3-2(e)	4
	Z2	2	1	2	3	3	2	2	3	2	3
	Zr	n.a.	n.a.	n.a.	n.a.	n.a.	1	4	4	4	4
	Zi	n.a.	n.a.	n.a.	n.a.	n.a.	1	4	4	4	4

Land unit		Land quality									
Mapping unit	Soil unit	Moisture availability	Dependable moisture availability (=) A	B	C	Soil fertility	Drainage	Workability	Possibilities mechan.	Erosion hazard	Capability maintaining surface water
Ul-g/(a)	G2	3-2	1	2	3	3	1	1	2	3	4
	G3	4-2	2-1	3-2	4-3(d)	3	1	1	2	2	4
Uo-g/(a)	G2	3-2	1	2	3	3	1	1	2	2	4
	G3	4-2	2-1	3-2	4-3(d)	3	1-2	1	2	1	4
	L1	4	3	4	4	3	2	1-3(c)	2	2	3
Ul-z	Z1	2	1	2	3	3	1	2	2	2	4
	Z2	2	1	2	3	3	2	2	2	2	3
Uo-z	Z1	2	1	2	3	3	1	2	2	2	4
	Z2	2	1	2	3	3	2	2	2	2	3
Mw(a)	L1	4	3	4	4	3	3	1-3(c)	1-2(c)	2	3-2(f)
	L2	2	1	1	2	3	3	1	1	1	1-3(g)
	L3	1	1	1	1	2	3-4	2	2	1	1-3(g)
Mf(a)	L2	2	1	1	2	3	3-4	1	1	1	1-3(g)
	L3	1	1	1	1	2	4	2	2	1	1-3(g)
Lt	G3	4-2(d)	2-1	3-2	4-3(d)	3	2	1	1	1	4
	L4	4	2	3	4	3	3	1-3(c)	1	1-2(h)	1-2(h)
Lb	G3	4-2(d)	2-1	3-2	4-3(d)	3	2	1	1	1	4
	L5	3-2(d)	1	2-1	3-2(d)	3	1-3	1	1	1	4

Notes

n.a. = not applicable : rocks and ironstone
(a) = the ratings apply to all mapping units that belong to this physiographic unit
(b) = depending on gravel content: better ratings apply to sites with little or no gravel
(c) = depending on soil depth : better rating applies to sites with deeper soils
(d) = better rating applies to water-receiving sites, either by seepage additions (G3-soils) or groundwater influence (L5-soils)
(e) = better rating applies to footslope parts, lower rating applies to hill parts
(f) = depending on micro relief and drainage : better rating applies to poorer drained and most level sites.
(g) = depending on microrelief : better rating applies to most level sites
(h) = depending on texture : better rating applies to sites with finer textured soils.

4) Possibilities for mechanization

Considerable constraints against mechanization exist in the hills, the hill-footslope associations and the lowland 'mbuga' plains. In the first two physiographic zones this limitation is mainly caused by rockiness and to a lesser extent by steep slopes. In the latter physiographic zone it is expected that deficient drainage and/or flooding may restrict mechanized farming operations.

5) Drainage

The ratings for drainage conditions in the growing season imply that no important restrictions exist for cultivation in the upland areas. However, in most parts of the lowland 'mbuga' plains and lacustrine plains poor drainage precludes the cultivation of most upland crops.

4.4.2. Ratings of land suitability

The ratings of land suitability per land unit in Geita-Sengerema districts are shown in table 14. In this table the land utilization types have been split up according to relevant crops and it is important to note that the suitability ratings for maize refer exclusively to UCA-varieties with 5-month growth cycle, while those for cotton apply to UK-varieties with 6-month growth cycle.

Where no improvements are suggested for a particular land utilization type, one rating is given only. Where improvements are recommended, the symbol for current suitability is shown on the left, the proposed improvement in the middle and the symbols for potential suitability is shown in brackets on the right.

The main improvements that are considered as relevant and feasible for the selected land utilization types are erosion control (E) and drainage (D). The first improvement refers specifically to the introduction of soil conservation techniques that are within the technical and financial reach of smallholders such as ridges along the contour, barrier hedges, strip cropping, bench terraces etc; this requires additional labour and effective propagation by the extension services. The second improvement refers to surface drainage methods, that are inexpensive but labour-intensive.

From table 14 it appears that in the hills and hill-footslope associations land suitability for smallholder cultivation is not particularly influenced by the particular soil type, because the main limitation of erosion hazard, which is chiefly imposed by steep topography, overrides the limitations imposed by soil factors. However, in more level areas such as the upland plains better moisture availability makes land units with G2-soils more suitable than those with G3-soils.

Table 14. Ratings of land suitability per land unit, Geita-Sengerema districts.

Land unit		Land use alternative					
Mapping unit	Soil unit	Smallholder rainfed arable farming					
		Maize			Cotton		
		A	B	C	A	B	C
Hl-g/1	G2	N/E/S2	N/E/S2	N/E/S3	N/E/S2	N/E/S2	N/E/S3
	Gr,Gs,Gl	N/E/(S1)	N/E/(S2)	N/E/(S3)	N/E/(S1)	N/E/(S2)	N/E/(S3)
Hl-g/2	Gr	N	N	N	N	N	N
	Gs	N	N	N	N	N	N
Ho-g/(+)	G2	N/E/S2	N/E/S/2	N/E/S3	N/E/S2	N/E/S2	N/E/S3
	G3	S/3/E/S2	S3/E/S2	N/E/S3	S3/E/S2	S3/E/S2	N/E/S3
	Gr,Gs,Gl	N/E/(S1)	N/E/(S2)	N/E/(S3)	N/E/(S1)	N/E/(S2)	N/E/(S3)
H2-z(o)							
Hl-z(o)	Zr	N	N	N	N	N	N
Ho-z(o)	Zs	N	N	N	N	N	N
HlPl-g/(+)	G2	S2	S3(S2)	S3	S2	S2	S3
	G3	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
HoPl-g/(+)	G2	S2	S3(S2)	S3	S2	S2	S3
	G3	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
HoPo-g/(+)	G2	S2	S3(S2)	S3	S2	S2	S3
	G3	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
HoPl-z	Zl	S2	S2	S3	S2	S2	S3
	Z2	S2	S2	S2	S3	S3	S3
	Zr	N	N	N	N	N	N
	Zi	N	N	N	N	N	N
Ul-g/(+)	G2	S2	S2	S3	S2	S2	S3
	G3	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
Uo-g/(+)	G2	S2	S2	S3	S2	S2	S3
	G3	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
	Ll	N(S3)	N	N	N(S3)	N	N
Ul-z	Zl	S2	S2	S3	S2	S2	S3
	Z2	S2	S2	S2	S3	S3	S3
Uo-z	Zl	S2	S2	S3	S2	S2	S3
	Z2	S2	S2	S2	S3	S3	S3
Mw/(+)	Ll	N(S3)	N	N	N	N	N
	L2	S3	S3	S2	S3	S2	S2
Mf(+)	L2	N	N	N(S3)	N	N(S3)	N(S3)
	L3	N	N	N	N	N	N
Lt	G3	S3(S2)	S3(S2)	N(S3)	S3(S2)	S3(S2)	N(S3)
	L4	S3	S3	S3	N(S3)	N(S3)	N
Lb	G3	S3(S2)	S3(S2)	N(S3)	S3(S2)	S3(S2)	N(S3)
	L5	S3(S2)	S3(S2)	S3(S2)	S3(S2)	S3(S2)	S3(S2)

Notes

(+) The ratings apply to all land units, regardless of soil association.
(o) These mapping units have the same soil units in common.

Table 14. Continued

Land unit		Land use alternative			
Mapping unit	Soil unit	Smallholder rainfed			Smallholder paddy rice
		Sorghum millets	Cassava Sweet potatoes	Ground-nuts	
Hl-g/1	G2	N/E/S2	S3/E/S1	N/E/S2	N
	Gr,Gs,Gl	N/E/(S1)	N/E/(S1)	N/E/S2	NN
Hl-g/2	Fr	N	N	N	N
	Gs	N	N	N	N
Ho-g/(+)	G2	N/E/S2	S3/E/S1	N/E/S2	N
	G3	N/E/S2	S3/E/S2	S3/E/S2	N
H2-z (o)	Zr				
	Zr	N	N	N	N
Hl-z(o) Ho-z(o)	Zs	N	N	N	N
HlPl-g/(+)	G2	S2	S1	S2	N
	G3	S2	S2	S3	N
HoPl-g/(+)	G2	S2	S1	S2	N
	G3	S2	S2	S3	N
HoPo-g/(+)	G2	S2	S1	S2	N
	G3	S2	S2	S3	N
HoPl-z	Z1	S2	S2	S2	N
	Z2	S2	S3	S3	N
	Zr	N	N	N	N
	Zi	N	N	N	N
Ul-g/(+)	G2	S2	S1	S2	N
	G3	S2	S2	S3	N
Uo-g/(+)	G2	S2	S1	S2	N
	G3	S2	S2	S3	N
	L1	N(S3)	N(S3)	N(S3)	S3
Ul-z	Z1	S2	S2	S2	N
	Z2	S2	S3	S3	N
Uo-z	Z1	S2	S2	S2	N
	Z2	S2	S3	S3	N
Mw/(+)	L1	N(S3)	N(S3)	N(S3)	S3(S2)
	L2	S3/D/S2	S3	S3/D/S2	S2
	L3	S3	N	N	S2
Mf/(+)	L2	S3	N	N	S3
	L3	N	N	N	N
Lt	G3	S2	S3(S2)	S3(S2)	N
	L4	N(S3)	N	N	S3
Lb	G3	S2	S3(S2)	S3(S2)	N
	L5	S3(S2)	S3(S2)	S3(S2)	S3(S2)

Table 14. Continued

Land unit		Land use alternative					
		Large scale mechanized rainfed					
Mapping unit	Soil Unit	Cotton			Maize		
		A	B	C	A	B	C
Hl-g/1	G2	N	N	N	N	N	N
	Gr,Gs,Gl	N	N	N	N	N	N
Hl-g/2	Gr	N	N	N	N	N	N
	Gs	N	N	N	N	N	N
Ho-g/(+)	G2	S3	S3	S3	S3	S3	S3
	G3	S3	S3	S3	S3	S3	S3
	Gr,Gs,Gl	N	N	N	N	N	N
H2-z (o)							
	Zr	N	N	N	N	N	N
Hl-z (o)							
	Zs	N	N	N	N	N	N
Ho-z (o)							
HlPl-g/(+)	G2	S3	S3	S3	S3	S3	S3
	G3	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
HoPl-g/(+)	G2	S3	S3	S3	S3	S3	S3
	G3	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
HoPo-g/(+)	G2	S3	S3	S3	S3	S3	S3
	G3	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
HoPl-z	Z1	S3	S3	S3	S3	S3	S3
	Z2	S3	S3	S3	S3	S3	S3
	Zr	N	N	N	N	N	N
	zi	N	N	N	N	N	N
Ul-g/(+)	G2	S2	S2	S3	S2	S2	S3
	G3	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
Uo-g/(+)	G2	S2	S2	S3	S2	S2	S3
	G3	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
	L1	N(S3)	N	N	N(S3)	N	N
Ul-z	Z1	S2	S2	S3	S2	S2	S3
	Z2	S3	S3	S3	S2	S2	S2
Uo-z	Z1	S2	S2	S3	S2	S2	S3
	Z2	S3	S3	S3	S2	S2	S2
Mw/(+)	L1	N	N	N	N(S3)	N	N
	L2	S3	S3	S2	S2	S3	S2
	L3	N	S3	S3	N	N	N(S3)
Mf/(+)	L2	N	N(S3)	N(S3)	N	N	N(S3)
	L3	N	N	N	N	N	N
Lt	G3	S3(S2)	S3(S2)	N(S3)	S3(S2)	S3(S2)	N(S3)
	L4	N(S3)	N(S3)	N	S3	S3	S3
Lb	G3	S3(S2)	S3(S2)	N(S3)	SS3(S2)	S3(S2)	N(S3)
	L5	S3(S2)	S3(S2)	S3(S2)	S3(S2)	S3(S2)	S3(S2)

In lowland areas with flat topography the particular drainage characteristics of individual soil types strongly affects the suitability, both for upland crops as for paddy rice.

In table 15 land suitability ratings are given for mapping units. These ratings are based on those for the land units, as given in table 14, taking into account the relative proportions of individual soil types (see table 12). On the basis of these ratings two suitability maps have been prepared, one for cotton and one for maize.

From table 15 it appears that for general smallholder rainfed cultivation the best areas are located on the upland plains and hill-footslope associations. The hill areas, although they contain higher proportions of better soils (GI and G2) are less suitable because of the erosion hazard. However, if adequate soil conservation practices are adopted, many of the less steep hill areas can also be considered as suitable.

For mechanized rainfed agriculture the hills and most of the hill-footslope associations are unsuitable or poorly suitable, mainly because of rockiness. It appears therefore that in hilly or dissected areas the smallholder arable farming system can make more efficient use of agricultural resources than the mechanized farming system, on condition that adequate erosion control is practised. The lowland areas are less suitable both for smallholder as for mechanized rainfed farming because of drainage limitations that are difficult to correct. They are in parts suitable for smallholder paddy rice. The main limitation for this land utilization type is the difficulty to control flooding so that it still relies to a large extent on rainfall.

If the land utilization types are subdivided according to crop, suitability ratings of the mapping units for different crops can be compared. From table 15 it can then be concluded that in general the area is best suited for drought resistant crops such as cassava, sweet potatoes, sorghum etc. For cotton the survey area is in general moderately suited. For more exacting crops, particularly maize, the area is less suited. From the suitability maps for cotton and maize under smallholder system it becomes also evident that in general the survey area is better suited for cotton than maize.

Table 16 gives the areas of land suitability per crop under smallholder cultivation. From this table it follows that the surveyed area is in general moderately suitable for cotton, sorghum and millet. It is mainly moderately or highly suitable for cassava and sweet potatoes, and moderately to marginally suitable for groundnuts. The area is in general marginally suitable to unsuitable for maize. Most of the area is unsuitable for paddy but in an important part of the area (12%) most of the land is moderately suitable.

Table 15. Land suitability classification for Geita-Sengerema districts

Mapping unit	Land use alternative					
	Smallholder rainfed arable farming					
	Maize			Cotton		
	A	B	C (+)	A	B	C
Hl-g/1	S2(N)	S2(N)	S3(N)	S2(N)	S2(N)	S3(N)
Hl-g/2	n.a.	N	N	N	N	N
Hl-g	n.a.	n.a.	S3(N)	n.a.	n.a.	S3(N)
Ho-g/1	S2(N)	S2(N)	S3(N)	S2(N)	S2(N)	S3(N)
Ho-g/2	S2	S2	S3	S2	S2	S3
Ho-g/3	n.a.	n.a.	S3	S2	S2	S3
Ho-g	n.a.	n.a.	S3	S2	S2	S3
H2-z	n.a.	N	N	N	N	n.a.
Hl-z	n.a.	N	N	N	N	n.a.
Ho-z	n.a.	N	N	N	N	n.a.
Ho-k	n.a.	N	N	N	N	N
HlPl-g/1	n.a.	n.a.	S3(N)	S2	S2(S3)	n.a.
HlPl-g/2	n.a.	n.a.	N(S3)	S2	S3(S2)	n.a.
HoPl-g/1	n.a.	S2(S3)	S3(N)	S2	S2(S3)	n.a.
HoPl-g/2	n.a.	S3(S2)	N(S3)	S2	S3(S2)	n.a.
HoPo-g/1	n.a.	n.a.	S3(N)	S2	S2(S2)	n.a.
HoPo-g/2	n.a.	n.a.	N(S3)	S2	S3(S2)	n.a.
HoPl-z	n.a.	S2(N)	S3(N)	S2(N)	S2(N)	n.a.
Ul-g/1	S2	S2(S3)	S3(N)	S2	S2(S3)	S3(N)
Ul-g/2	n.a.	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
Ul-g/3	n.a.	S3(S2)	N(S3)	S2	S2(S3)	S3(N)
Ul-g/4	n.a.	n.a.	S3	S2	S2	S3
Ul-g	n.a.	n.a.	S3(N)	n.a.	n.a.	S3(N)
Uo-g/1	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
Uo-g/2	n.a.	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
Uo-g/3	n.a.	n.a.	N(S3)	S2	S3(S2)	N(S3)
Uo-g	n.a.	n.a.	N(S3)	n.a.	n.a.	N(S3)
Ul-z	n.a.	S2	S3	S2	S2	S3
Uo-z	n.a.	S2	S3	S2	S2	S3
Mw/1	S3	S3	S2(S3)	S3	S2	S2
Mw/2	n.a.	S3(N)	S2(N)	S3(N)	S2(S3)	S2(S3)
Mw/3	n.a.	n.a.	N(S2)	N(S3)	S3(S2)	S3(S2)
Mw	n.a.	n.a.	S2(N)	n.a.	n.a.	S2(S3)
Mf/1	N	N	N	N	N(S3)	N(S3)
Mf/2	N	N	N	N	N	N
Mf	n.a.	n.a.	N	n.a.	n.a.	N(S3)
Lt	S3(S2)	S3(S2)	N(S3)	S3(N)	S3(N)	n.a.
Lb	S3(S2)	S3(S2)	N(S3)	S3(S2)	S3(S2)	S3(N)
Lp	N	N	N	N	N	N

Notes

1. The first rating applies to most of the mapping unit (> 50%) The second rating (between brackets) applies to a part of the mapping unit (20-50%)
2. (+) A, B, C : moisture zones
3. n.a. : not applicable because the mapping unit does not occur in the concerned moisture zone.

