NATURAL RESOURCES SYSTEMS PROGRAMME

FINAL TECHNICAL REPORT

DFID Project Number

R5752

Title

Evaluation and promotion of rainwater harvesting in semi-arid areas of Tanzania

Author

Hatibu, N

Organisation

Soil – Water Management Research Group
Department of Agricultural Engineering
Sokoine University of Agriculture
Morogoro
Tanzania

Date

March 1997

NRSP Production System

Semi-Arid

The citation for this report is:

Hatibu, N., Kayombo, B., Mahoo, H.F. and Mzirai, O. 1997. DFID NRSP Final Technical Report R5752: *Evaluation and promotion of rainwater harvesting in semi-arid areas of Tanzania*. Sokoine, Tanzania : Sokoine University of Agriculture.

This is a report submitted to the UK Department for International Development's (DFID) Natural Resources Systems Programme (NRSP) under the research contract R5752: Evaluation and promotion of rainwater harvesting in semi-arid areas of Tanzania. The views expressed are not necessarily those of DFID or NRSP.

DFID Natural Resources Systems Programme

NRSP, HTSPE, Thamesfield House, Boundary Way, Hemel Hempstead, HP2 7SR, United Kingdom

t: +44 (0) 1442 202447
f: +44 (0) 1442 219886
e: nrsp@htspe.com
w: www.nrsp.org.uk

SOKOINE UNIVERSITY OF AGRICULTURE

EVALUATION AND PROMOTION OF RAINWATER HARVESTING IN SEMI-ARID AREAS OF TANZANIA RESEARCH PROJECT

DRAFT

FINAL TECHNICAL REPORT

Hatibu, N., H.F. Mahoo, B. Kayombo and O. Mzirai

SOIL-WATER MANAGEMENT RESEARCH GROUP

March, 1997

SUMMARY

BACKGROUND

1. Soil-water in most of Tanzania is dependent on erratic rainfall and is therefore not adequate for crop growth. It is therefore a critically vital resource needing effective development, and efficient utilization and management. This requires not only the improvement of soil-water management/conservation techniques to hold more water in the soil, but also improved cultural practices and more optimal use of inputs, to ensure efficient utilization of soil-water by plants.

2. Rain water harvesting is defined as any system that encompasses methods for collecting, concentrating and storing various forms of run-off for various purposes. When the harvested run-off is used for providing the soil-water required for plant growth the system is called run-off farming.

3. The first step in any RWH system involves methods to increase the amount of water stored in the soil profile by trapping or holding the rain where it falls. The next level is a system where there is a distinct division of Catchment Area and Croped Basin but the areas are adjacent to each other. The third type involves the collection of runoff from large areas which are at an appreciable distance from where it is being used. It is difficult to differentiate this system from conventional irrigation systems but in this report the system is called RWH as long as the water for harvesting is not available beyond the rainy season.

4. In many parts, runoff occur on hill-tops (with stone outcrops), sloping grounds, grazing lands or other compacted areas and flow and naturally collect on low lying flat areas. Farmers grow their crops on the wetted part of the landscape and use the runoff without any further manipulation or management. This approach is widespread in the whole semi-arid zone which covers Dodoma, Singida and Shinyanga regions, and parts of Mara, Mwanza, Tabora, Arusha, Kilimanjaro, Tanga and Iringa.

RESEARCH PURPOSE

5. The Sokoine University of Agriculture is pursuing a program of research in Soil and Water Management in Semi-arid Areas, whose objective is to develop, test and introduce appropriate and socially acceptable management interventions for improving the capture of rainfall by soils and soil-water availability to plants. The research project "Evaluation and Promotion of Rain-Water Harvesting" reported here was a four year project started at the end of 1992. The aim of the project was to increase sustainability of production and population carrying capacity of flood-and-drought prone semi-arid lowlands through more effective management of rain-water.

RESEARCH ACTIVITIES

7. The most important activities included

- A planning review workshop at the beginning of the project at which researchers and extension workers analyzed the researchable issues and the objectives of the research.

- A survey of 120 grey and published literature (1930 - 1992) related to RWH in Tanzania, which showed that no previous research has been conducted on RWH as a whole, but significant research work has been carried out on important components of RWH process.

- Assemblying and processing of historical weather data from four relevant locations to characterize the climate of the target area.

- Establishment and operation for six seasons of two experimental farms of approximately 2 ha in Morogoro and Kisangara. The experimental treatments were:

  Morogoro

  - Four blocks of catchment run-off experiments each with run-off

TABLE OF CONTENTS

PREFACE AND ACKNOWLEDGEMENTS

This report describes the results of the research activities during six seasons of the project, from September 1992 to June 1996. These include three short rainy ("Vuli") seasons and three long rainy ("Masika") seasons. This report superceedes the 2nd Interim Technical Report. Only the results from the field experiments are included. The results from the socio-economic study are given in a separate report.

Other previous reports produced under the project include the following:

- Rapid Rural Appraisal of Mwanga District;
- Bibliography of literature related to Rain-Water Harvesting Research in Tanzania;
- Field and laboratory manual;
- Proceedings of the Second Farmers Seminar;
- 1st Interim Technical Report; and
- 2nd Interim Technical Report.

This work was financially supported by the Overseas Development Administration of United Kingdom. We are grateful for this assistance. The technical and administrative backup given by the Natural Resources Institute (NRI) of UK, especially Mr. David Jackson, is highly appreciated.

We would like to recognize the invaluable support of the Karimjee Agriculture Ltd of Tanga, Tanzania, who provided us with more than 10 ha of land at Kisangara. Without this generous provision it would have been difficult to conduct the research in Mwanga district.

At SUA, the administrative backup given by the Directorate of Research made the project to run smoothly. We are truely gratefull.

We are also indebted to the authorities of Mwanga district, and especially Mr. A.P.P. Mchomvu for their technical advice and support. The research has also benefitted highly from the contact with keen farmers, especially from Kiruru and Lembeni villages.

We are grateful to the Directorate of Meteorology for providing us with weather data for Morogoro and Same.

Our collaboration with the RWH research team of the University of Newcastle upon Tyne in UK, has been a major factor contributing to the achievements of the project and the production of this report.

LIST OF ABBREVIATIONS, SYMBOLS AND UNCOMMON WORDS

Majaruba	Local name for bunded basins for flooded paddy production
Masika	Long rainy season
Vuli	Short rainy season
B	Bare
BA	Basin area
CA	Catchment area
CBAR	Catchment to basin area ratio
ET_{crop}	Crop evapotranspiration
ET_o	Reference crop evapotranspiration
FAO	Food and Agriculture Organization
FC	Flat cultivation
FP	Fertilizer package
GNP	Gross National Product
IDRC	International Development Research Centre
K_c	Crop factor
LMC	Low managed crop
N	Nitrogen
NF	No fertilizer
NRI	Natural Resources Institute
NV	Natural vegetation
ODA	Overseas Development Administration
P_o	Design rainfall
R	Rainfall
RD	Rainfall duration
RI	Rainfall intensity
RO	Runoff
RRA	Rapid Rural Appraisal
RWH	Rain water harvesting
SR	Staggered ridges
SUA	Sokoine University of Agriculture
TMV1	Tanzania maize variety 1 (composite)
TSP	Triple super phosphate
UK	United Kingdom
UNESCO	United Nations Educational Scientific and Cultural Organization
USDA	United States Department of Agriculture

1. BACKGROUND

1.1 Land and Water Resources Limitation to Agricultural Production in Tanzania

Tanzania has a land area of 886,000 km^2 with complex climate, soils and topography. It is estimated that only 5% (7 million ha) of the total land area is under cultivation, of which 14 % is occupied by permanent crops. Several methods have been used to classify Tanzania into agro-ecological zones. The classification shown in Figure 1 gives six major zones according to soil type, altitude, mean annual rainfall and duration of the growing season (LRDC, 1987). The zones are (1) Coast, (2) Arid Lands, (3) Semi-Arid Lands, (4) Plateaux, (5) Southern and Western Highlands, and (6) Northern Highlands and isolated granitic mountains.

On the basis of the 1988 census and an annual increase of 3% the current (1996) population of mainland Tanzania is estimated to be 28 million people, 90% of whom live in 8500 rural villages. The most densely populated areas include the Northern and Southern highlands. Agricultural production is predominantly subsistence and is undertaken by some 2.5 million farm families each operating on average 2 ha of cropping land. Agriculture is Tanzania's key economic sector accounting for half the country's GNP, 80% of recorded export earnings and 90% of rural employment. Agriculture grew rapidly in the 1960s, it stagnated in the 1970s and early 1980s, leading to an inability to meet the country's long term development objectives, namely food security, sustainable food self sufficiency and increased foreign exchange earnings.

Agricultural potential is limited over large areas of the country by a combination of low soil fertility, low and erratic rainfall, and tsetse infestation. Truly fertile soils are confined to: (i) the volcanic soils of the Northern highlands, (ii) soils of Southern highlands, and (iii) the alluvial soils in large river basins.

Only 22% of the land receives 570 mm or more of rainfall in 9 years out of 10. Further to this, nearly throughout the country, potential evapotranspiration exceeds rainfall during more than nine months of the year.

In general, land with a combination of adequate soil fertility, adequate rainfall and free of tsetse infestation is limited to less than 10% of the total area of Tanzania. Consequently, the potential for lateral agricultural expansion, to meet the food security needs of a population growing at 3% annually, is very constrained, mostly by erratic and unreliable rainfall.

On the basis of rainfall alone, the country can be divided into four broad zones in relation to performance of maize (Figure 1). In zone I, local potential yield of maize is achieved only in 7 years out of 10. The situation gets worse in the other zones and in zone IV, the chance of obtaining maximum potential yield of even sorghum (which is a drought resistant crop) is very low at 2-3 years out of 10.

Therefore, soil-water is a critically vital resource needing effective development, and efficient utilization and management. This requires not only the improvement of soil-water management/conservation techniques to hold more water in the soil, but also improved cultural practices and more optimal use of inputs, to ensure efficient utilization of soil-water by plants.

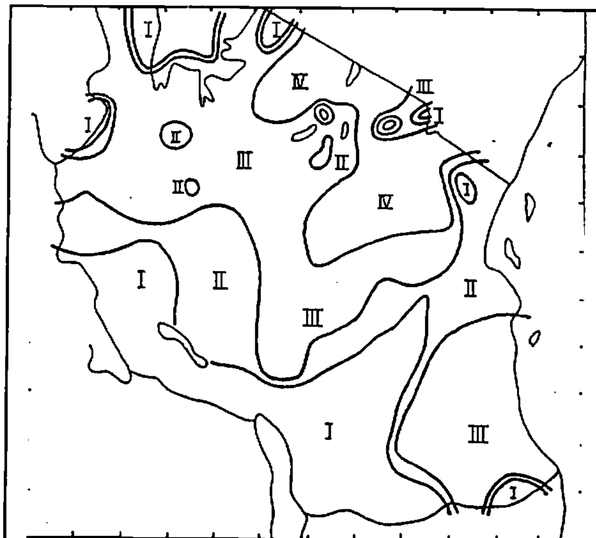


Figure 1: Tanzania, rainfall reliability classification [Gommes & Houssiau, 1982]

Rain water harvesting (RWH) defined as any system that encompasses methods for collecting, concentrating and storing various forms of runoff for various purposes (Myers, 1975). It is one of the important tools which can be used to manage the scarce rainfall, especially in the semi-arid areas where it is vital in:

i) enhancing plant production, and therefore household income of resource poor inhabitants of these areas, and

ii) protecting the land against degradation caused by erosion.

This is because effectiveness of rainfall in many parts is reduced by surface run-off. However, this is not always bad as a significant portion of run-off is generally a redistribution of water. In some parts this redistribution occurs in localized areas that may cover only one or few villages. Where this occurs there is a big potential for RWH and farmers are already taking advantage of this phenomenon by allocating higher water demanding crops such as maize and vegetables, to those areas which receive and retain run-off.