Table 15. Continued

Mapping unit	Land use alternative: Smallholder rainfed arable farming			Smallholder paddy rice
	Sorghum millets	Cassava Sweet potatoes	Ground-nuts	
Hl-g/1	S2(N)	S1(N)	S2(N)	N
Hl-g/2	N	N	N	N
Hl-g	N2(N)	S1(N)	S2(N)	N
Ho-g/1	S2	S1(S2)	S2	N
Ho-g/2	S2	S1	S2	N
Ho-g/3	S2	S2(S1)	S2	N
Ho-g	S2	S1(S2)	S2	N
H2-z	N	N	N	N
Hl-z	N	N	N	N
Ho-z	N	N	N	N
Ho-k	N	N	N	N
HlPl-g/1	S2	S1(2)	S2(S3)	N
HlPl-g/2	S2	S2(S1)	S3(S2)	N
HoPl-g/1	S2	S1(S2)	S2(S3)	N
HoPl-g/2	S2	S2(S1)	S3(S2)	N
HoPo-g/1	S2	S1(S2)	S2(S3)	N
HoPo-g/2	S2	S2(S1)	S2(S2)	N
HoPl-z	S2	S2	S2	N
Ul-g/1	S2	S1(S2)	S2(S3)	N
Ul-g/2	S2	S2	S3	N
Ul-g/3	S2	S2(S1)	S3(S2)	N
Ul-g/4	S2	S1	S2	N
Ul-g	S2	S1(S2)	S2(S3)	N
Uo-g/1	S2	S2(S1)	S3(S2)	N
Uo-g/2	S2	S2(S1)	S3(S2)	N
Uo-g/3	S2	S2(S3)	S3(S2)	N
Uo-g	S2	S2(S1)	S3(S2)	N
Ul-z	S2	S2	S3	N
Uo-z	S2	S2	S3	N
Mw/1	S2	S3	S2	S2
Mw/2	S2(S3)	S3(N)	S2(N)	S2
Mw/3	S3(S2)	N(S3)	N(S2)	S2
Mw	S2(S3)	S3(N)	S2(N)	S2
Mf/1	S3(N)	N	N	S3(N)
Mf/2	N(S3)	N	N	N(S3)
Mf	S3(N)	N	N	S3(N)
Lt	S2(N)	S3(N)	S3(N)	N(S3)
Lb	S2(S3)	S3(S2)	S3(S2)	N(S2)
Lp	N	N	N	N

Table 15. Continued

Mapping unit	Land use alternative					
	Large scale mechanized rainfed					
	Cotton			Maize		
	A	B	C	A	B	C
Hl-g/1	N	N	N	N	N	N
Hl-g/2	N	N	N	n.a.	N	N
Hl-g	n.a.	n.a.	N	n.a.	n.a.	N
Ho-g/1	S3(N)	S3(N)	S3(N)	S3(N)	S3(N)	S3(N)
Ho-g/2	S3	S3	S3	S3	S3	S3
Ho-g/3	S3	S3	S3	n.a.	n.a.	S3
H0-g	n.a.	n.a.	S3(N)	n.a.	n.a.	S3(N)
H2-z	N	N	n.a.	n.a.	N	N
Hl-z	N	N	n.a.	n.a.	N	N
Ho-z	N	N	n.a.	n.a.	N	N
Ho-k	n.a.	n.a.	na.	n.a.	N	N
HlPl-g/1	S3(S2)	S3	n.a.	n.a.	N	N
HlPl-g/2	S2(S3)	S3	n.a.	n.a.	n.a.	S3(N)
HoPl-g/1	S3(S2)	S3	n.a.	n.a.	n.a.	N(S3)
HoPl-g/2	S2(S3)	S3	n.a.	n.a.	S3	S3(N)
HoPo-g/1	S3(S2)	S3	n.a.	n.a.	S3	N(S3)
HoPo-g/2	S2(S3)	S3	n.a.	n.a.	n.a.	S3(N)
HoPl-z	S3	S3	n.a.	n.a.	S3	S3
Ul-g/1	S2	S2(S3)	S3(N)	S2	S2(S3)	S3(N)
Ul-g/2	S2	S3(S2)	N(S3)	n.a.	S3(S2)	N(S3)
Ul-g/3	S2	S3(S2)	N(S3)	n.a.	S3(S2)	N(S3)
Ul-g/4	S2	S2	S3	n.a.	n.a.	S3
Ul-g	n.a.	n.a.	S3(N)	n.a.	n.a.	S3(N)
Uo-g/1	S2	S3(S2)	N(S3)	S2	S3(S2)	N(S3)
Uo-g/2	S2	S3(S2)	N(S3)	n.a.	S3(S2)	N(S3)
Uo-g/3	S2	S3(S2)	N(S3)	n.a.	n.a.	N(S3)
Uo-g	n.a.	n.a.	N(S3)	n.a.	n.a.	N(S3)
Ul-z	S2	S2	S3	n.a.	S2	S3
Uo-z	S2	S2	S3	n.a.	S2	S3
Mw/1	S3	S2	S2	S3	S3	S2
Mw/2	S3(N)	S2(N)	S2(N)	n.a.	S3(N)	S2(N)
Mw/3	N(S3)	S3(S2)	S3(S2)	n.a.	n.a.	N(S2)
Mw	n.a.	n.a.	S2(N)	n.a.	n.a.	S2(N)
Mf/1	N	N(S3)	N(S3)	N	N(S3)	N(S3)
Mf/2	N	N	N	N	N	N
	n.a.	n.a.	N(S3)	n.a.	n.a.	N(S3)
		[illegible]	n.a.	S3(S2)	[illegible]	N(S3)
						(S3)

Main Suitability Class	Land Suitability Unit (*)	Smallholder rainfed											
		Cotton		Maize		Sorghum Millet		Cassava Sweet potatoes		Groundnuts		Paddy rice	
		Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	%	Sq.km	
Mainly highly suitable	S1	-	-	-	-	-	-	475	4.8	-	-		
	S1(S2)	-	-	-	-	-	-	2395	24.4(39.9)	-	-		
	S1(S3)	-	-	-	-	-	-	-	-	-	-		
	S1(N)	-	-	-	-	-	-	1049	10.7	-	-		
Mainly Moderately suitable	S2	5510	56.2	1671	17.0	6563	66.9	1398	14.3	1688	17.2	1209	12.3
	S2(S1)	-	-(73.4)	-	-(38.7)	-	-(83.5)	1696	17.3(33.1)	-	- (49.0)		
	S2(S3)	717	7.3	1080	11.0	495	5.0	149	4.5	1664	17.0		
	S2(N)	970	9.9	1046	10.7	1136	11.6	-	-	1447	14.8		
Mainly Marginally suitable	S3	261	2.7	902	9.2	-	-	450	4.6	1379	14.1		
	S3(S1)	-	-(13.2)	-	-(32.3)	-	-(7.5)	-	-(10.5)	-	-(34.7)		
	S3(S2)	716	7.3	918	9.4	361	3.7	95	1.0	1927	19.7		
	S3(N)	317	3.2	1347	13.7	377	3.8	485	4.9	87	0.9	377	3.8
Mainly unsuitable	N	1027	10.5	1215	12.4	537	5.5	1250	12.8	1250	12.8	7699	78.5
	N(S1)	-	-(11.2)	-	-(26.8)	-	-(8.9)	-	-(16.5)	-	- (16.5)		(83.8)
	N(S2)	-	-	261	3.7	-	-	-	-	361	3.7	95	1.0
	N(S3)	73	0.7	1051	10.7	336	3.4	361	3.7	-	-	423	4.3

(*) Note

The first rating indicates the suitability of most of the unit concerned (> 50%) : the second rating (between brackets) indicates suitability of a part of the unit.

4.5. CONCLUSIONS AND RECOMMENDATIONS

From the land suitability classification it can be concluded that Geita-Sengerema districts have a moderate potential for agriculture. Except for the rocky hills and the permanent swamps most of the survey area can be cultivated for one crop or another. The main physical constraints to an increase of agricultural productivity are low soil fertility and inadequate moisture availability. Other thus far less severe constraints are erosion hazard in hilly country and poor drainage and flooding in the lowlands.

In respect of the fertility and moisture limitations some comments may be appropriate. These comments are based on the analyses of soil fertility and moisture availability presented in technical appendices 6 and 3 respectively.

1) The fertility limitation is to a large extent inherent. Most of the survey area was previously covered by 'miombo' woodland, substantial areas still are. A characteristic of the 'miombo' ecosystem is that most of the nutrients are stored in the organic matter, only few are stored on the soil exchange complex. Indeed the analytical results obtained by the present soil survey point out that low exchangeable base levels are one of the main fertility deficiencies, while organic matter contents are fairly adequate. Under these conditions nutrient availability to plants is largely determined by organic matter levels, which themselves are closely related to the kind and intensity of land use.

The implication is that once the woodlands are cleared and the initial nutrient store of the organic fraction is depleted by intensive cultivation, crop yields are bound to drop dramatically, unless fertility is restored. In the traditional shifting cultivation system fertility would be restored by bush fallows, but in the densely populated areas of Geita-Sengerema districts the optimum fallow periods can no longer be respected.

It is also felt that the problem of soil acidification, widely reported in the survey area, should be seen as a consequence of ecological imbalance rather than by the (very localized) application of ammonia sulphate. Soils with low exchangeable base capacity and organic fractions depleted by intensive cultivation are poorly buffered against the acidifying effect of leaching by a rather high rainfall regime. Most susceptible to acidification appear the G3-sands.

2) Most soils in the survey area have fairly good water retention properties. Only in the G3-sands, shallow and gravelly soils, the moisture availability limitation is mainly caused by inadequate moisture storage capacity.

The main limiting factor is the high rainfall variability in the survey area.

This variability affects the amount and distribution of rainfall, but also the start and end of the growing season, which makes it difficult to plan agricultural operations. Thus although Geita-Sengerema districts receive on the average sufficient annual and growing season rainfall, the high variability is responsible for crop failures in many years.

The waterbalance study presented in Appendix 3 indicates that the limitation of moisture availability is most severe in the eastern part of the survey area. This limitation is also more severe for maize than for cotton. To some extent the moisture limitation arising out of unreliable rainfall can be corrected by choosing a planting time that will minimize the risk of crop failure during the remainder of the growing season. From the study it appears that the most suitable planting time for cotton is December. For maize it appears that planting can be spread in most of the area over a 2-4 month period without considerable increase in risk of crop failure.

In the light of foregoing conclusions and comments the main recommendations can be summarized into following four points:

1) Maintenance and enhancement of soil fertility
2) Cultivation of drought tolerant or drought evading crops and adoption of timely planting
3) Control of soil erosion
4) 'Mbuga' development

1) Maintenance and enhancement of soil fertility

In theory the maintenance of ecologically optimal fertility leveles can be achieved solely by bush fallows. However in view of the inherent low fertility status of soils in the 'miombo' ecosystem and the concentration of smallholders on crops with high fertility requirements, it is reckoned that only short cultivation periods are possible and need to be followed by long fallows. This traditional technique can therefore only work when land is unlimited, but this is unfortunately not the case.

A more suitable alternative to maintain soil fertility is by incorporating leguminous crops in the rotations or crop mixtures, ex.g. groundnuts, bambara groundnuts, cowpeas, chickpeas, beans etc., a practice which is already widely adopted.

On land with very low fertility such as the G3-sands it is recommended to restrict the cultivation of exacting crops such as cotton, and to concentrate on crops that yield well under low fertility conditions such as cassava. It is expected that on these soils the maintenance of fertility may not be sufficient to raise the yields of more exacting crops, and that this goal can only be achieved by fertility enhancement.

Fertility can be enhanced by application of either chemical fertilizer or manure. The application of chemical fertilizers particularly phosphatic can be recommended with caution. Overuse of acidifying fertilizers (ammonium sulphate) has led to short-term soil acidification problems, in the past. It is also expected that due to frequent dry spells and high rainfall variability in the area the response to chemical fertilizers will vary from season to season. It is thought that particularly in the upland sands little or no responses should be expected in dry years. In such conditions the economic aspects of fertilizer use deserve careful analysis.

The use of manure is strongly recommended. There is a large cattle population in the survey area but unfortunately it is mainly raised in areas that are in general not reserved for agriculture. Means need to be found to utilize this fertilizer wealth more efficiently. For instance, by propagating the use of animal draught power for tillage operations, farmers may gradually learn to appreciate the benefits of mixed farming, particularly for the fertility status of their landholdings.

2) Cultivation of drought tolerant or drought evading crops

The study on climate-soil moisture relationships outlined in Appendix 3 evidences the considerable risks of crop failure by drought in large parts of the survey area. There exists therefore a clear need to shift from drought sensitive to drought resistant and drought evading crops.

In general cotton is little affected by imbalanced rainf. distribution but maize is to a large extent. Especially the eastern part of the area appears most susceptible to crop damage by poor rainfall distribution. Also soils with low waterholding capacity are likely to be most affected.

It can therefore be recommended to grow on soils with high drought susceptibility (particularly the G3-soils) drought resistant crops, particularly cassava which is also undemanding in fertility and a cash crop at the same time. On these soils the growth of drought prone crops is to be discouraged, particularly maize but also cotton. In the case of maize, shifting from the longer-maturing UCA-varieties to the short-maturing Katumani composites would to a significant extent reduce drought hazards on soils with good waterholding capacity.

Drought risks can also be reduced to a certain extent by timely planting. Especially for cotton the range of suitable planting times is rather narrow. Planting beyond or before this optimum planting period is likely to lead to considerable yield reductions. Wherever feasible moisture conservation practices like mulch farming or tie-ridging (see further) can be recommended.

3) Control of soil erosion

Adequate soil conservation measures are needed in all upland areas because the natural soil evolution already leads to the elimination of the better agricultural soils (G1 and G2-soils) by separation into opposite fractions (see appendix 4). The sandy fraction (G3-soils) is rather infertile and the clayey fraction (L-soils), although fertile, is more difficult to cultivate. Without soil conservation measures this natural proces may be considerably accelerated. Especially the hills and hill-footslope areas are most susceptible to water erosion, because the risk of soil erosion is proportional with the steepness of the topography. Apart from sheet erosion, also rill and gully erosion can be expected in these areas and even landslides.

Soil conservation measures that can be recommended for the hilly areas include strip cropping, live barrier hedges, bench terraces, contour tillage and tie-ridging. The practice of ridging across the slope appears adequate in flatter land but in the hills it is advised to make the ridges exactly along the contour, otherwise there is the risk that the furrows act as drainage channels and provoke exactly what they are supposed to prevent, gullies. The practice of tie-ridging can be recommended with caution. Tie-ridging is not a popular conservation practice in the area for various reasons. One of the reasons is that allegedly the extra-labour involved in tie-ridging will give higher returns when utilized for cultivating more land (Anthony and Uchendu, 1974). Nevertheless it is a fact that tie-ridging is an excellent soil conservation practice that allows at the same time to conserve soil moisture. It is therefore expected that in the drier part of the survey in particular this practice would benefit yields by increasing available moisture. Also when animal draught power is gradually introduced there is no good excuse to overlook this valuable soil conservation method.