The phenomenon of redistribution of rainfall through run-off is evident in the rate of decrease in run-off yield with increasing size of the catchment (Rapp et al., 1972). Recently, the land and water management research project in Botswana showed that for land with slopes of 4% or less, net run-off from smallfarm size areas was very low. For example, it was found that a cultivated 0.4 ha plot yielded a maximum of only 9% run-off per year over the three year research period. Similarly, run-off yields from rangelands was limited to a maximum of 27%. It was concluded that under these situations, run-off management should be aimed at controlling within-field water redistribution (Harris, et al., 1992). It is partly due to this observation that the current research project focused on micro-catchment rain-water harvesting.

1.2 Techniques of RWH for Crop Production and Extent of Use in Tanzania

1.2.1 Historical Perspective

As land pressure rises, more and more marginal areas in the world are being used for agriculture. Much of this land is located in the arid and semi arid areas where rain falls irregularly and much of the precious water is soon lost as surface runoff. Recent droughts have highlighted the risks to human beings and livestock, which occur when rains fail. While irrigation may be the most obvious response to drought, it has proved costly and can only benefit a few.

There is now increasing interest in a low cost alternative to irrigation-generally referred to as rain water harvesting. Various forms of rain water harvesting (RWH) have been used traditionally throughout the centuries. Some of the earliest agriculture in the Middle East e.g. in the Negev desert of Israel was based on techniques such as diversion of "wadi" flow onto agricultural fields (Evenari et al, 1971). These schemes involved the clearing of hill sides from vegetation to increase runoff, which was then directed to fields on the plains. In the desert areas of Arizona and northwest New Mexico, flood water farming has been practised for at least 1000 years (Zaunderer and Hutchinson, 1988). In Tunisia, Pacey and Cullis (1986) reported micro catchment techniques used for tree growing dating to the 19th century. The importance of traditional smallscale systems for rain water harvesting in Sub-Sahara Africa (SSA) has just begun to be recognised. Simple stone lines are used in some West African countries, notably Burkina Faso, and earth bunding systems in Eastern Sudan and Central rangelands of Somalia (Critchley and Reij, 1989).

In Africa a growing awareness of the potential of rain water harvesting for improved crop production arose in the 1970s and 1980s, after the widespread droughts which left a trail of crop failures. However, much of the experience with RWH gained in countries such as Israel, USA and Australia has limited relevance to resource poor areas in the semi-arid regions of Africa and Asia. Whereas in Israel RWH research emphasized on the hydrological aspects of micro-catchments for fruit trees, in the USA and Australia it emphasized on improving runoff yields from treated catchment surfaces for domestic and livestock water supply.

During the past decade, a number of RWH projects have been set up in Sub-Sahara Africa with the objectives of combating the effects of drought by improving plant production (Critchley and Reij, 1989). However, few of these projects have succeeded in combining technical efficiency with low cost and acceptability to the local farmers. This is partially due to the lack of technical "know how" and often due to the selection of an inappropriate approach with regard to the prevailing socio-economic conditions.

1.2.2 Categories of RWH

In crop production systems, RWH is composed of a runoff producing area normally called catchment area (CA) and a runoff utilization area,, normally called cropped basin (CB) (Figure 2). Therefore, RWH systems for crop production are divided into different categories basically determined by the distance between CA and CB as follows:

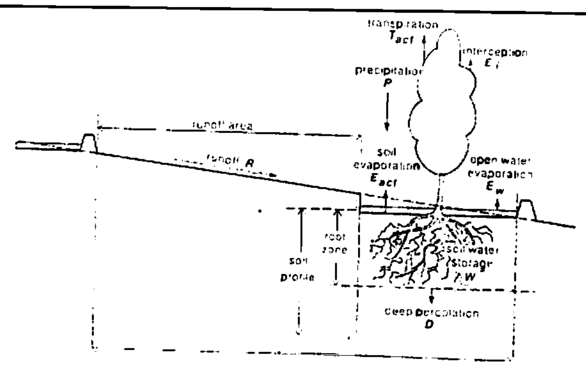


Figure 2 Relation between CA and CB in RWH systems [After Boers, 1994]

(i) **In-Situ RWH**

The first step in any RWH system involves methods to increase the amount of water stored in the soil profile by trapping or holding the rain where it falls. This may involve small movements of rain water as surface runoff in order to concentrate the water where it is wanted most.

(ii) **Internal (micro) catchment RWH**

This is a system where there is a distinct division of CA and CB but the areas are adjacent to each other.

(iii) **External (macro) catchment RWH**

This system involves the collection of runoff from large areas which are at an appreciable distance from where it is being used. This is sometimes used with intermediate storage of water outside the crop basin for later use as supplementary irrigation.

It is difficult to differentiate this system from conventional irrigation systems but in this report the system is called RWH as long as the water for harvesting is not available beyond the rainy season.

1.2.3 In-situ Rain Water Harvesting

1.2.3.1 Major characteristics

In-situ RWH is sometimes called water conservation and is basically a prevention of net runoff from a given cropped area by holding rain water and prolonging the time for infiltration. This system works best where the soil water holding capacity is large enough and the rainfall is equal or more than the crop water requirements, but moisture amount in the soil is restricted by the amount of infiltration and or deep percolation. The in-situ RWH is achieved mainly by the following means:

(i) Deep tillage

Tillage normally assist in increasing the soil moisture holding capacity through increased porosity, increasing the infiltration rates and reducing the surface runoff by providing surface micro-relief or roughness (Figure 3) which help in temporary storage of rain water, thus providing more time for infiltration.

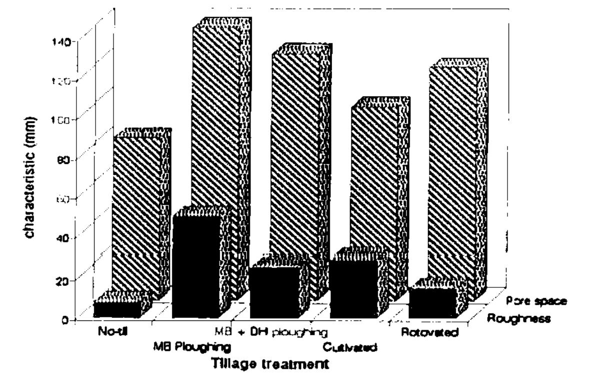


Figure 3: Effect of tillage on porosity and surface roughness

Previous research results have shown that the depth of tillage is the most important factor controlling/affecting soil moisture characteristics. Deep tillage helps to increase porosity, reduce surface sealing of the soil and permits roots proliferation to exploit soil water and nutrients at deep horizons (Hudson, 1987).

Significant reduction of surface runoff and increase in crop yields have been shown to occur with increased depth of tillage in Hombolo, Central Dodoma (Fig. 4).

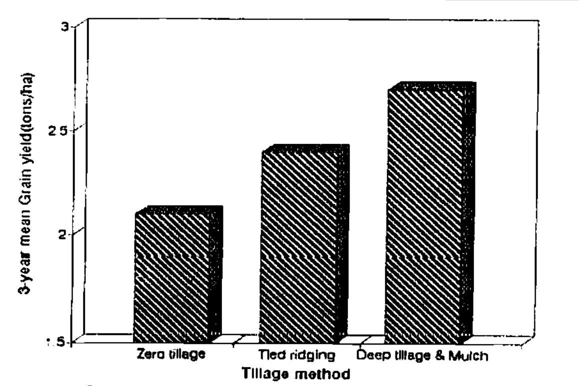


Figure 4: Effect of tillage on grain yield of sorghum at Hombolo (SWMRG, 1995a)

(ii) Contour farming and ridging

This is important where cultivation is done on slopes greater than 3% All farm husbandry practices such as tilling and weeding are done along the contours so as to form cross-slope barrier to the flow of water. Where this is not enough, it is complemented with ridges which are sometimes tied to create a high degree of surface roughness to enhance the infiltration of water into the soil (Figure 4).

1.2.3.2 Extent of use in Tanzania

(i) Deep tillage

Deep tillage requires high draught power which is normally in short supply in many parts of Tanzania. The use of animal and tractor power for primary tillage operations is limited to only three out of the six major farming systems in Tanzania (Table 1).

In most parts of the country therefore, deep tillage is rarely achieved since hand hoe is the main method of cultivation. In many areas, farmers do not implement primary tillage before sowing. In a study conducted under the livestock/maize sorghum-millet farming system, local people said that zero tillage before planting is the norm in many parts [Hatibu & Mtenga, 1996 and Mahoo at al, 1996]. It has been estimated that for more than 70% of the fields, no primary tillage is done prior to sowing. This leads to high losses of the first rain storms as runoff. Loosening of soil on these fields is implemented during the first weeding operation.

Table 1: Methods of Land preparation (After ADIS, 1992)

	Tractor	Oxen	Manual
Cassava/Cashew	0	1	99
Maize/Legumes-Coffee	10	74	76
Maize/Legumes-Tobacco	1	9	92
Livestock/Maize-Sorghum-Millet	2	72	43
Agro-Pastoralist	0	1	93
Coffee-Banana/Dairy	65	5	37

Despite the large herd of cattle in the semi-arid areas of Tanzania, draught animal power (DAP) is not widely used in full because of the following reasons:

- traditional cattle owners are reluctant to use their animals for work,
- animals are poorly fed during the dry season prior to the main work period,
- lack of knowledge of using other animals such as donkeys.

(ii) Contour farming and ridging

Contour farming and/or ridging is not widely practised in the semi-arid areas in Tanzania. However, some ridging is used for crops such as groundnuts and sweet potatoes in some areas. Some of the reasons advanced by the farmers for not using ridging include lack of power and equipment to till and ridge the land and poor implementation of ridging which leads to low crop population density (Mahoo at al, 1997).

1.2.4 Internal (micro) Catchments RWH

1.2.4.1 Major characteristics

This system is mainly used for growing medium water demanding crops such as maize, sorghum, groundnuts and millet. The major characteristics of the system include:

(i) Pitting

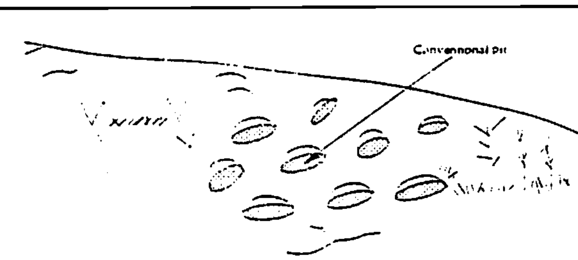


Figure 5: Layout of Pitting RWH

These are small semi-circular pits dug to break the crusted soil surface (Figure 5). In West Africa where they are called 'Zay', the pits are about 30 cm in diameter and 20 cm deep. Farm yard manure is added in the pits thus permitting the concentration of water and nutrients. Seeds are planted in the middle of the pits. The same system is called Katumani pitting in Kenya. They are used in areas with rainfall of between 350-600 mm.

(ii) Strip catchment tillage

This involves tilling strips of land along rows and leaving appropriate sections of the inter-row space uncultivated so as to release runoff. It is normally used where the slopes are gentle and the runoff from the uncultivated parts add water to the cropped strips (Figure 6). The CBAR used is normally equal to or less than 2:1. The system can be used for nearly all types of crops and is easy to mechanize.

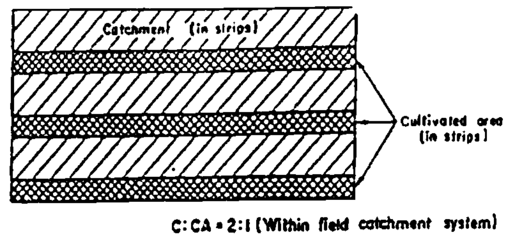


Figure 6: RWH with Strip Catchment Tillage

(iii) Contour bunds

This system consists of small trash, earth or stone embankments constructed along the contour lines. The embankment trap the water flow behind the bunds allowing deeper infiltration into the soil (Figure 7). The height of the bund determines the net storage of the structure.