4) 'Mbuga' developement

The natural process of soil evolution leads inevitably to the expansion of G3-and L-soils at the expense of the G2-soils. In the same process hills are levelled to become upland plains. This process, a very slow one, can be retarded (by soil conservation), accelerated (by poor land use) but never reversed. In simple words, the G2-soils are the soils of the past, the G3-soils and L-soils are those of the future and it will therefore become increasingly important to manage these soils resources as efficiently as possible.

The situation at present is that apart from extensive grazing and some rice cultivation the potential of the 'mbugas' is largely underutilized. The reasons for this fact are known:

1) the inundations by seasonal floods are difficult to harness
2) the 'mbuga' soils are usually very strenuous to work by handtools and the moisture range in which mechanized tillage operations in possible is very narrow.

Yet it is exactly in these soils that most of the fertility lost from the uplands is concentrated and it is expected that with proper management very high yields can be obtained. Apart from their high fertility status the 'mbugas' offer more trumps :

1) their soils have high available waterholding capacity
2) they are flat and present therefore few risks of soil erosion

The 'mbugas' offer a good possibility of double cropping: one crop can be grown during the rainy season and one crop in the period immediately following it. Adapted techniques aimed at flood control are hereby essential. An important benefit of 'mbuga' cultivation is that more fallow land would become available on the uplands for grazing. Fertility would thus be brought upward to the infertile G3-sands.

The technical knowledge required to develop these lowland areas for intensive cultivation is not entirely absent. Long experience in rice cultivation exists, already and on this basis it should be possible to develop improved techniques for the utilization of the 'mbugas'.

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Technical Appendix 1

SOIL SURVEY METHODS

The soil survey of Geita-Sengerema districts was carried out on the basis of field observations, together with interpretation of aerial photographs, satellite imagery, topographic maps and other base materials.

The survey methods comprised an interacting set of operations which can conveniently be grouped as Field Methods, Office Methods and Laboratory Methods.

A1.1 FIELD METHODS

The fieldwork was started in December, 1976 and completed in August, 1977. Three field parties carried out the soil survey of which two were contineously in the field. One party was in charge of the correlation of incoming field data and the interpretation of aerial photographs and satellite imagery at the field office.

Initially reconnaissance trips were undertaken throughout the area and soil observations were mainly made along roads. Preliminary physiographic and soils legends were then prepared and on the basis of the provisional physiographic units field traverses were selected. The traverses were covered on foot or by car where possible, and soil observations were made by spade and auger. Major soils were described in detail from pits and samples were taken for laboratory analysis and soil correlation. Notes on land use, geology, natural vegetation, relief, etc., were also taken. As field work progressed the physiographic and soil legends were gradually improved and the mapping updated. Field work was confined to the mainland. No soil observations were made on Kome, Maisome and Rubondo islands.

A total of 723 soil observations were made and 105 profiles were sampled. The soils were described using the standard methods and terminology of the USDA-Soil Survey Manual together with the FAO-Guidelines for Soil Description. Special boxes made of galvanized iron sheeting were used for soil correlation.

A1.2 OFFICE METHODS

Following a preliminary visit to the area, existing information on climate, geology, vegetation and soils was compiled and studied. The main base documents were 1:50,000 topographic maps of the survey and mapping division, Dar es Salaam and aerial photographs at 1:40,000 and at 1:80,000 scale. The first set of photographs, dating from 1965, was obtained from the Survey and Mapping Division, the second one dating from 1976, from Geosurvey, Nairobi. Other available base materials included reports and maps (at 1:250,000 scales) of the Geological Division, one 1:250,000 LANDSAT-image (Cat.No. E-1374-07292), dated 1.8.73, in false colour and black and white (band 7), and various reports and climatic records from the Meteorological Department, Dar es Salaam.

Interpretation of earial photographs, topographic maps, geological maps and satellite imagery was undertaken in the field office and a continuous feedback existed between field and office operations.

The aerial photographs and topographic maps were very useful for the delineation of landforms and mapping units, as well as for the identification of soil patterns and estimation of proportions. By means of stereoscopes the boundaries of the mapping units were drawn on the 1:40,000 aerial photographs and then transferred visually to the topographic maps. Some soil patterns were easily identified and mapped on the aerial photographs on the basis of their associated vegetation types, e.g. the deep, red clays ZI-soils and surface ironstone (Zi) occuring side by side on the banded ironstone footslopes.

The study of satellite imagery gave in general poor results. It proved impossible to identify landforms and soil patterns consistently from the imagery. Even valleys and banded ironstone hills were difficult to separate. To a large extent these difficulties were due to the forest cover which obscured soil patterns in many areas, but mainly to the catenary distribution of soil patterns on granite country. According to their topographic position the soils may change drastically over distances of a few hundred meters and the resolution of the imagery proved insufficient to observe this variability. Also burning patterns and even the spatial and temporal variability of rainfall confused the identification of landforms and vegetation types.

From this experience it can be concluded that in areas covered by 'miombo' woodland, as in NW Tanzania, the interpretation of satellite imagery does not yield enough information for a reliable identification and mapping of landforms and soil patterns. The interpretation of aerial photographs at large scales and even topographic maps gave far better results, but of course more time and effort are needed. On the other hand, the satellite imagery gave a very good idea of the occurrence of major land use and vegetation types, particularly the extent of deforestation in the area. Largely on the basis of the satellite image a map of land use and vegetation types was prepared for the surveyed are at 1:500,000 scale.

After completion of the field work, a final correlation of the soils recognized in the area was carried out at ARI Mlingano. Available field and analytical data were used for the purpose. To assist in the correlation process the soils were classified in terms of both the FAO/UNESCO Legend of the Soil Map of the World and the USDA Soil Taxonomy. Final physiographic and soils legends were then prepared.

Following a detailed review of the mapping units established in the field and transferred from the aerial photographs onto the 1:50,000 g topographic maps, a final soil legend was prepared. Reduction to publication scale (1:250,000) was made by pantograph.

Because of the scale of mapping and complexity of the soil patterns, it was not possible to differentiate individual soils on the soils map. Instead soil associations were delineated, which include one or more main soils as the most common within a specific mapping unit. On the islands, where no soil observations could be made, the mapping units shown on the map are in practice physiographic units, based on aerial photo-interpretation.

A 1.3 LABORATORY METHODS

The soil samples were analyzed at the Central Soils Laboratory, Agricultural Rsearch Institute, Mlingano, using internationally accepted methods.

Particle size distribution was estimated by the Bouyoucos hydrometer method using Calgon as dispersing agent.

Soil pH was measured in water and 0.01 M calcium chloride suspension using a pH-meter with glass and reference electrodes. A soil: solution ratio of 1:2.5 was used.

Walkley and Black's chromic acid oxidation method was used in determining organic carbon. Nitrogen was estimated by the semi-micro Kjeldahl method.

Available phosphorus was extracted with 0.03 M ammonium fluoride in 0.025 M hydrochloric acid (Bray and Kurtz 1 solution) and estimated colorimetrically.

Electrical conductivity was measured in 1:5 soil water extracts with an electronic switch gear conductivity bridge.

Exchangeable cations were extracted with neutral, 1 M ammonium acetate solution. Sodium and potassium were determined by flame photometer. Calcium and Magnesium were estimated (complexometrically by titration by the bariumchloride-triethanolamine buffer method). Exchangeable acidity was estimated by titration after $BaCl_2$-triethanolamine extraction. However, for a large number of samples exchangeable acidity was extracted by I N KCl, due to unavailability of triethanolamine. This procedure gave unusually low values for exchangeable acidity, and, consequently, very high base saturation estimates, which did not correlate well with measured pH-values. In the analytical data given in Appendix 5, it has been indicated which extraction reagent was used for the particular profile.

Cation exchange capacity (CEC) was estimated by the summation of the exchangeable cations.

Technical Appendix 2

METHODS FOR THE RATING OF THE LAND QUALITIES

A 2.1 INTRODUCTION

The basic concepts and practical aspects of the land suitability classification for agriculture as applied to Geita and Sengerema Districts are discussed in Chapter 4 of this report. In this appendix the emphasis is on the technical criteria for the rating of those land qualities selected for assessing the land suitability classification of the area.

A land quality is a complex attribute of land which acts in a distinct manner in its influence on the suitability of land for a specidic kind of use. Examples of land qualities are : moisture availability, flooding hazard, erosion hazard. Land qualities themselves are combinations of land characteristics which are attributes of the land that can be measured or estimated, such as rainfall, available waterholding capacity, texture, slope etc.

As land qualities cannot be measured directly, they are usually rated in relative terms such as good, poor, etc. based on the measured land characteristics which determine them.

The suitability of a specific tract of land for a particular land use is determined on the basis of certain relevant land qualities. The land qualities that were considered relevant for the suitability appraisal of the land units recognized in the survey area, are:-

1) moisture availability
2) dependable moisture availability (applied to maize and cotton only)
3) soil fertility
4) drainage conditions in the growing season
5) work ability
6) possibilities for mechanization
7) erosion hazard
8) capability to maintain surface water (for paddy rice)

Other land qualities are also considered as relevant, such as "adequacy of topography for gravity irrigation" and "drainability for irrigated agriculture", but there was not enough information to rate these land qualities.

Each land quality is rated as good, moderate, poor or very poor for the land use under condideration. The code numbers given to these ratings are respectively:

1) good (no or slight limitation)
2) moderate (moderate limitation)
3) poor (severe limitation)
4) very poor (very severe limitation)

The rating of these land qualities is based on the methodology developed in the Sudan by Van der Kevie (1976), with exception of the land quality "dependable moisture availability", which in this study is only used for the suitability assessment of cotton and maize. This land quality is rated according to the methodology outlined in Technical Appendix 3.

A2.2 LAND QUALITY: MOISTURE AVAILABILITY

The moisture in the soil which is available to plants in determined by two major factors : the water supply by rainfall and/or irrigation, and the quantity of water the soil can store. In the survey area there is no supply of water by irrigation at present.

The water supply under rainfed conditions depends on the total amount of rainfall, potential evapotranspiration and length of the rainy season. On the basis of these variables compared in a simple waterbalance model, a number of climatic zones were recognized in the Sudan by Van der Kevie (1976), that are supposed to be significant for the production of crops. The climatic regime of Geita and Sengerema districts can best be correlated with climatic zone M2 in the Sudan : Dry Monsoon Climate with medium dry season.

This regime is characterized mainly by a water surplus in the rainy season that is lower than 10% of the annual potential evapotranspiration (Penman). The growing season is 6 to 8 months long, but there is the risk of dry spells. Because of the higher elevation temperatures are somewhat lower in the survey area than in zone M2, notably the mean minimum temperature which differs by about 5°C.

The influence of soil characteristics on the water supply available to plant growth is expressed by the available waterholding capacity (AWC). It is the maximum amount of water that can be stored in the soil and is readily available for plants.. It can be estimated by determining the moisture content of samples taken at different depths, at field capacity (1/3 bar suction) and permanent wilting point (15 bar suction). If soil moisture data are not available, the AWC can be inferred from a number of soil characteristics such as texture, structure, organic matter content, depth and amount of gravels and stones in the profile (table 16).

Table 17 - Estimation of AWC in cm if no soil moisture data are available

AWC in cm		Texture	Max.vol. coarse fragments allowed if soil is deep (weighted average)	Minimum soil depth allowed if there are no coarse fragments (for AWC of subsoil)	
Topsoil 0-30 cm	Subsoil 30-120 cm			hard	soft
>4	>12	Sandy clay loam, loam	5	120	100
		clay loam, sandy clay	15	105	85
		clay	30	90	70
3-4	9-12	sandy loam	5	120	100
		sandy clay loam, loam	20	105	85
		clay loam, sandy clay	35	90	70
		clay	50	75	55
2-3	6-9	loam sand	5	120	100
		sandy loam	20	105	85
		sandy clay loam, loam	40	90	70
		clay loam, sandy clay	50	75	55
		clay	65	60	40
1-2	3-6	fine sand	5	120	100
		loamy sand	20	105	85
		sandy loam	40	90	70
		sandy clay loam, loam	50	75	55
		clay loam, sandy clay	65	60	45
		clay	75	50	40

The ratings of moisture availability as functions of climatic moisture regime and AWC's is given in table 17.

The assessment of this land quality in respect of the soil units recognized in the survey area is shown in table 18.

As mentioned above, the climatic moisture regime M2 of Sudan is assumed for the area.

Table 18 - Rating of moisture availability (abridged after Van der Kevie, 1976)

Climatic moisture regime	AWC in cm		Rating
	Topsoil 0-30 cm	Subsoil 30-120 cm	
M2	>4 and	>12	1
M2	>3 and	>9	2
M2	>2 and	>6	3
M2	>1 and	>3	4

Table 19 - Ratings of moisture availability per soil unit, Geita-Sengerema

Land Unit	Land Characteristics			Rating of land quality
Mapping unit Soil unit	climatic moisture regime	AWC in cm		
		Topsoil 0-30 cm	Subsoil 30-120 cm	
G1	M2	0-3	0-12	4-2(a)
G2	M2	3-4	9-12	3-2(bc)
G3	M2	1-3	3-6	4-2(c)
Gr	M2	0	0	4
Gs	M2	0-1	0	4
Z1	M2	3-4	6-9(d)	3-2
Z2	M2	3-4	6-9(d)	3-2
Zr	M2	0	0	4
Zs	M2	0-1	0	4
Zi	M2	0	0	4
Kr	M2	0	0	4
Ks	M2	0-1	0	4
L1	M2	3-4	insign.(e)	4
L2	M2	3-4	9-12	2
L3	M2	4	12	1
L4	M2	1-4	insign.(e)	4
L5	M2	2-3	3-6	3-2(cz)

Notes:

(a) Depending on soil depth
(b) Depending on gravel content
(c) Highest rating for water-receiving areas, either by seepage additions (G3-soils) or groundwater influence (L5-soils)
(d) Soils high in kaolinitic clay : AWC of subsoil lower than in soils with predominance of other clays.
(e) Hardpan or very compact subsoil hampers root development and water uptake by plants.

A2.3 LAND QUALITY: DEPENDABLE MOISTURE AVAILABILITY (for cotton and maize only)

This land quality is only used for the land suitability assesment for cotton and maize, and is rated according to the methodology outlined in Technical Appendix 3

A2.4 LAND QUALITY : SOIL FERTILITY

This land quality refers to the presence of plant nutrients in the soil and whether these nutrients are readily available to the plants. At present the appraisal of soil fertility is based on chemical data only, major parameters being nitrogen content, available phosphorus, exchangeable potassium, cation exchange capacity, base saturation and soil reaction.

Although the presence of micro-elements such as boron, copper, zinc or sulphur are important to plant growth, no information is available for the soils of the survey area. They are therefore not considered in the rating.

The rating of this land quality is given in table 21. The soil fertility status of the soils of the survey area is assessed in table 22.

It may be noted that available information for the rating of phosphorus is scanty. For further details on analytical data is referred to the technical appendix with soil body descriptions.

Table 20 - Rating of soil fertility (1)

Soil characteristic						Rating
pH (water)	% O.C.	% N	ppm P	meq/100 g soil K	meq/100 g soil sum bases	
6.0-8.0	>2.25	>0.15	>15	>0.4	>14	1
5.0-6.0 8.0-9.0	0.75-2.25	0.05.0.15	5-15	0.2-0.4	8-14	2
4.5-5.0	0.15-0.75	0.01-0.05	1-5	0.1-02	2-8	3
<4.5	<0.15	<0.01	<1	<0.1	<2	4

Notes
(1) Modified after Van der Kevie (1976) as follows:
- CEC replaced by Sum bases due to lack of CEC-data
- P-levels modified after Singh (1979)
- Base saturation ratings not included due to lack of data
- $pH(H_2O)$ instead of pH-paste

(2) To be rated at one of the rating levels at least 5 of the 6 listed characteristics should satisfy that level or higher.