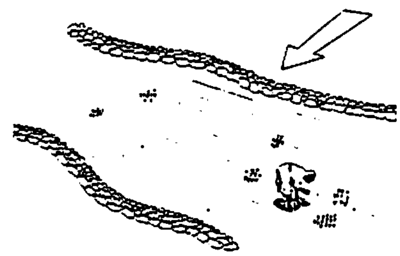


Figure 7: RWH with Contour Bunding

The water is stored in the soil profile and above ground to the elevation of the bund or overflow structure. This is a versatile system for crop production in a variety of situations. They can be easily constructed but they are limited to availability of power (for earth moving), stones and trash. They are useful where ground slope is not more than 5%, soil depth is at least 1 m and rainfall intensity is less than 20 mm/h for 1-hour duration storms with a probability (P) of 20%. They are designed with CBAR of less than 3:1.

(iv) Semi-circular bunds

These are constructed in series and in staggered formation (Figure 8). Runoff water is collected within the hoop from the area above it and impounded by the depth decided by the height of the bund and the position of the tips. Excess water is discharged around the tips and is intercepted by the second row and so on. Normally the semi-circles are of 4-12m radius with height of 30cm, base width of 80 cm, side slopes 1:1.5 and crest width of 20cm. The percentage of enclosed area which is cultivated depends on the rainfall regime of the area. Basic requirements of the semi-circular bunds are: ground slope must be less than 3%, soil depth of at least 1 m, average annual rainfall of at least 100 mm, CBAR of at least 3:1, and rainfall intensities of I_{60} equal to 50mm/h for rainfall of P = 20%.

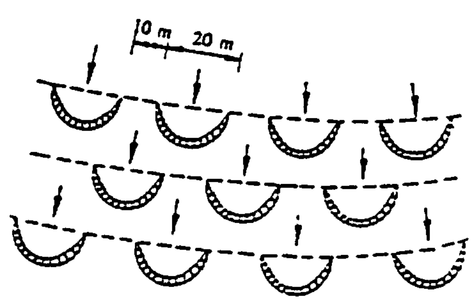


Figure 8: RWH with semi-circular Bunding

(v) Meskat-type system

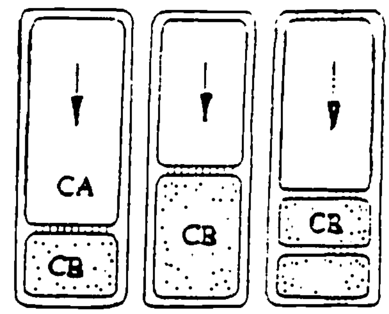


Figure 9: RWH with Meskat-type Bunding

In this system instead of having CA and CB alternating like the previous methods, here the field is divided into two distinct parts, the CA and CB, whereby the CB is immediately below the CA. (Figure 9).

In this system, the CA is treated either by removal of vegetation and/or compaction in order to increase the generation of runoff. The cropped basin (CB) is enclosed by a U-shaped bund to pond the harvested water. The CBAR is 2:1. It can be used for almost all cereal crops such as maize, sorghum and millet. This is the system which was tested during the current research project.

1.2.4.2 Extent of use in Tanzania

(i) Pitting

There is no use of systematically designed pits in the semi-arid areas. However, in the traditional system of sowing, the large pits made on un-tilled soil, collects runoff during the early growing stages of the crop. They thus act as RWH pits.

(ii) Meskat-type system

There is no use of systematically designed Meskat system in the country. However, due to microtopography, water may be redistributed within the field from elevated portions into low lying areas. As explained earlier farmers exploit this redistribution which may be considered as Meskat-type RWH.

(iii) Contour bunds

These are used in many parts by few farmers due to the fact that it is the method of soil and water conservation being extended by extension officers. In many parts the main strategy for promoting soil and water conservation has been the construction of earth bunds along the contours as a runoff control measure within the cropped areas.

(iv) Land conservation aspects

Micro-catchment approaches have a high potential for combining water conservation/harvesting with soil conservation. The main problem is that, in most projects there has been a bias towards promoting conservation rather than soil and water conservation with production. Conservation of both moisture and soil has two major advantages:

- Due to increased crop yields, farmers will be more willing to implement and maintain the system;

- The rapid vegetation development made possible by improved soil-moisture status, provide early protection to the soil against erosion.

Micro-catchment rain-water harvesting provides a good means for changing from soil conservation based on just runoff control to a focus on land husbandry integrating conservation and production.

1.2.5 External (Macro) Catchments RWH

1.2.5.1 Major characteristics

This system involves harvesting of water from catchments of areas ranging from 0.1 ha to thousands of hectares either located near the cropped basin or long distances away. The catchment areas usually have slopes ranging from 5-50% while the harvested water is used on cropped areas which are either terraced or on flat lands. When the catchment is large and located at a significant distance from the cropped area the runoff water is conveyed through structures of diversion and distribution networks. The most important systems include the following:

(i) Hillside sheet/rill runoff utilization

In this system, runoff which occur on hill-tops (with stone outcrops), sloping grounds, grazing lands or other compacted areas flow and naturally collect on low lying flat areas. In many areas farmers grow their crops on the wetted part of the landscape and use the runoff without any further manipulation or management.

However, where the runoff is not high, bunds are constructed on the cropped area in order to form earth bunds which assist in holding the water and increasing infiltration into the soil.

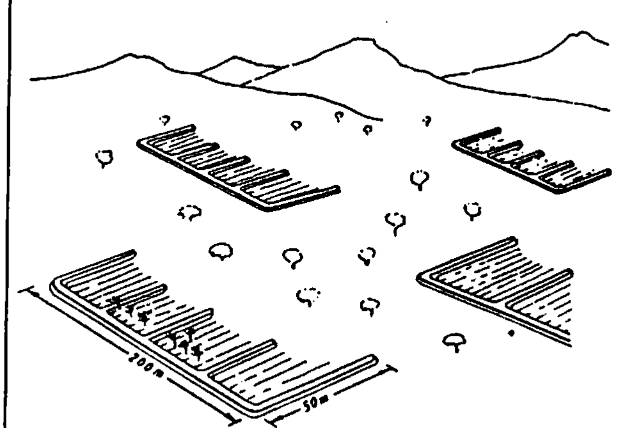


Figure 10: Examples of hill sheet flow RWH

These bunds are important when the cropped area is not at the bottom of the landscape. However, earth bunds are used to facilitate the distribution of the water even if the cultivated area is on flat land. Several layouts of these earth bunds are used and sometimes mentioned as types of RWH systems by themselves. These include, for example, trapezoidal basins bunded on three sides, rectangular basins bunded on three sides e.g Teras (Figure 10), and cultivated basins bunded on all the four-sided with only small inlets and overflow spillway, e.g 'majaruba'.

(ii) Floodwater harvesting within the stream bed

This is a system that uses barriers such as permeable stone dams to block the water flow and spread it on the adjacent plain and enhance infiltration. The wetted area is then used for crop production (Figure 11).

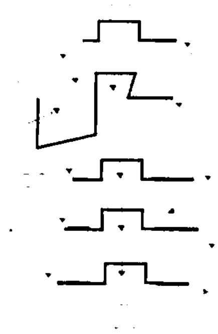


Figure 11: Flood water harvesting with the stream bed

(iii) Ephemeral stream diversion

This system involves means for diverting water from its natural ephemeral stream and conveying it to arable cropping areas. There are two main methods of diverting and distributing the water.

In the first method, the cultivated field close to the ephemeral stream is initially divided into open basins using either trapezoidal, semi-circular or rectangular bunds (Figure 12).

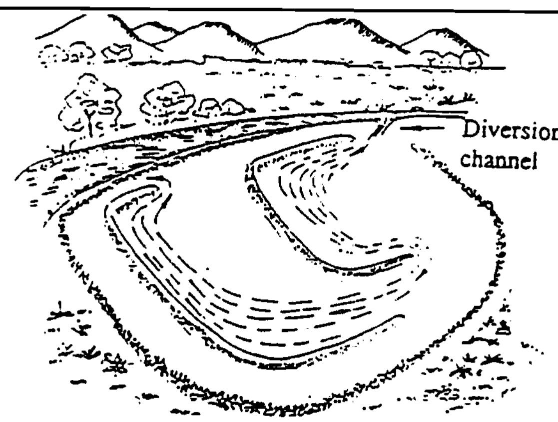


Figure 12: Ephemeral stream diversion

By means of a weir, water is diverted from the stream into the top most basin. The water fills this basin and the surplus spills to the next basin and so on until the whole farm is fully wetted. In this method, one intake point can only be used by a single farm which must be relatively close to the source.

In the second system, the field is divided into a closed rectangular basins such as "majaruba" and the water is diverted using a weir and a series of channels to deliver it to the basins (Figure 13). The system works using the same principles of surface flood irrigation and it can therefore serve several farms which may be located far away from the intake.

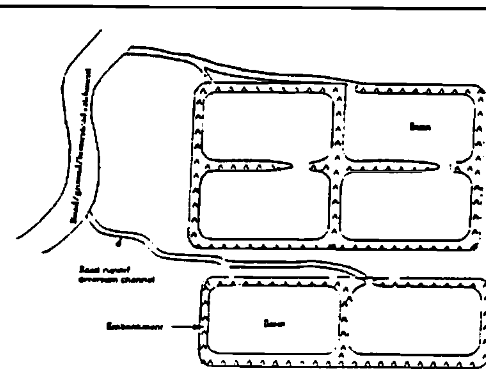


Figure 13: Ephemeral stream diversion with distribution canals

(iv) RWH with storage

Sometimes macro-catchment RWH, produces high volumes of runoff that can not be stored in the soil profile. In such circumstances, the harvested water is stored in dams or water holes. Small dams are normally constructed in rolling topography where creeks can be found and the dams are constructed across them. Water holes are storage ponds dug in a flat terrain and they are normally referred to in their Spanish name "Charco dams". In India they are called 'tanks'. They are normally used to store runoff generated from hillside catchments with sheet or rill flow. The system requires methods for controlling siltation especially if the area is prone to soil erosion, evaporation, and seepage losses especially if the subsoil is sandy.

1.2.5.2 Extent of use in Tanzania

(i) Hillside sheet/runoff utilization

This system is the most widely used through exploitation of the valley bottoms and plains where the runoff collects, by growing high water demanding crops. Farms in these areas are called "Mashamba ya Mbugani" and are common in many parts of semi-arid zone. These are mainly used to grow maize. In flooded valley bottoms, they are used for sugar cane and vegetable production. This method is widespread in the whole semi-arid zone which covers Dodoma, Singida and Shinyanga regions, and parts of Mara, Mwanza, Tabora, Arusha, Kilimanjaro, Tanga and Iringa. However, the extent of this practice has not been fully investigated and documented.

The bottom lands are also attractive to many farmers due to their high fertility levels which is a result of fertility enrichment from the up-slope areas where nutrients are transported and deposited in these plains during seasonal flooding. One of the most important characteristic of this system is the lack of flood control measures. Thus this system does not use large investment of labour to manage the water. If anything is done at all, is to leave the catchment area uncultivated in order to generate more runoff. However, few farmers collect the runoff and lead it into bunded fields or majaruba for growing paddy rice. In some villages there is high demand of the low lying areas which receive runoff to an extent that there is land marketing and renting of these valuable pieces of land.

(ii) Floodwater harvesting within the stream bed

This system is not being used much in Tanzania although the potential exists.

(iii) Ephemeral Stream Diversion

The most commonly used stream diversion system is the one with closed bunded basins (majaruba) and elaborate diversion and conveyance channels. This is the system supporting the rapid expansion of paddy production in the semi-arid areas of Tanzania.