(3) Ratings should be raised one level if the soil has a high content of weatherable minerals.

Table 21 - Rating of soil fertility per soil unit, Geita-Sengerema

Land unit		soil characteristic (a)						Rating land quality
Mapping unit	Soil unit	pH water	% O.C.	% N	ppm P	exchang. K	(meq/100g) sum bases	
	G1	6.8	4.02	0.23	100	0.48	14	I(b)
	G2	6.4	1.16	0.08	10	0.34	5	3
	G3	6.5	0.80	0.07	12	0.17	4	3
	Gr	n.a.(c)	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Gs	n.a.(d)	n.d	n.d	n.d.	n.d.	n.d.	-
	Z1	6.3	2.07	0.10	7	0.42	6	3
	Z2	6.5	2.19	0.12	13	0.53	5	3
	Zr	n.d	n.d.	n.d.	n.d.	n.d.	n.d.	-
	Zi	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Kr	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
	Ks	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	-
	L1	6.7	0.74	0.06	9	0.11	6	3
	L2	6.5-5.7	1.09	0.08	4	0.17	5-13	3
	L3	6.1	1.75	0.09	9	0.19	30	2
	L4	6.2	1.62	0.13	9	0.21	7	3
	L5	6.3	2.32	0.22	34	0.07	5	3(b)

(a) Average value for top 30 cm
(b) Based on analytical results of only one profile
(c) n.a. = not applicable; n.d. = no data

A2.5-LAND QUALITY : DRAINAGE CONDITIONS IN THE GROWING SEASON

This land quality refers to the drainage condition of a soil estimated by the frequency and duration of the periods when the soil is saturated with water. These conditions are seldom accurately measured, but can be inferred from soil characteristics such as texture, colour, mottling, quality and kind of organic matter and groundwater leveles. Length and frequency of periods with standing water above the soil surface need also to be estimated.

The rating of this land quality is given in table 22. The ratings of the land units recognized in the survey area are shown in table 23.

Table 22 - Rating of drainage conditions in the growing season

	Land characteristic (a)			Rating
Soil drainage	ponding hazard, frequency (b)			
	every 1-2 years	every 3-5 years	every 6-10 years	
Good to excessive	none	none	2 weeks	1
moderately well	none	2 weeks	2-6 weeks	2
imperfect	2 weeks	2-6 weeks	6-10 weeks	3
poor to very poor	2-6 weeks	6-10 weeks	10 weeks	4

Notes:
(a) Not applicable to paddy rice; see quality on maintaining surface water.
(b) Ponding is inundation of the soil surface by nearly still waters, which may be due to a temporary rise of the groundwater table or to seepage and runoff from adjacent land, or by high rainfall on nearly flat sites with soils of low permeability.

Table 23 - Drainage conditions in the growing season per mapping unit, Geita-Sengerema

Land unit		Land characteristic				Rating
Mapping unit	Soil unit	Soil drainage	Ponding hazard, frequency			
			every 1-2 years	every 2-5 years	every 6-10 years	
HI-g/1	G2	g. - s.ex.	none	none	<2 weeks	1
	Gr,Gs,GI	g. - ex.	"	"	"	1
HI-g/2	Gr	ex.	"	"	"	1
	Gs	ex.	"	"	"	1
Ho-g(c)	G2	g.	"	"	"	1
	G3	s.ex.	"	"	"	1
H2-z	Zr	ex.	none	none	2 weeks	1
	Zs	ex.	"	"	"	1
-z	Zr	ex.	"	"	"	1
	Zs	ex.	"	"	"	1
Ho-z +	Zr (Kr)	ex.	"	"	"	1
Ho-k	Zs (Ks)	ex.	"	"	"	1
H1Pl-g(c)	G2	g. - s.ex.	None	None	2 weeks	1
	G3	s.ex.	"	"	"	1
HoPl-g (c)	G2	g.	"	"	"	1
	G3	s.ex.	"	"	"	1
HoPo-g (c)	G2	g.	"	"	"	1
	G3	s.ex. - g.	"	"	"	1
H1Pl-z	Z1	g.	none	none	2 weeks	1
	Z r (Zi)	ex. (ex.-m.)	"	" (2 weeks)	" (0-6 weeks)	1(1-2)
HoPl-z	Z 1	g.	"	"	"	1
	Zr (Zi)	ex. (ex.-m)	"	" (2 weeks)	" ()-6weeks)	1(1-2)
HoPo-z	Z1	g.	"	"	"	1
	Zr(Zi)	ex.(ex.-m)	"	"(<2weeks)	"(0-6weeks)	1(1-2)
Ul-g (c)	G2	g.	none	none	<2 weeks	1
	G3	s.ex. - g.	"	"	"	1
Uo-g (c)	G2	g.	"	"	"	1
	G3	g.-m.	"	< 2 weeks	0-6 weeks	1-2
	L1	g. - m.	"	"	2-6 weeks	2
Ul-z	Z1	g.	"	none	<2 weeks	1
Uo-z	Z1	g.	"	none	"	1
Mw (c)	L1	m. - imp	<2 weeks	2-6 weeks	6-10 weeks	3
	L2	im.	"	"	"	3
	L3	im. - p.	2-6 weeks	2-10 weeks	>10 weeks	3-4
Mf (c)	L2	imp. - p.	"	"	"	3-4
	L3	p. - v.p.	"	6-10 weeks	"	4
Lt	G3	m.	none	<2 weeks	2-6 weeks	2
	L4	im.	<2 weeks	2-6 weeks	6-10 weeks	2
Lb	G3	m.	none	<2 weeks	2-6 weeks	2
	L5	g. - im.	0-2 weeks	0-6 weeks	0-10 weeks	1-3

Notes:

(a) With the exception of L1-soils, only dominant and associated soils are rated.

(b) Abbreviations : g. : good, well drained
m. : moderately well drained
im.: imperfectly drained
p. : poorly drained
v.p: very poorly drained
ex.: excessively drained
s.ex: slightly excessively drained

(c) In these physiographic units all mapping units contain the same soil units in different proportions.

A2.6 - Land quality : Workability

This land quality refers to the ease with which a soil can be worked by hand tools or animal drawn ploughs, and therefore only applies to agricultural systems without mechanization.

This land quality is not easy to evaluate since it depends on a number of interrelated soil characteristics such as texture, organic matter content, structure, consistence (particularly plasticity limits), and occurence of gravels or stones in the surface layer. Also the moisture content plays an important role.

The rating for workability as a function of stoniness and consistence is given in table 24. The ratings of this land quality for the land units recognized in the area are given in table 25.

Table 24 - Ratings for workability

Land characteristics				Rating
Stoniness, % of surface coverage(a)		Wet consistence (b)	Dry consistence (b)	
Coarse gravels	Stones, boulders			
<3	<0.1	Nonsticky + slightly sticky; non plastic to plastic	loose to hard	1
3-15	0.1-3	Sticky + very sticky; plastic + very plastic	very hard	2
15-40	3-15 (1-2m apart)	-	extremely hard	3
>40	15 (<1m apart)	-	-	4

Notes: (a) Coarse gravel : 2.5-7.5 cm largest dimension
stones : 7.5 - 25 cm " "
boulders : >25 cm " "

(b) Consistence of upper 20 cm. If hardpan is present within 20cm the quality rating should not be higher than 3. For paddy rice consistence of hardpan is no limitation and should not be considered.

Table 29 - Ratings for workability, per land unit, Geita-Sengerema

Land Unit		Land characteristic			
Mapping unit	Soil unit(a)	Stoniness, % surface coverage stones, boulders	Wet consistence (b)	Dry consistence	Rating
Hl-g/1	G2	0.1-3	ns+np to ss+sp	loose to hard	2
	Gr,Gs,Gl	>15	"	"	4
Hl-g/2	Gr	100	n.a.	n.a.	4
	Gs	>15	ns+np to ss+sp	loose to hard	4
Ho-g/(c)	G2	<0.1	ns+np to ss+sp	loose to hard	1
	G3	<0.1	ns+np	loose	1
H2-z	Zr	100	n.a	n.a.	4
	Zs	>15	ns+np to ss+sp	loose to hard	4
Hl-z	Zr	100	n.a.	n.a	4
	Zs	>15	ns+np to ss+sp	loose to hard	4
Ho-z+	Zr(Kr)	100	n.a.	n.a	4
Ho-k	Zs(Ks)	>15	ns+np to ss+sp	loose to hard	4
HlPl-g(c)	G2	<0.1(e)	ns+np to ss+sp	loose to hard	1(e)
	G3	<0.1	ns+np	loose	1(e)
HoPl-g(c)	G2	<0.1	ns+np to ss+sp	loose to hard	1(e)
	G3	<0.1	ns+np	loose	1(e)
HoPo(c)	G2	<0.1	ns+np to ss+sp	loose to hard	1(e)
	G3	<0.1	ns + np	loose	1(e)
HlPl-z	Zl	<0.1(e)	s+vs, p+vp	loose to hard	2(e)
	Zr(Zi)	100	n.a	n.a	4
HoPl-z	Zl	<0.1(e)	s+vs, P+vp	loose to hard	2(e)
	Zr(Zi)	100	n.a	n.a	4
HoPo-z	Zl	<0.1(e)	s+vs, p+vp	loose to hard	2(e)
	Zr(Zi)	100	n.a	n.a	4
Ul-g(c)	G2	<0.1	ns+np to ss+sp	loose to hard	1
	G3	<0.1	ns+np	loose	1
Uo-g(c)	G2	<0.1	ns+np to ss+sp	loose to hard	1
	G3	<0.1	ns+np	loose	1
	Ll	<0.1	ns+np to ss+sp	hardpan 0-50cm	1-3(d
Ul-z	Zl	<0.1	s+vs, p+vp	loose to hard	2
Uo-z	Zl	<0.1	s+vs, p+vp	loose to hard	2
Mw(c)	Ll	<0.1	ns+np to ss+sp	hardpan 0-50cm	1-3(d
	L2	<0.1	ns+np to ss+sp	loose to hard	1
	L3	<0.1	s+vs, p+vp	very hard	2
Mf(c)	L2	<0.1	ns+np to ss+sp	loose to hard	1
	L3	<0.1	s+vs, p+vp	very hard	2
Lt	G3	<0.1	ns+np	loose	1
	L4	<0.1	ns+np to ss+sp	loose to extr. hard	1-3(d
Lb	G3	<0.1	ns+np	loose	1
	L5	<0.1	ns+np	loose	1

Notes:

(a) With the exception of L1-soils, only dominant and associated soils are rated.
(b) Abbreviations:

ns + np : nonsticky and nonplastic
ss + sp : slightly sticky and slightly plastic
v + vs : sticky and very sticky
P + vp : plastic and very plastic

(c) n.a. : not applicable

In these physiographic units all mapping units contain the same soil units in different proportions

(d) Depending on depth to hardpan layer.

(e) Ratings and figures apply to footslope areas only; hill areas have rating 4.

A2.7 - Land quality : Possibilities for mechanization

This land quality refers to the feasibility of the use of tractors and modern agricultural implements. The Main land characteristics that determine this land quality are:

1) land form and steepness of slope preventing use of tractors and other motorized equipment

2) micro-relief which hampers mechanization, and which, if strongly pronounced, would require land levelling before mechanization is possible.

3) occurence of gravels, stones, boulders and rocks on or below the surface tilth of the soil. This is difficult to evaluate many factors play a role, but is approximated by the characteristic "consistence".

The ratings for this land quality are given in Table 26. The ratings for the land units in the area are given in Table 27.

Table 26 - Ratings of possibilities for mechanization

Land characteristic							Rating
Stoniness in % of surface			Landform and steepest slope (%)	micro-relief (cm)(b)	consistence surface soil (c)		
gravel	stones (a)	rocks			wet	dry	
<3	<0.01	<1	flat to undulating(0-8)	30 (10)	ns+np to s+p	loose to hard	1
3-15	0-01-0.1 (10-30m apart)	1-2 (100-300m apart)	rolling(8-16)	30-60 (10-25)	vs+vp	very hard	2
15-30	0.1-3 (2-10m apart)	2-10 (30-100m apart)	hilly(16-30)	60-90 (25-40)	-	ext. hard	3
> 30	> 3	> 10	steeply dissectes(> 30)	>90	-	-	4

Notes:

(a) Includes stones (7.5-25 cm) and boulders (25 cm)

Gravel includes coarse fragments 0.2-7.5 cm.

(b) Microrelief refers to relief irrigularities and undulations within less than 50 m distance; it is expressed as the average difference in height between low and high spots. Figures in parentheses refer to gilgai relief of Vertisols for current land suitability classification.

(c) Abbreviations:

ns + np : nonsticky and non plastic
ss + sp : slightly sticky and slightly plastic

s + p : sticky and plastic
vs + vp : very sticky and very plastic

Table 27. Rating of possibilities for mechanization per land unit, Geita-Sengerema

Land unit		Land characteristic					Rating
Mapping unit	Soil unit (a)	Rockiness in % of surface	Landform and steepest Slope (%)	micro-relief (cm)(xx)	Consistence surface soil wet (b)	dry	
HI-g/1	G2	>10	hilly (16-30)	<30	ns+np to ss+sp to	loose to hard	4
	Gr,Gs, G1	>10	hilly (16-30)	n.a.	ns+np to	loose to hard	4
HI-g/2	Gr	>10	" "	n.a.	n.a.	n.a.	4
	Gs	>10	" "	n.a.	ns+np to ss+sp	loose to hard	4
Ho-g(c)	G2	2-10	rolling(8-16)	<30	ns+np	hard	3
				<30	ns+np	loose	3
H2-z	Zr	>10	steeply dissect. (30)	n.a.	n.a.	n.a.	4
	Zs	>10		"	"	"	4
H1-z	Zr	>10	hilly (16-30)	"	"	"	4
	Zs	>10	"	"	"	"	4
Ho-z +	Zr(Kr)	>10	rolling(8-16)	"	"	"	4
Ho-k	Zs(Ks)	>10	"	"	"	"	4
H1P1-g(c)	G2	2-10	undulat.(2-8) (d)	<30	ns+np to ss+sp	loose to hard	3 (d)
	G3	1-2	" "	<30	ns+np	loose	2 (d)
HoP1-g	G2	2-10	undulat.(2-8) (d)	<30	ns+np to	loose to hard	3 (d)
	G3	1-2	" "	<30	ns+np	loose	
HoPo-g	G2	2-10	almost flat (2-2) (d)		ns+np ss+sp	loose to hard	3 (d)
	G3	1-2	" "	<30	ns+np	loose	2 (d)
H1P1-z	Z1(zi)	2-10	undulating (2-8)	<30	s+p to vs + vp	loose to hard	3 (d)
	Zr	>10	hilly (undulating)	"	n.a.	n.a.	4
HoP1-z	Z1(Zi)	2-10	undulating (2-8)	"	s+p to vs + vp	loose to hard	3 (d)
	Zr	>10	hilly (undulating)	"	n.a.	n.a.	4
HoPo-z	Z1(Zi)	2-10	almost flat	"	s+p to vs + vp	loose to hard	3 (d)
	Zr	>10	hilly (undulating)	"	n.a.	n.a.	4

UI-g (c)'	G2	I-2	Undulat. (2-8)	<30	ns+np to	loose to	
					ss+sp	hard	2
	G3	I-2	" "	<30	ns+np	loose	2
Up-g	G2	I-2	almost flat(0-2)	<30	ns+np to	loose to	
					ss+sp	hard	2
	G3	I-2	" "	<30	ns+np	loose	2
	L1	I-2	" "	<30	Ns+np to	loose to	
					ss+sp	very hard	2
Ul-z	ZI	1-2	undulat. (2-S)	<30	sp+p to	loose to	
					vs+vp	hard	2
Uo-z	ZI	1-2	almost flat (0-2)	<30	s+p vp	loose to	
					vs+vp	hard	2
Mw (c)	L1	<1	" "	<30	ns+np to	loose to	
					ss+sp	very hard	1-2 (e)
	L2	<1	" "	<30	ns+np	loose to	
					ss+sp	hard	1
	L2	<1	" "	(0-25)	s+p	very hard	2
Mf (c)	L2	<1	flat (0-1)	<30	ns+np to	loose to	
	L2	<1			ss+sp	hard	1
	L3	<1	" "	(0-25)	s+p	very hard	2
Lt	G3	<1	" "	<30	ns+np	loose	1
	L4	<1	" "	<30	ns+np to	loose to	
					ss+sp	extr.hard	1-3 (e)
Lb	G3	<1	" "	<30	ns+np	loose	1
	L5	<1	" "	<30	ns+np	loose	1

Notes:

(a) With the exception of L4-soils, only dominant and allociated soils are vated.
(b) Abbreviations:

ns+np : nonsticky and nonplatic
ss+sp : slightly sticky and slightly plastic
s+p : sticky and plastic
vs+vp : very sticky and very plastic
n.a. : not applicable

(c) In these physiographic units all mapping units contain the same soil units in different proportions.
(d) Ratings apply to footslope areas only, rocky hill (areas have rating 4)
(e) Depending on depth to hardpan.