Land subjected to seasonal flooding is the most suitable for paddy production due to accumulation of clay particles and nutrients over a long period. These soils are referred to as "Mbuga" in Tanzania. They are vertic, black-grey cracking clays. The major occurrence of "Mbuga" is in the regions of Dodoma, Singida, Tabora, Shinyanga and Mwanza. Farmers in these regions have developed an elaborate system of retaining the seasonal floods in bunded basins called "Majaruba".

Records show that the development of this system started in the early 1940's (Allnutt, 1942). It is estimated that 32% of rice in Tanzania is produced under the "Majaruba" system [Kanyeka et al., 1994]. In Shinyanga and Tabora regions for example, valley fields are subdivided by bunds of 25-100 cm height to form cultivated reservoirs or "Majaruba" which are transplanted with rice crop (Mwakalila and Hatibu, 1992). The importance of runoff farming is made evident by the indication that the biggest increase in rice production in Tanzania over the last 15 years has occurred in the semi-arid marginal areas (MoA, 1993). However, yields under rain water harvesting are estimated to be only 1 t ha^{-1} as compared to high performing irrigation projects, whose yields average 6 t ha^{-1}.

Very little research has been done to evaluate the performance of the system in relation to moisture and soil conservation. Water is not the only limiting factor that reduces yields under rain water harvesting, but also low yielding varieties and poor agronomic practices (Silva, 1989). The main constraints facing the run-off paddy farming systems in Tanzania are:-

- Poor control of water in the majaruba, leading to too little water during seasons of low rainfall and too much during seasons of high rainfall. Flooding is a major problem early in the season.

- Low strength of the bunds due to poor construction methods, leading to flood damage and loss of water.

- Poor levelling of the cultivated basin causing differential crop performance and sometimes bund damage as well.

- Lack of extension advice on design, operation and maintenance of the system.

- High losses of water by evaporation and percolation from the cultivated basin.

2. PURPOSE

The Sokoine University of Agriculture is pursuing a program of research in Soil and Water Management in Semi-arid Areas, whose objective is to develop, test and introduce appropriate and socially acceptable management interventions for improving the capture of rainfall by soils and soil-water availability to plants, in the semi-arid areas. The program is divided into two major components namely:

- Rainfed Farming, Soil and Water Management.
- Improvement of Water Management in Rain Water Harvesting Rice Systems.

The first Project under this program was implemented from 1991 in Dodoma to test the performance of different tillage and water conserving techniques, in terms of sorghum (*Sorghum bicolor* var. Tegemeo) and maize (*Zea mays* L.) yields. It was conducted over a period of four rain seasons. It was found that tied-ridging and deep tillage with tractor resulted in increased grain yields over the control. Farm Yard Manure (FYM) application at 10 t ha^{-1} at the beginning of every rainy season, resulted in the most significant improvement of yields over the control in all the four years (Hatibu et al., 1995b). The Sokoine University of Agriculture is now funding a four year research project to explore and adapt a system of no-till tied-ridging. This system is intended to exploit the high benefits of tied-ridges but without the associated costs of annual tillage. The research work was started during the 1996/97 rainy season at Hombolo in Dodoma.

The research project "Evaluation and Promotion of Rain-Water Harvesting" reported here was a four year project started at the end of 1992. The aim of the project was to increase sustainability of production and population carrying capacity of flood-and-drought prone semi-arid lowlands through more effective management of rain-water. The following were the specific objectives of the research:

i) Appraise and describe farming systems and indigenous soil-water management and conservation in the semi-arid areas of Tanzania.

ii) Review past research work in rain-water harvesting with particular attention to Tanzania.

iii) Assess the technical, economic and social potential for rain-water harvesting, in semi-arid areas of Kilimanjaro region in Tanzania.

iv) Develop and validate a structured model of rain-water harvesting.

Kilimanjaro region was chosen as a major research area because it has its population concentrated on the top belt and slopes of the mountain ranges. The area has the highest population density in the country (1988 census); and with the heavy concentration of population in the highlands, the land has reached its maximum agricultural potential.

The present government policy is to encourage people to shift from the high lands and slopes to the low semi-arid lands. The success of this policy will, however, depend on increased water supplies in the semi-arid lowlands to enable the farmers to grow the crops they are used to.

Specific objective (iv) involved close collaboration with a parallel modelling project implementation at the University of Newcastle upon Tyne in UK . The work reported here therefore has already partly contributed to the validation of the model, especially the run-off yield component (Gowing & Young, 1996).

The two projects together seek to address the identified development problem by:

- demonstrating viable approaches for using rain water harvesting to enhance crop production in semi-arid areas; and
- to develop a model which can aid in the identification of rain water harvesting suitability and suitable options in different areas.

3. RESEARCH ACTIVITIES

3.1 Climatic Characterisation

3.1.1 Instrumentation

The weather data was collected from Morogoro [6° 50'S, 37° 42'E; altitude of 520m asl], Same [4° 5'S, 37° 43'E; altitude of 920m asl], and Kisangara [3° 43'S, 37° 35'E; altitude of 870m asl] stations.

Morogoro and Same are full meteorological stations while only rainfall has been monitored at Kisangara for the past 30 years using a non-recording rain gauge. However, a Dines tilting siphon recording rain gauge, an evaporation pan, and maximum and minimum thermometers have been installed at Kisangara since 1992. For long term analysis of weather, Same data has used to give a picture of what would be expected at Kisangara.

3.1.2 Rainfall

Long-term rainfall data for Morogoro and Same were obtained from the Directorate of Meteorology in Dar es Salaam. Daily and monthly rainfall records for Kisangara were obtained from the Karimjee Agriculture Ltd (Kisangara Sisal Estate). Processing of rainfall data based on seasonality (viz.short rainy season (Vuli) during August-January, and long rainy season (Masika) during February-July) was conducted in steps as follows:

- Digitization of continuous rainfall record charts using a Graphtec Digitizer and necessary computer software. This process produced the following information:
    - Peak 5 minutes intensity (I_5)
    - Peak 30 minutes intensity (I_{30})
    - Total rainfall recorded on the chart
    - Duration of rainfall

- Statistical analysis of long-term records for:
    - Minimum
    - Maximum
    - Mean
    - 70% probability rainfall
    - Wet days
    - Dry spells.