(xx) Figures between brackets refer to gilgai microrelief of Vertisols.

A2.8. Land quality: Erosion hazard

As used here this land quality refers to the susceptibility of the soils of the survey area to water erosion only. The risk of soil loss by the action of wind appears to be insignificant and it is not considered.

In general, soil erosion in tis most conspicuous form, gully erosion, has had a significant impact only in small, heavily stocked areas, mainly in the eastern part of the surveyed area. However in view of the sloping character of most of the area it can be expected that accelerated erosion in its less visible form, sheet erosion, is taking place. Since most of the fertility of the soils of the area is stored in the surface horizons, there is no doubt that the erosion hazard is an important factor to reckon with if sustained crop yields are to be achieved.

In the absence of severe damage by erosion, the erosion hazard in Geita-Sengerema is mainly determined by the susceptibility of the soils to water erosion. The system to rate the erosion hazard is based on Van der Kevie (1976), with certain modifications. It appears that this system overestimated the outlined by Van-der Kevie.

The erosion hazard is rated as a function of susceptibility to erosion and of past erosion as follows:-

Table 28. Rating of erosion hazard

Evidence of past erosion	Susceptibility to soil erosion	Rating
none	none	1
moderate (*)	slight	2
severe (*)	moderate	3
very severe (*)	severe	4

Note:

Moderate: Occasional occurrence of rills or gullies; partial stripping of organic horizon
Common occurrence of rills or qullies; soil truncation with removal of organic horizon; rock at shallow depth (50cm)
Very severe: total stripping of soil cover; rock at very shallow depth (10cm or at surface)

The susceptibility to soil erosion depends on the rainfall characteristics (total amount, rainfall intensity and frequency), slope gradient and slope length, soil erodibility vegetative cover. It is estimated as follows:

Table 29. Rating of susceptibility to soil erosion

Climatic zone	Slope % class	Erodibitility factor low	moderate	high
M2	0-1	insignificant	insignificant	slight
M2	1-2	"	slight	moderate
M2	2-8	slight	moderate	severe
M2	8-16	moderate	severe	"
M2	>16	severe	"	"

(Note: As in the case of the land quality 'Moisture Avaialability' climatic conditions similar to zone M2 in the Sudan have been assumed for rating 'Erosion hazard)

The soil erodibility, which is the inherent susceptibility of the soil to detachment and transport by rainfall and run-off, is estimated according to the methodology devised by Erickson (Erickson, 1973, USDA, 1975).

1. The main points of this methodology are following:

   Soil erodibility is diddiuult to measure quantitatively because of the many variables involved. There are however soil properties which in combination affect erodibility, such as texture, structure, chemical composition, the degree of weathering and the content of organic matter.

2. The combined influence of these soil properties which affect erodibility can be assessed by means of a soil erodibility factor K. This factor depends on texture of the surface soil (particularly percentage silt and very fine sand, fraction 0.002-0.10 mm), organic matter content; soil permeability and content of coarse fragments.

   The K-factor is estimated by using the Textural Triangle Nomograph for Soil Erodibility (fig.20). This nomograph is designed for soils that do not contain coarse fragments and have a normal range of 5-15% very fine sand (0.05-0.10 mm), a permeability which is normal for the texture class, and a organic matter content of 2%. If soil characteristics deviate from this, adjustments should be made as outlined in the nomograph. A soil may be considered compact if its bulk density is 1.5 in loamy or finer textured soils, or 1.7 in soils more sandy than sandy loam. The same correction of the K-value (+.0.3) should be made if soils are shallow (rock or hardpan within 50 cm from the surface).

   The content of very fine sand, which is usually not determined in the laboratory, can be estimated as follows:

I° estimate percentage of the fine fraction passing through a mesh 200 sieve (0.74 mm), by using the diagram in fig. 21;

2° estimate the percentage of very fine sand by using the formula :

% very fine sand = f x (% <.74 mm - .% clay) - % silt

in which clay is the fraction <0.002 mm and silt the fraction 0.002-0.05 mm, and f is a textural factor, varying with textural class as follows:

f = 1.0 for clay, silty clay, silty clay loam (respectively C, Sic, SiCL)
= 1.1 for clay loam (CL), loam (L) and Silt loam (SiL)
= 1.2 for fine sandy loam (FSL), sandy loam (SL)
= 1.35 for sandy clay loam (SCL)
= 1.5 for loamy sand (LS)
= 1.75 for sandy clay (SC), sand (S) and fine sand (FS).

Table 31 shows the step-by-step determination of the erodibility factor K for the soil units of the area, following the methodology by Erickson. Table 32 presents the ratings of susceptibility to soil erosion and the erosion hazards per land unit.

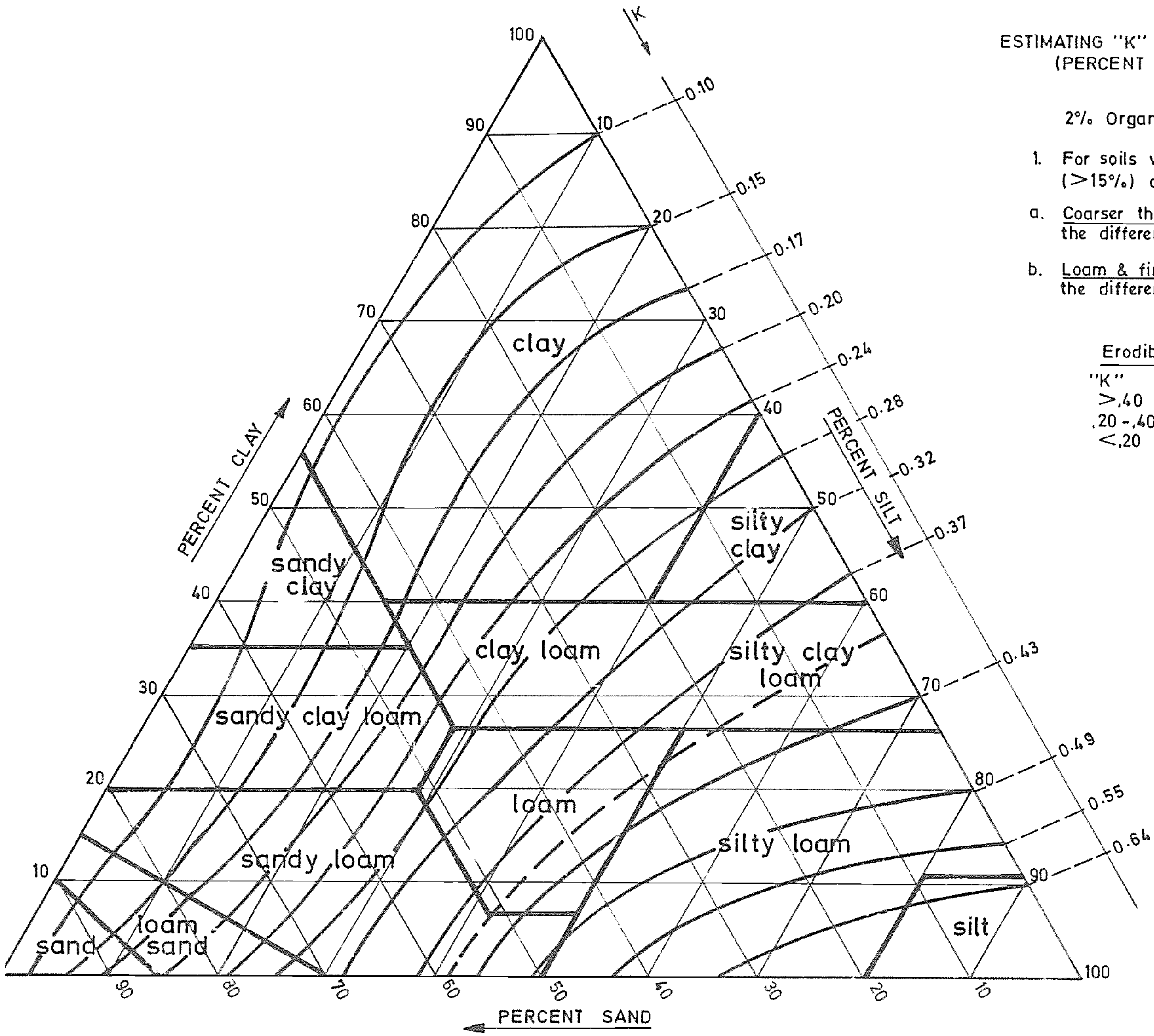


Figure 19 TEXTURAL TRIANGLE NOMOGRAPH FOR SOIL ERODIBILITY

Source:- Taken from Erickson

ESTIMATING "K" VALUE CLASS FROM TEXTURE
(PERCENT SILT, CLAY & SAND)

2% Organic matter & structure other than granular.

1. For soils with high content of <u>very fine sand</u> (>15%) and texture

a. <u>Coarser than loam</u>: Subtract 5% from the % vfs and add the difference to the silt content.

b. <u>Loam & finer</u>: Subtract 10% from the % vfs and add the difference to the silt content.

<u>Erodibility Group</u>

"K" Value	
>.40	- High
.20 -.40	- Moderate
<.20	- Low

2. <u>Corrections</u>

a. Structure:

very fine granular	- .09
fine granular	- .06
moderate or coarse granular	- .03

b. <u>Organic Matter:</u>

"K" Value	Percent O.M. 0	1	2	3	4
> .40	+.14	+.07	0.	-.07	-.14
.20 -.40	+.10	+.05	0.	-.05	-.10
< .20	+.06	+.03	0.	-.03	-.06

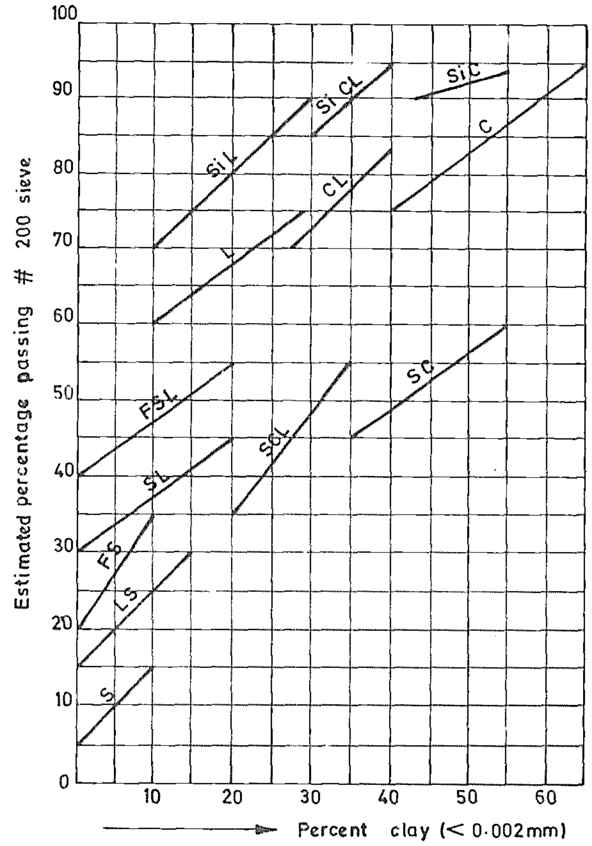
c. <u>Rock Fragments (by Volume)</u>

Rock Fragment Content - (Percent) 0-20	20-35	35-50	50-70
.10	.10	.10	.10
.15	.15	.10	.10
.17	.15	.10	.10
.20	.17	.15	.10
.24	.20	.17	.15
.28	.24	.20	.17
.32	.28	.24	.20
.37	.32	.28	.24
.43	.37	.32	.28
.49	.43	.37	.32
.55	.49	.43	.37
.64	.55	.49	.43

d. <u>Permeability</u>

Compact soil or PH> 9.0	+.03
Many medium or coarse pores	- .03

Figure 20 DIAGRAM FOR ESTIMATING PERCENT OF FINE FRACTION PASSING # 200 SIEVE (0.74mm)



Procedure:

Go vertical from % clay on abscissa to appropriate texture class line; then go horizontal to ordinate to find estimate of percent of fine fraction passing # 200 sieve.

Source:

Taken from Erickson

Table 30. Determination of the erodibility factor K per soil unit, Geita-Sengerema

Soil unit	Average % (topsoil)			Average texture (topsoil)	% pass. # 200 sieve	Text. factor (f)	% very fine sand	upgrad. % silt	K1	Average % O.M. (tops.)	O.M. correct	Struct. correct	Permeab. + shall. correct.	Final K	Erodibility group
	sa.	si.	clay												
G1(a)	66	21	13	sl	40	1.2	11	21	.21	7.0	-.10	0	-.03-0(b)	.14-11	low
G2	74	9	17	sl	42	1.2	21	25	.24	2.0	0	0	0	.24	moderate
G3	86	8	6	ls	21	1.5	15	8	.15	1.4	+.03	0	0	.18	low
Z1	40	20	40	cl-c	79	1.1-1.0	23-19	33-29	.28-.25	3.5	-.10	-.09	0	.09	low
Z2(a)	40	20	40	cl-c	79	1.1-1.0	23-19	33-29	.28-.25	3.8	-.10	-.09	0	.09	low
L1	76	7	17	se	42	1.2	23	25	.24	1.3-2.3	+.05-0	0	+.03	.32	moderate
L2	81-57	9-14	10-29	ls-scl	25-48	1.5-1.35	14-12	9-14	.15-.16	1.4	+.03	0	0	.18	low
L3	49	10	41	sc	50	1.75	6	10	.14	3.03	-.03	0	+.03	.14	low
L4	73	16	11	sl	38	1.2	16	27	.26	2.8	-.05	0	+.03	.24	moderate
L5(a)	91	2	7	s	12	1.75	7	2	.07	4.0	-.06	0	0	.01	low

(a) Mechanical analysis available for one profile only.

(b) depending on depth bed rock

Table 31. Rating of erosion hazard per land unit. Geita-Sengerema

Land unit		Land characteristic				Rating erosion hazard
Mapping unit	Soil unit(a)	Slope % class	Erodibility factor K	Evidence past erosion	Susceptibility to erosion	
HI-g/1	G2	16-30	moderate	none-moder.	severe	4
	Gr,Gs,	"	n.a.	n.a.	n.a.	-
	G1	"	low	very severe	"	4
HI-g/2	Gr	"	n.a.(c)	" "	n.a.	4
	Gs	"	n.a.	" "	n.a.	4
Ho-g(b)	G2	8-16	moderate	none-moder.	severe	4
	G3	"	low	" "	moderate	3
H2-z	Zr	30	n.a.	very severe	n.a.	4
	Zs	"	n.a.	" "	n.a.	4
H1-z	Zr	16-30	n.a.	" "	n.a.	4
	Zs	"	n.a.	" "	n.a.	4
Ho-z	Zr(Kr)	8-16	n.a.	" "	n.a.	4
Ho-k	Zs(Ks)	"	n.a.	" "	n.a.	4
HIPI-g(b)	G2	(16-30)+(2-8)	mode-rate	none-moder	sev.+moder.	4-3(d)
	G3	" "	low	" "	sev.+slight	4-2(d)
HoPl-g(b)	G2	(8-16) +(2-8)	moderate	" "	sev.+moder.	4-3(d)
	G3	" "	low	" "	mod.+slight	4-2(d)
HoPo-g (b)	G2	(8-16)+(0-2)	moderate	" "	sev.+slight	4-2(d)
	G3	" "	low	" "	mod.+insign.	3-1(d)
HIPI-z	Z1	(16-30)+(2-8)	low	none-severe	sev.+slight	4-2(d)
	Zr+Zi	" "	n.a.	very severe	n.a.	4
HoPl-z	Z1	(8-16)+(2-8)	low	none-severe	mod.+slight	3-2(d)
	Zr+Zi	" "	n.a.	very severe	n.a.	4
HoPo-z	Z1	(8-16)+(0-2)	low	none-moder.	mod+insign.	3-1(d)
	Zr+Zi	" "	n.a.	very severe	n.a.	4
Ul-g(b)	G2	2-8	moderate	none-	moderate	3
	G3	"	low	"	slight	2
Uo-g(b)	G2	0-2	moderate	"	slight	2
	G3	"	low	"	insignificant	1
	L1	"	moderate	moderate	slight	2
Uo-z	Z1	2-8	low	none	slight	2
Uo-z	Z1	0-2	low	"	insignificant	
Mw (b)	L1	0-2	moderate	moderate	slight	2
	L2	0-2	low	none	insignificant	1
	L3	"	"	"	"	1
Mf (b)	L2	0-1	"	"	"	1
	L3	"	"	"	"	1
Lt	G3	"	low	"	"	1
	L4	"	moderate	"	"	1
Lb	G3	"	low	"	"	1
	L5	"	low	"	"	1

Notes: (a) With the exception of L1-soils, only dominant and associated soils are rated.

(b) In these physiographic units all mapping units contain the same soil units in different proportions.

(c) n.a. = not applicable

(d) Rating depends on slope at particular site and severity past soil erosion.

A.2.9. Land quality : Capability for maintaining surface water

This land quality is rated only in case of suitability classification for paddy rice, which is a crop that needs to be grown in waterlogged or shallowly flooded soils. Thus soils on which surface water can be maintained are most favourable. Soils therefore should have imperfect to poor drainage and have slow permeability and infiltration rate. The latter can be accomplished by puddling if soil textures are favourable. Fields should be level with no strong microrelief which may cause surface run-off or uneven distribution of surface water .

Table 32 gives the rating system of this land quality and Table 33 presents the ratings for the land units recognized in the survey area.

Table 32. Rating of capability for maintaining surface water

Land characteristic				Rating
Slope %	Microrelief (*)	Drainage class	Texture of surface and sub-surface horizon	
< 0.5	0.5	imperfectly to poorly drained	clay, silty clay, sandy clay, clay loam, silty clay loam	1
< 2	5-10	imperfectly to poorly drained	same as above plus sandy clay loam	2
< 3	10-20	moderately well drained	same as above plus loam and sandy loam	3
< 3	> 20	excessively to well drained	clay to sand	4

Notes:

(*)Microrelief is expressed as the average difference in height between low and high spots within 50 m distance. No major improvement by levelling is considered.

Table 33. Rating of capability for maintaining surface water, per land unit Geita-Sengerema

Land Unit		Land characteristic				Rating of land quality
Mapping unit	Soil unit(a)	Slope %	Microrelief (cm) (b)	Drainage class (c)	Texture of surface and subsurface horizon (d)	
Hl-g/1	G2	16-30	n.a.	g.-s.ex.	sl and scl	4
	Gr,Gs,Gl	"	"	g.-ex.	sl	4
Hl-g/2	Gr	"	"	ex.	n.a.	4
	Gs	"	"	ex.	sl	4
Ho-g/(e)	G2	8-16	"	g.	sl and scl	4
	G3	"	"	s.ex.	(l) s	4
H2-z	Zr	> 30	"	ex.	n.a.	4
	Zs	"	"	"	"	4
Hl-z	Zr	16-30	"	"	"	4
	Zs	"	"	"	"	4
Ho-z	Zr	8-16	"	"	"	4
(+ Ho-k)	Zs	"	"	"	"	4
HIPI-g (e)	G2	2-8 (f)	"	g.-s.ex.	Sl and scl	4
	G3	"	"	s.ex.	(l) s	4
HoPI-g(e)	G2	"	"	g.	sl and scl	4
	G3	"	"	s.ex.	(l) s	4
HoPo-g (e)	G2	0-2 (f)	"	g.	sl and scl	4
	G3	"	"	s.ex. - g.	(l) s	4
HIPI-z	Zl (oo)	2-8 (f)	"	good	cl and c	4
HoPI-z	Zr (oo)	"	"	ex.	n.a.	4
HoPo-z	Zi (oo)	0-2 (f)	"	ex.-m.	n.a.	4
UI-g (e)	G2	2-8	"	g.	sl and scl	4
	G3	"	"	s.ex.-g.	(l) s	4
Uo-g (e)	G2	0-2	"	g.	sl and scl	4
	G3	"	"	g.-m.	(l) s	4
	Ll	"	"	m.	sl-sc over hardpan	3
UI-z	ZI	2-8	"	g.	cl and c	4
Uo-z	ZI	0-2	"	g.	cl and c	4
Mw (e)	L1	0-2	0-20	m.-im.	sl-sc over hardpan	3-2 (g)
	L2	"	0-20	im.	ls or sl and scl or sc	1-3 (h)
	L3	"	0-20	im.-p.	sc and c	1-3 (h)
Mf (e)	L2	0-1	0-20	im.	ls or sl and scl or sc	1-3 (h)
	L3	"	0-20	im.-p.	sc and c	1-3 (h)
Lt	G3	0-1	0-10	m.	(l) s	4
	L4	"	"	im.	ls and scl or sc	1-2
Lb	G3	"	"	m.	(l) s	4
	L5	"	"	g.-im.	s	4

Notes

(a) With the exception of Ll-soils, only dominant and associated soils are rated.

(b) Microrelief is not considered applicable to upland soils which have no capability to maintain surface water by slope constraints. Termite mounds are not considered for rating the quality because they are usually further apart than the size of rice fields.

(c) Drainage abbreviations:

g. : well drained ; m. : moderately well drained; im. : imperfectly drained; p. : poorly drained; ex. : excessively drained; s.ex.: somewhat excessively drained

(d) Texture abbreviations:

(1) s : (loamy) sand; sl : sandy loam; scl : sandy clay loam; sc: sandy clay; cl: clay loam; c: clay.

(e) In these physiographic units all mapping units contain the same soil units in different proportions.

(f) Slope classes apply to footslope areas only, not to hill areas.

(g) Depending on drainage

(h) Depending on texture.

A.3. Technical Appendix 3.

THE ASSESSMENT OF DEPENDABLE MOISTURE AVAILABILITY FOR COTTON AND MAIZE IN GEITA-SENGEREMA DISTRICTS

A.3.1. INTRODUCTION

One of the major obstacles to increased crop production by rainfed agriculture in most parts of Tanzania is high rainfall variability. Rainfall variability refers to the considerable variation in rainfall amounts, duration and distribution, which is common to many parts of the wet and dry tropics. This phenomenon has two important implications for rainfed agriculture : it causes periodic droughts, even in areas with higher rainfall, and makes the planning of agricultural activities, particularly planting, problematic.

In Geita-Sengerema districts rainfall variability is an important land characteristic (see section 2.2.2.) with a profound impact on rainfed agriculture. When rainfall amounts are inadequate or poorly distributed, crop failures are common, particularly for drought-sensitive crops such as maize. But also drought tolerant crops may suffer. Cotton for instance may experience considerable yield reductions not only from moisture deficits, but also from excess rainfall at times that it is not needed, particularly the end of the growing period. Under such conditions the choice of a planting time may be critical to achieve consistently good crop yields. If the farmer plants too early, the crop may enter a dry spell after the first rains or eventually get spoilt by excessive late rains; if he plants too late the growing season may be insufficient to meet the water demand of the crop.

Under such conditions it is essential that the hazards to crops due to inadequate or poorly distributed moisture are correctely perceived and if possible quantified. In other words, practical field methods need to be developed to assess the suitability of land for relevant land use alternatives under conditions of pronounced rainfall variability. However, at present most land suitability classification systems tend to incorporate rainfall variability at a low category only or to ignore it altogether. Present systems in use rely in general on the interpretation of average climatic data which tend to overestimate moisture availability. A typical illustration of this situation has been presented in section 2.2.4. where the waterbalance for Mwanza in an average rainfall year was compared with the waterbalance in a dry year. The conclusion from this example was that the use of average data to assess moisture availability was likely to give misleading results.

It is felt that a true picture of moisture availability can only emerge if one makes a probability assessment of moisture availability, or, alternatively, if one estimates the probability athat available moisture will be inadequate for optimum crop growth and yield formation. The relevant questions that need to be answered under conditions of prominent rainfall variability are therefore :

1. "What is the probability of a crop failure by inadequate rainfall distributuion ?" (particularly relevant for low capital intensity farming systems).

2. "What is the probability of yield reductions below economical levels by inadequate rainfall distribution?" (particularly relevant for high capital intensity farming systems).

The purpose of this appendix is to present a methodology that has been developed to address the first question and has been applied in the land suitability classification of Geita-Sengerema districts for cotton and maize. These crops were chosen because they are the main cash and food crops, not only in the districts, but in the country as a whole and because they lend themselves particularly well to this exercise.

The newly developed methodology is based on the concept of "dependable moisture availability", which can be defined as the moisture amount available to plants that can reasonably be expected over a long series of growing periods. "Dependable moisture availability" replaces "moisture availability" as a land quality in the land suitability evaluation and is rated through a probability assessment of crop failure caused by inadequate rainfall distribution (drought or excessive rainfall). This assessment is based on a crop-specific waterbalance technique which considers the waterdemand of particular crops and the criticality of moisture stress at various growth stages.

The principles of the methodology are explained in section A.3.2. Section A.3.3. presents the waterbalance specifications used in this methodology. The procedure is presented in section A.3.4. The results of calculations for cotton and maize are given in section A.3.5. The application of the methodology in the land suitability classification for Geita-Sengerema districts is presented in section A.3.6. A fully worked out example of calculations for cotton is given in section A.3.7.

A.3.2. PRINCIPLES OF THE METHODOLOGY

The methodology developed to assess the land quality "dependable moisture availability is essentially a waterbalance approach, based on following principles:

a. A waterbalance is crop-specific. The water demand is expressed by the crop water requirement or maximum crop evapotranspiration. (ETm), not by the potential evapotranspiration (ETo). Moreover each waterbalance model takes specific crop characteristics related to moisture needs into account, such as the length of the growing period, length of various growth stages and critical of moisture stress at these growth stages.

b. A waterbalance is based on actual rainfall figures, not on average. This implies that a long series of years have to be considered, a waterbalance made for each year (or growing season) and a probability assessment of moisture availability made afterwards.

c. The major parameter to assess moisture availability in each time period is the ratio of actual evapotranspiration (ETa) to crop water requirement (ETm). It is hereby accepted that an evapotranspiration deficit will express itself by a yield deficit, compared to a theoretical, water-constraint free yield.

d. Each growing period is characterized by an <u>index</u>, obtained from a crop-specific combination of individual ETa/ETm-rations. When this crop water index does not exceed a critical value, a crop failure is defined. The probability that such crop failure will occur is then assessed by means of a cumulative frequency distribution curve.

e. Through the obtained probabilities of not exceeding a critical value, dependable moisture availability is finally assessed as follows :

Probability of crop failure by imbalanced rainfall	Degree of limitation	Rating
0-10% probability of crop failure	No or slight limitation	1
11-20% " " " "	Moderate limitation	2
21-40% " " " "	Severe limitation	3
> 40% " " " "	Very severe limitation	4

At this stage it is appropriate to define some frequently used terms.

The term "drought" is defined in a general way as a water deficit in crops severe enough to reduce or inhibit growth, development or yield. The term "imbalanced rainfall" refers here to a rainfall distribution in which either drought or excessive rainfall, or both, with damaging effects to crops, are common.

The term "crop failure" is used to represent a very substantial reduction of crop yield and is defined when the crop water index does not exceed a critical value (50%). It should be noted that in this particular method there exists no direct relationship between the crop water index and yields. The index is only meant to provide a qualitative picture of moisture availability.

A.3.3. METHODOLOGY

For ten rainfall stations in and outside the survey area monthly rainfall records were compiled. The rainfall amounts were matched in a waterbalance with monthly crop water requirement data and related to the storage capacity of a modal, medium textured soil. On the basis of the waterbalance a crop water index was calculated for each growing period. The set of crop water indices was calculated for each growing period. The set of crop; water indices was plotted in a cumulative frequency diagram and from this curve "probabilities of crop failure" were derived.

For another planting time the procedure was repeated. The most suitable planting time was the one in which the growing period had the lowest probability of crop failure.

The following specifications were built into the model :

a. The waterbalance model is a very simple one, adopted from Sansom (1954) with one notable difference : instead of potential evapotranspiration (ETo), the crop water requirement (ETm) represents the water demand. The basic equations of this waterbalance model are:

$$\text{if } R_i + (Sa)_{i-1} \geq (ETm)_i \quad \text{then} \begin{cases} (Sa)_i = R_i + (Sa)_{i-1} - (ETm)_i \leq Smax \\ (ETa)_i = (ETm)_i \end{cases}$$

$$\text{if } R_i + (Sa)_{i-1} < (ETm)_i \quad \text{then} \begin{cases} (ETa)_i = R_i + (Sa)_{i-1} \\ (Sa)_i = 0 \end{cases}$$

in which ETm : crop water requirement
R : rainfall
Sa : actual soil moisture storage
ETa : actual crop evapotranspiration
Smax: maximum soil moisture storage = AWC x d with
AWC : available waterholding capacity (mm/m)
d : rooting depth
$(ETa)_i$; $(ETm)_i$, $(Sa)_i$ etc...: actual evapotranspiration, crop water requirement, actual soil moisture storage etc. during month i.

$(Sa)_{i-1}$: actual soil moisture storage in month immediately preceding month i.

The shortest period considered for the waterbance calculations is a month. A single rooting depth (150 cm) has been chosen for both crops for the whole growing season. The available waterholding capacity for a reference, medium-textured soil has been estimated at 100 m/m. Inherent assumptions in this model are that all precipitation infiltrates into the soil and that actual evapotranspiration is not affected by depletion of soil moisture.

b. The waterbalance calculations refer to particular crop varieties with specific crowth cycles. The maize-variety considered relevant for the area is a five-month variety, Ukiriguru composite A. In the case of cotton the six-month UK-varieties are the normal cotton types grown in the area.

c. Storage at planting time is assessed by including the month prior to planting in the waterbalance calculations. It was accepted that moisture stored in the soil two months before planting would be depleted by the time of planting.

d. The concept of <u>crop water index</u> is central in this methodology. A crop water index is a generalized rating that expresses the adequacy of a particular season in meeting the water requirement of the considered crop. This index expresses to what extent available moisture from rainfall and soil storage can be utilized to meet the crop water needs for the season under consideration. This index is crop-specific and is obtained from a crop-specific combination of selected monthly ETa/ETm-ratios. The formulas for the crop water indices for maize and cotton are respectively:

Maize :

$$\sqrt[11]{\left(\frac{ETa}{ETm}\right)_2^2 \times \left(\frac{ETa}{ETm}\right)_3^8 \times \left(\frac{ETa}{ETm}\right)_4}$$

in which Is : crop water index
lower exponents : number of month of the growing period
upper exponents : weighing factors of geometric mean

Cotton:

$$\sqrt[4]{\frac{\sum_{i=1}^{2}(ETa)_i}{\sum_{i=1}^{2}(ETm)_i} \times \left[\frac{\sum_{i=3}^{5}(ETa)_i}{\sum_{i=3}^{5}(ETm)_i}\right]^3} \times C$$

in which Is : crop water index for cotton
$\sum_i^j (ETa)_i$: sum of ETa-values from month i to j
$\sum_i^j (ETm)_i$: sum of ETm-values from month i to j

C: depreciation factor

C is 0.8 if rainfall in the last month of the growing period exceeds 100 mm.
C is 0.5 if rainfall in the last month of the growing period exceeds 200 mm.

These formulas appear more complicated than they actually are. As already stressed the crop water indices are merely weighed averages of selected monthly ETa/ETm-ratios. As a measure of the average the <u>geometric mean</u> has been chosen, in which the upper exponents express the relative weight given to each individual period indicated by the lower exponents. The weighing factors are related to the criticality of moisture stress at different growth stages and are specific for each crop. How these weighing factors have been obtained will be explained later.

e. The adequacy of moisture availability at planting is not reflected by the crop water indices. To assess whether a particular month has adequate moisture for planting or not, the ratio ETa/ETm for the first month of the growing period Im 1 is calculated. If this ratio is less than 50% it is assumed that moisture is inadequate for planting. For the first month of the growing period a similar probability assessment of not exceeding 50% is then made as for the crop water indices. The two probability assessments are then compared and the highest of the two is then taken as the probability of crop failure.

A few clarifications are required at this stage. First it will be explained why 50% has been chosen as the critical value to define crop failure. Secondly it will be explained how the weighing factors in the crop water indices have been obtained.

a. The critical value of 50% for the crop water indices was chosen for following reasons;

1) From historical records in annual agricultural reports for the area concerned it was found that all years with marked low crop performance, that could be related to poor rainfall distribution, were characterized by a crop water index below 50%, for cotton as well as maize.

2) Fig. 16 in Doorenbos and Pruitt (1974) illustrates the relationship between relative yield and actual crop evapotranspiration for maize. The figure indicates that if actual evapotranspiration does not exceed 40% of the maximum, averaged over the growing period, the actual yield would be virtually nil and a total crop loss would result.

b. The weighing factors are related to the criticality of moisture stress at different growth stages as follows:

Maize

In the case of maize the susceptibility of different growth stages to moisture stress was assessed from the same figure in Doorenbos & Pruitt (1974), which illustrates the relationship between relative yield and actual crop evapotranspiration (ETa).

From the graph was inferred that :

1) Severe water stress during tasseling (approximately the third month of the growing period) dropped yield by 90-95%. Actual yield was thus 10-5% of the expected yield.

2) Water stress after pollination to maturity (approximately the fourth month of the growing period) reduced yield by 50%.

3) Water stress in the period between germination and tasseling (approximately the second month of the growing period) is to all sources more critical than after the tasseling stage, but less critical than during the tasseling stage. It was inferred to cause a yield reduction of about 75%.

The weighing factors are related to these yield reductions as follows: If under moisture stress the actual yield is only 5-10% of the expected yield, the criticality of moisture stress is about 10 to 5 times higher than when the yield is reduced by 50%, the weighing factor is accordingly, on the average, about 8 times higher. Similarly the criticality of moisture stress in the second month of the growing period is twice as high as for the fourth and the weighing factor is then also twice as high.

Thus the weighing factors for maize are 2 for the second month of the growing period, 8 for the third month and 1 for the fourth month.

Cotton

In the case of cotton the weighing factors are based on a qualitative comparison of crop water requirements for different growth stages. A quantitative relationship between relative yield and actual avapotranspiration was not found in the available literature.

According to the consulted sources the water requirement of cotton is highest in the period of flowering and boll formation, which corresponds roughly with the third to fifth month of the growth cycle of the UK-varieties. Since East-African cotton can compensate for early crop losses (ex.g. by moisture stress) by moisture stress) by extra growth on top of the plant at a later stage that moisture is adequate, it is not necessary to split this three-month period in smaller periods with different susceptibility to water stress. For this reason the period between the third and fifth month of the crop cycle is represented by the index

For the first two months of the growing period, before flowering, water requirements are rather low. Nevertheless adequate water is needed to ensure good growth, otherwise germination may be poor or even a complete crop failure may occur. Moisture availability for the first two months of the growing period is assessed through the index

According to the sources moisture is most critical between the third and fifth month of the growing period. Yet moisture stress is not as critical for cotton as for maize. For this reason the weighing factor for the period between the third and fifth month is 3 as compared to the period between the first and second month.

A final characteristic of the cotton crop that had to be represented by an index is its susceptibility to excess rainfall. Very high rainfall is undesirable for cotton, especially after boll splitting. Heavy rains reduce the amount of solar radiation, cause discoloration of the lint, delay picking and promote higher incidence of pests.

To appreciate the adverse effect of excessive rainfall a depreciation factor C was introduced. This factor reduces the seasonal crop water index by 20% if rainfall in the last month of the growing period exceeds 100 mm, and by 50% if it exceeds 200 mm.

A.3.4. PROCEDURE

The procedure for calculating the probability of crop failure by imbalanced rainfall is outlined in following paragraphs. This procedure needs to be repeated for each rainfall station.

Step I

Compile monthly rainfall records for each cropping season. A series of 30 years is optimal for this exercise, a series of 15 years is considered a minimum.

Step 2

Calculate crop water requirements for each month of the growing period as outlined in Doorenbos and Pruitt (1974). Include the month prior to planting.

Step 3

Calculate waterbalances with the average crop water requirement and monthly rainfall as variable inputs. The water demand and rainfall in the month prior to planting have to be included in the waterbalance. The maximum soil moisture storage of the modal soil is estimated at 150 mm for an average rooting depth of 150 cm for cotton and maize.

Repeat this step for each cropping season and for the selected planting periods.

Step 4

Calculate the crop water indices for maize as given in formula (1) and for cotton as given in formula (2). Calculate also the ETa/ETm-ratio for the first month of the growing period both for cotton and maize. Repeat this step for each cropping season and with different planting times.

Step 5

When steps 2-4 are completed for all cropping seasons, plot the cumulative frequency distribution of the crop water indices on probability graph paper, using the formula of Weibull for estimating the cumulative frequencies.

$$\text{Cumulative frequency} = \frac{100\ m}{N + 1}$$

(N is the total number of data; m is the rank number with m=1 for the highest value)

Similarly plot the cumulative frequency distribution of the ETa/ETm-values for the first month of the growing period. Repeat this step for each planting time.

Step 6

From the cumulative frequency curves derive

1) the probability that the crop water index will not exceed 50%
2) the probability that the ETa/ETm-ratio for the first month of the growing period will not exceed 50%.

Equate the probability of crop failure by imbalanced rainfall as the higher probability of the two.

Step 7

Assess the land quality "moisture availability" on the basis of the limitation "probability of crop failure by imbalanced rainfall" as follows :

Probability of crop failure by imbalanced rainfall	Degree of limitation	Rating
0-10% probability of crop failure	No or slight limitation	1
11-20% probability of crop failure	Moderate limitation	2
21-40% probability of crop failure	Severe limitation	3
> 40% probability of crop failure	very severe limitation	4

Select the most suitable planting time as the one for which the growing period has the lowest probability of crop failure.

A.3.5. DEPENDABLE MOISTURE AVAILABILITY FOR COTTON AND MAIZE, RESULTS

On the basis of the method outlined in sections A.3.2. To A.3.4. the dependable moisture availability for cotton and maize has been assessed for 10 rainfall stations within and outside the surveyed area.

The results of the calculations for cotton are summarized in table 34. A small-scale map was prepared showing the hazards of crop failure by imbalanced rainfall, related to the most suitable planting time (fig.25). The boundaries of this map are approximate only because of the limited number of rainfall stations. A summary of results for maize is given in table 35. On the basis of these results a similar map (fig.26) has been drawn as for cotton that illustrates the pattern of dependable moisture availability in the area. In table 36 the most suitable planting times for cotton and maize, grouped in classes according to the severity of the rainfall limitations are compared for the different stations.

A major conclusion from the comparison of fig.25 with fig. 26 is that Geita-Sengerema districts are in general more suited to cotton than for maize. The limitation of rainfall variability is apparently more severe for maize than for cotton, although the latter crop has a somewhat higher water requirement and a longer growing period. This result is attributed to the high susceptibility of maize to waterstress at particular growth stages, causing an irreversible yield depression. Cotton on the other hand has the capacity to overcome waterstress at one growth stage by compensatory growth at another, if sufficient moisture is available.

Some conclusions in respect of dependable moisture availability and the role of planting times are given for cotton and maize separately in following paragraphs.

Cotton

Most of Geita-Sengerema districts have only a slight rainfall variability limitation, with 0-10% probability of cotton failure by imbalanced rainfall. In the extreme East a moderate rainfall variability limitation exists, resulting in a II-20% probability of crop failure. Climatologically least suited areas for cotton growing appear to be the islands Maisome and Kome, with a 21-40% probability of dotton failure by imbalanced rainfall.

From the comparison of dependable moisture availability data for different planting seasons over a long number of years (table 34) it is concluded that the month of December is the most suitable planting time in all the stations for which rainfall data is available, except Kome Island. Table 36, based on class intervals, confirms this trend.

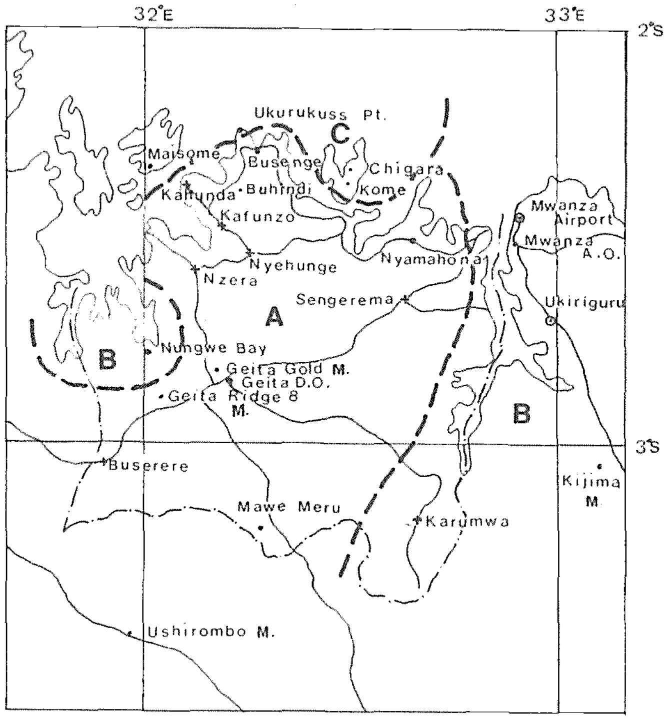


Fig. 23 Dependable moisture availability for cotton.

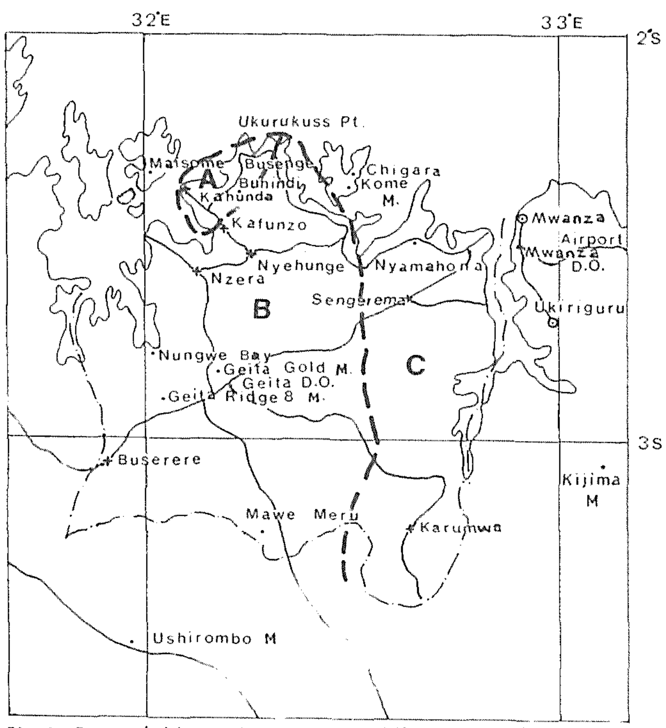


Fig. 24 Dependable moisture availability for maize.

LEGEND

A Moisture zone A
0–10% Probability of crop failure

B Moisture zone B
11–20% Probability of crop failure

C Moisture zone C
21–40% Probability of crop failure

— — Approximate boundaries of moisture zones

• *Rainfall station*

Table 34. Dependable moisture availability and most suitable planting times for cotton.

Station	Planting time	No. grow. seasons	Probability non-exceed. (1)	Probability non-exceed. (2)	Probability crop damage imbalanced rainfall	Severity limitation	Most suitable planting time
Geita	October	26	42	22	42	4	December
	November	26	21	28	28	3	
	December	26	6	7	7	1	
	January	26	15	5	15	2	
Ukiriguru	October	28	53	31	53	4	
	November	28	28	39	39	3	
	December	28	12	20	20	2	December
	January	28	16	18	18	2	January
Nyamahona	October	29	23	33	33	3	
	November	29	22	54	54	4	
	December	29	<3	10	10	1	December
	January	29	13	15	15	2	
Mwanza	October	30	50	38	50	4	
	November	30	38	70	70	4	
	December	31	18	14	18	2	December
	January	31	24	4	24	3	
Nungwe Bay	October	14	33	38	38	3	
	November	14	18	50	50	4	
	December	13	<7	11	11	2	December
	January	14	18	22	22	3	
Maisome	October	14	26	62	62	4	
	November	14	8	68	68	4	
	December	14	17	27	27	3	December
	January	14	40	14	40	3	
Ukurukuss	October	15	27	46	46	4	
	November	14	15	50	50	4	
	December	14	<7	30	30	3	December
	January	17	42	23	42	4	
Busenge	October	12	16	15	16	2	
	November	12	<8	40	40	3	
	December	12	<8	8	8	1	December
	January	12	26	<8	26	3	
Buhindi	October	12	22	30	30	3	
	November	11	<7	34-50	34-50	3-4	
	December	11	<7	10	10	1	December
	January	12	<7	<8	<8	1	January
Kome-Chigara	October	23	42	36	42	4	
	November	22	18	30	30	3	November
	December	22	19	60	60	4	
	January	21	25	32	32	3	January
	September	24	36	13	36	3	

(1) ETa/ETm-ratios for first month of the growing period

(2) Crop water inices

Table 35. Dependable moisture availability and most suitable planting times for maize.

Station	Planting time	No. grow. season	Probability non-exceed. (1)	Probability non-exceed. (2)	Probability crop damage imbalanced rainfall	Severity limitation	Most suitable planting time
Geita	October	26	50	11	50	4	
	November	26	22	25	25	3	
	December	26	6	14	14	2	December
	January	26	15	11	15	2	January
Ukiriguru	October	28	56	16	56	4	
	November	28	28	32	32	3	
	December	28	12	35	35	3	
	January	28	14	26	26	3	January
Nyamahona	September	29	60	36	60	4	
	October	30	28	19	28	3	October
	November	29	30	24	30	3	
	December	29	<3	33	33	3	
	January	29	14	27	27	3	January
Mwanza	October	30	49	26	49	4	
	November	30	34	36	36	3	
	December	31	18	25	25	3	December
	January	32	22	25	25	3	January
Nungwe Bay	October	16	28	12	28	3	
	November	15	17	29	29	3	
	December	15	<6	36	36	3	
	January	15	19	18	19	2	January
Maisome	October	14	19	35	35	3	October
	November	14	8	60	60	4	
	December	14	17	38	38	3	
	January	14	43	32	43	4	
Ukurukuss	September	15	40	35	40	4	
	October	14	22	9	22	3	October
	November	15	15	41	41	4	
	December	14	6	32	32	3	
	January	15	35	12	35	3	
Busenge	September	11	28	10	28	3	
	October	12	16	<8	16	2	
	November	12	<8	18	18	2	
	December	12	<8	<8	<8	1	December
	January	12	28	9	28	3	
Buhindi	September	13	24	<7	24	3	
	October	12	26	<7	26	3	
	November	12	<8	<8	<8	1	November
	December	11	<8	9	9	1	December
	January	12	<8	<7	<8	1	January
Kome-Chigara	September	24	44	28	44	4	
	October	24	25	35	35	3	October
	November	23	22	60	60	4	
	December	22	33	46	46	4	
	January	22	38	38	38	3	January

(1) ETa/ETm-ratios for first month of the growing period
(2) Crop water indices.

Table 36. Comparison of suitable planting times for different stations by degree of limitation

Station	Maize Planting month					Cotton Planting month				
	Sep.	Oct.	Nov.	Dec.	Jan.	Sep.	Oct.	Nov.	Dec.	Jan.
Geita				-----	-----				.....	-----
Ukiriguru			*****	*****	*****				-----	-----
Nyamahona		*****	*****	*****	*****				.....	-----
Mwanza			*****	*****	*****				-----	
Nungwe Bay		*****	*****	*****					-----	
Maisome		*****		*****					*****	*****
Ukurukuss		*****		*****	*****				*****	
Busenge		-----	-----	.....			-----		.....	
Buhindi			.....	.....	.....				.....	.....
Kome@Chigara		*****	*****		*****	*****		*****		*****

..... little or no limitation

----- moderate limitation

***** severe limitation

On the other hand, research carried out in Mwanza area indicates that the beginning of December is the optimum planting time for cotton (Acland, 1971). Also most farmers prefer December for sowing this crop.

There is a good correlation therefore between the theoretical planting time as calculated by the method, used in this report, the time recommended by research and the time preferred by farmers.

Maize

In the survey area there are three zones with substantially different hazards of maize failure by imbalanced rainfall distribution. From this figure it appears that in general the hazard of maize failure is considerable in the surveyed area. The area with a slight or negligible rainfall limitation is small and occurs in the western part of the Buhindi peninsula. Most of the surveyed area, especially the west and the centre has a moderate rainfall limitation, with a 11-20% risk of maize failure. The eastern part and the islands Kome and Maisome have a severe rainfall limitation, with a 21-40% chance of maize failure.

From the comparison of dependable moisture availability for different planting times it is concluded that in most stations January is the most suitable planting time. However it is observed that in Geita, Mwanza and Buhindi December is an equally suitable and in Busenge the only suitable planting time. Near Victoria lake, in Nyamahona and Kome-Chigara stations the moisture availability is reliable not only in January but also in October, In Ukurukuss and Maisome the best planting time is the month of October only.

It needs to be cautioned here that the term "best planting time" is relative only. For most stations the risks of maize failure are very substantial (see fig. 26). From table 52 it follows that in most stations maize planting can be spread over a 2-4 month period without significantly increasing the risk of crop failure.

How do these theoretical findings correlate with actual and recommended planting practices ?

The recommended period for maize planting in the Mwanza area is early January (Acland, 1971). The most common maize planting period in Geita-Sengerema districts is indeed December-January. However there is a tendency to take advantage of the first rains. Thus in the central part of the surveyed area it is a normal practice to spread maize planting between October and December. It is also reported that along the lake shore planting may even start as early as August-September to harvest green maize for cooking. Reported planting periods on the lake shore are October-November with harvest in March and late December with harvest in May. It is thus a normal practice by smallholders to spread maize planting over a wide period, with December-January being the most common period. It is thought that the major aim of this practice is to avoid peaks in labour requirements related to the cotton growing season. Indeed the method used in this report indicates that considerable flexibility is permissible for maize planting as compared to cotton, for which the growing period is rather fixed. However it should be realized that site factors may largely affect the feasibility of spreading maize planting, particularly moisture additions by groundwater.

A.3.6. RATING OF THE LAND QUALITY "DEPENDABLE MOISTURE AVAILABILITY"

As seen in section A.3.2. and A.3.4. "dependable moisture availability" is assessed by the severity of the limitation "probability of crop failure by imbalanced rainfall". In section A.3.5. moisture zones with similar dependable moisture availability have been mapped (figs. 25 and 26). The ratings for dependable moisture availability are given in table 37.

Table 37. Rating of dependable moisture availability

Rating	Probability of crop failure by imbalanced rainfall	Moisture zone
1	0-10%	A
2	11-20%	B
3	21-40%	C
4	> 40%	-

It should be noted that these ratings refer specifically to a modal soil with an estimated waterholding capacity, that is assumed to have similar waterholding properties as the G2 - and ZI-soils. For other soil types these ratings have to be adjusted according to soil texture, effective soil depth and groundwater or seepage additions. For instance, sandy soils are downgraded by one rating as compared to the modal soil, except when they occur in water receiving sites with regular seepage or groundwater additions of when they are high in organic matter.

The ratings of the land quality in respect of the soil units recognized in the surveyed area are given in table 38.

Table 38. Rating of dependable moisture availability per soil unit, Geita-Sengerema districts

Land Unit		Moisture zone		
Mapping unit	Soil Unit	A	B	C
	G1	4-1(a)	4-2(a)	4-3(a)
	G2	1	2	3
	G3	2-1(b)	3-2(b)	4-3(b)
	Gr	4	4	4
	Gs	4	4	4
	Z1	1	2	3
	Z2	1	1	2
	Zr	4	4	4
	Zs	4	4	4
	Zi	4	4	4
	Kr	4	4	4
	Ks	4	4	4
	L1	3	4	4
	L2	1	1	2
	L3	1	1	2
	L4	2	3	4
	L5	1(c)	2-1(c)	3-2(c)

Notes

(a) Depending on soil depth
(b) Best rating for water-receiving sites with regular seepage additions (G3-soils) or groundwater influence (L5-soils)
(c) Better water retention due to high organic matter content.

A.3.7. EXAMPLE OF CALCULATIONS FOR COTTON

Station: Geita D.O. (Ref. No. 92.3210)

Location: 2°52'S; 32°15'E; 1280 m altitude

Crop: Cotton

Growing period : 6 months

Crop development stages (estimated after Doorenbos and Pruitt, 1974)

- initial stage : 30 days
- crop development stage : 50 days
- mid-season stage : 55 days
- late-season stage: 45 days

Procedure

Step 1 Compile monthly rainfall data: table 39.

Season	Month of growing period								
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1951-52	26	46	59	456	70	135	131	172	211
1952-53	57	28	61	29	93	18	131	93	82
1953-54	13	63	156	134	57	62	94	184	168
1954-55	3	61	23	94	54	68	30	69	29
1955-56	28	25	34	145	188	166	98	186	115
1956-57	64	161	82	132	200	63	174	263	80
1957-58	6	40	143	165	103	90	117	48	83
1958-59	9	76	94	153	116	69	57	146	61
1959-60	41	76	165	117	89	51	204	194	23
1960-61	73	54	148	46	48	125	177	206	24
1961-62	25	270	464	208	77	41	104	204	158
1962-63	62	129	83	98	237	51	122	123	88
1963-64	85	17	311	181	97	98	100	298	0
1964-65	25	26	140	243	55	179	189	173	38
1965-66	21	52	212	131	159	124	140	162	20
1966-67	30	31	145	98	64	81	140	117	61
1967-68	50	153	118	188	66	149	60	212	71
1968-69	2	198	107	175	197	199	102	165	64
1969-70	0	133	154	58	70	80	291	184	62
1970-71	8	47	148	308	122	142	23	28	36
1971-72	42	28	45	63	57	302	81	46	116
1972-73	87	94	158	148	58	63	52	153	45
1973-74	61	61	165	49	51	98	171	103	51
1974-75	85	66	51	39	44	66	228	98	66
1975-76	179	90	21	152	73	110	133	140	112
1976-77	8	26	186	64	110	80	71	275	167

Source : Meteorological Department, Dar es Salaam

Step 2. Calculate average crop water requirements for cotton (after Doorenbos and Pruitt, 1974) for different planting times : see following table

Table 40. Average monthly crop water requirements (ETm-cotton) for different planting times

Planting time	Month of the growing period									
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.
Sep.	56	104	138	152	155	99				
Oct.	(56)	110	102	141	163	136	103			
Nov.		(110)	114	123	156	143	141	95		
Dec.			(114)	110	132	137	149	130	105	
Jan.				(110)	109	109	140	137	145	110

Step 3. Calculate waterbalances for each cropping season and for the selected planting periods.

An example of these calculations is given in table.41

Table 41. Example of a waterbalance calculation format

Station: Geita D.O.

Crop: Cotton Planting time: October Season: 1971-72

Water Balance element	Month of the growing period						
	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.
ETm	56	110	102	141	163	136	103
R	421	28	45	63	57	302	81
Sa	0	0	0	0	0	150	128
Sc	0	0	0	0	0	+150	22
ETa	42	28	45	63	57	136	103
D	14	82	57	78	106	0	0
S	0	0	0	0	0	16	0

with ETm: crop water requirement (cotton)
R : rainfall
Sa: available water storage
Sc: storage change
ETa: actual evapotranspiration
D : deficit
S : surplus

Step 4. Calculate the crop water indices for cotton (Is). Calculate also the ETa/ETm-ratio for the first month of the growing period.

The results for each cropping season and planting time are summarized in table 42.

Table 42. Crop water indices for cotton

Cropping Season	Planting Times							
	October		November		December		January	
	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
1951-52	42	67	52	79	100	50	100	100
1952-53	26	27	54	51	26	56	85	67
1953-54	57	72	100	55	100	60	74	83
1954-55	55	46	20	38	89	44	50	35
1955-56	23	73	30	72	100	80	100	100
1956-57	100	99	72	46	100	100	100	100
1957-58	36	67	100	90	100	98	100	73
1958-59	69	78	82	55	100	75	100	72
1959-60	69	38	100	64	100	87	88	90
1960-61	65	52	100	37	73	83	44	92
1961-62	100	63	100	44	100	74	100	93
1962-63	100	73	100	80	89	96	100	96
1963-64	42	91	100	50	100	100	100	100
1964-65	24	70	100	80	100	100	100	100
1965-66	47	74	100	80	100	100	100	98
1966-67	28	52	100	59	100	81	59	73
1967-68	100	100	100	46	100	92	100	99
1968-69	100	80	100	80	100	100	100	100
1969-70	100	36	100	58	89	81	64	91
1970-71	43	91	100	99	100	85	100	65
1971-72	25	52	39	68	57	67	52	88
1972-73	100	83	100	51	100	69	88	62
1973-74	60	51	100	57	91	81	47	75
1974-75	86	25	45	57	81	75	40	80
1975-76	100	68	18	59	100	73	100	95
1976-77	24	73	100	35	100	61	100	85

)1) ETa/ETm-ratios for the first month of the growing period

(2) Crop water index for cotton

Step 5 Plot the cumulative frequency distribution of the crop water indices and of the ETa/ETm-ratios for the first month of the growing period.

In table 43 the indices for the growing season and the first month of the growing period are ranked for plotting in function of the cumulative frequencies. In fig. the cumulative frequency curve for the ETa/ETm-ratios for the first month of the growing period is drawn for the considered planting times. In fig. similar curves are drawn for the crop water indices.

Table 43. Cumulative frequencies (plotting positions) of crop water indices and ETa/ETm-ratios for the first month of the growing period

Planting times								Cumulative frequency
October		November		December		January		
(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)	
100	100	100	99	100	100	100	100	96
100	99	100	90	100	100	100	100	93
100	91	100	80	100	100	100	100	89
100	91	100	80	100	100	100	100	85
100	83	100	80	100	100	100	100	82
100	80	100	80	100	98	100	100	78
100	78	100	75	100	96	100	99	74
100	74	100	72	100	92	100	98	70
86	73	100	68	100	87	100	96	67
69	73	100	64	100	85	100	95	63
69	73	100	59	100	83	100	93	59
65	72	100	59	100	81	100	92	56
60	70	100	58	100	81	100	91	52
57	68	100	57	100	81	100	90	48
55	67	100	57	100	80	100	88	44
47	67	100	55	100	75	88	85	41
43	63	100	55	100	75	88	83	37
42	52	82	51	100	74	85	80	33
42	52	72	51	91	73	74	75	30
36	52	54	50	89	69	64	73	26
28	51	52	46	89	67	59	73	22
26	46	45	46	85	61	52	72	19
25	38	39	44	81	60	50	67	15
24	36	30	38	73	56	47	65	11
24	27	20	37	57	50	44	62	7
23	25	18	35	26	44	40	35	4

(1) ETa/ETm-values for the first month of the growing period

(2) crop water indices

Step 6 Derive from the cumulative frequency curves the probabilities that the concerned indices will not exceed 50%.

See table.44

Step 7 Rate the land quality "dependable moisture availability" and select the most suitable planting time

See table.44

Table 44. Dependable moisture availability. Most suitable planting time

Planting time	Probability of non-exceedance (1)	(2)	Probability of crop failure	Rating	Most suitable planting time
October	42	22	42	4	
November	21	28	28	3	
December	6	7	7	1	December
January	15	5	15	2	

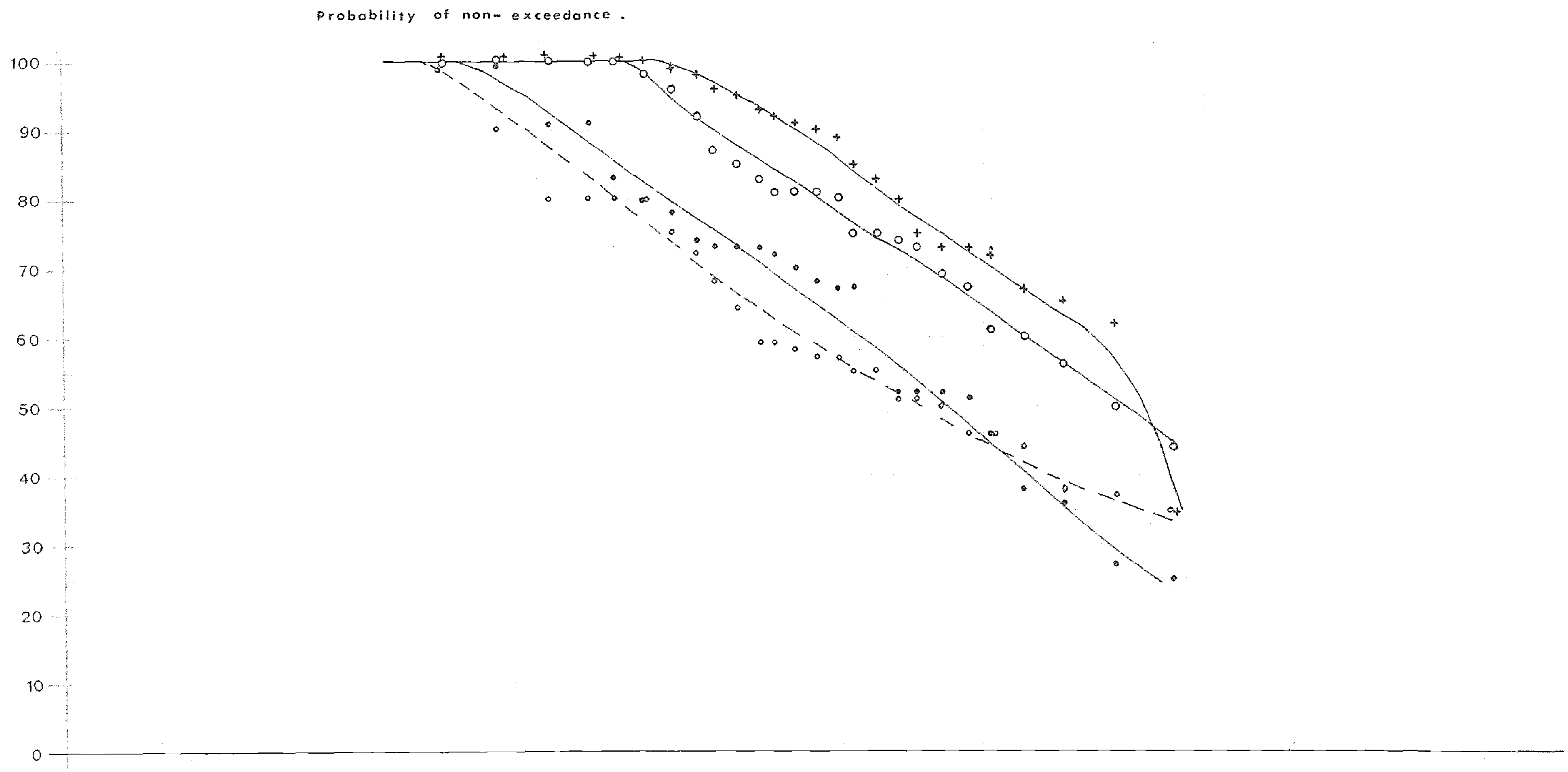


Fig.21 Geita cumulative frequency curves crop water indices cotton

SYMBOLS :-

Crop planted early October

Crop planted early November

Crop planted early December

Crop planted early January