The 70% probability rainfall was calculated as follows:-

$$P\,(\%) = \frac{m - 0.375}{N + 0.25} \times 100$$

where: P = Probability in % of the observation of the rank; m = the rank of observation; and N = total number of observations.

Longest dry spells for each month were recorded by considering a wet day with 3 mm of rain or more and counting the number of days backwards to the last wet day. A dry spell was considered to belong in the month where it ended.

3.1.3 Other Weather Parameters

Long-term historical temperature and evaporation data for Morogoro and Same stations were obtained and analysed as for rainfall. The following parameters were considered:

- Monthly Evaporation
  - Minimum
  - Mean
  - 70% probability evaporation
  - Maximum

- Monthly minimum temperature
  - Minimum
  - Mean
  - Maximum

- Monthly maximum temperature
  - Minimum
  - Mean
  - Maximum

3.2 Experimental Work

3.2.1 Fieldwork Sites

The experiments were conducted at two sites, namely, at Sokoine University of Agriculture (SUA) farm, Morogoro and at Kisangara Sisal Estate near Mwanga township in Kilimanjaro Region (Figure 14).

The Morogoro site had been under maize cultivation for several years and then under vegetation fallow for two years prior to the initiation of the experiments. Slope of the site is 3-4% on the upper side and 6-8% on the lower part. The surface soils are reddish brown sandy clay loam underlined with sandy clay subsoils, said to originate from metasediments of the Uluguru Mountains. The soils are fairly deep (> 100 cm) and well drained. These soils have been classified as Typic Ustorthent (USDA Soil Taxonomy) and as Eutric regosol (FAO/UNESCO System) (Kaaya, 1989).

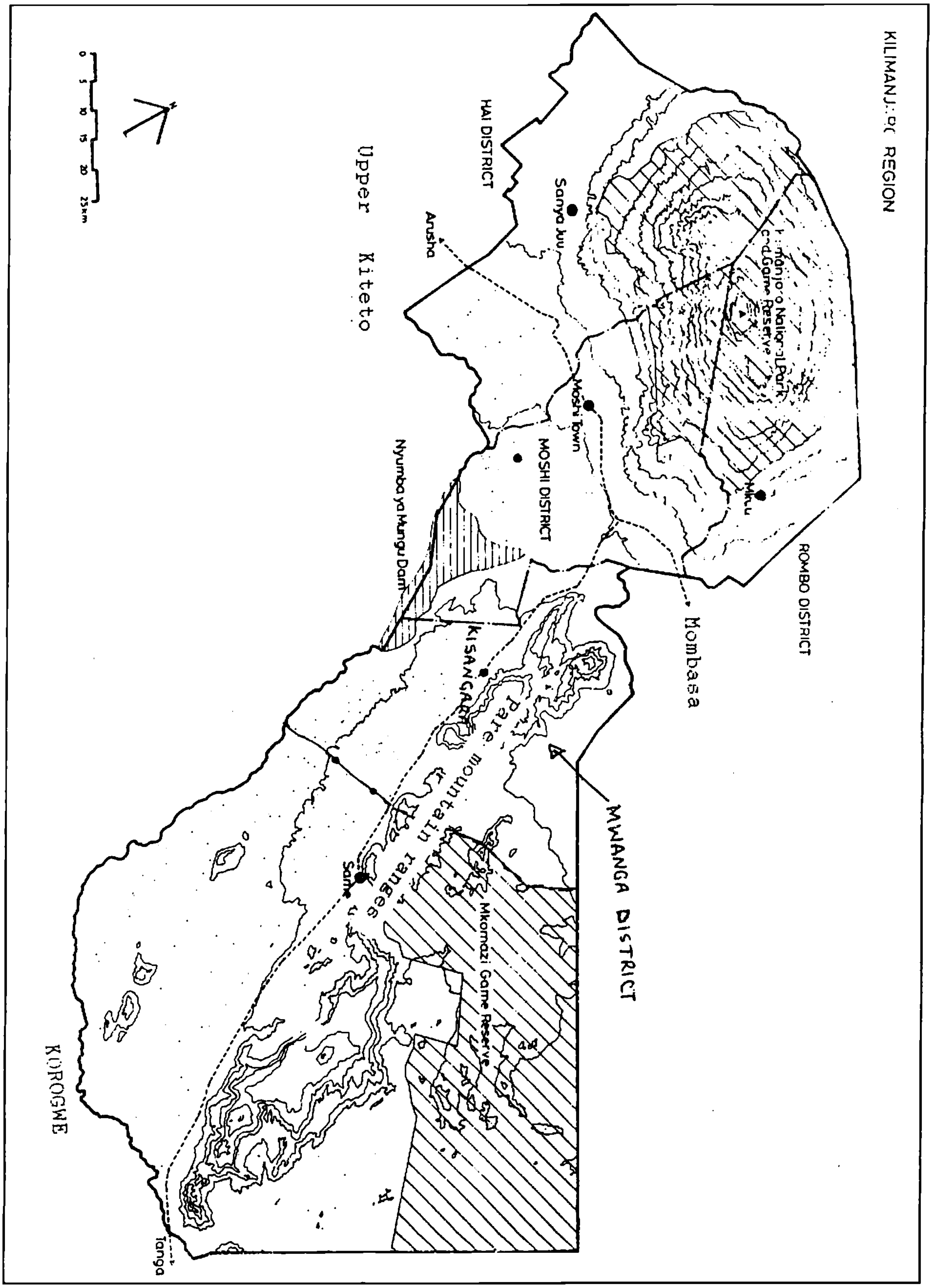


Figure 14: Kilimanjaro region

The Kisangara site is located within the Karimjee Agriculture Ltd owned Sisal Estate in Mwanga district. The site was cleared of sisal (planted in 1975) with a front mounted shear blade to pave way for the experiments. The slope at the site is 3% on the lower part and 8% on the upper side. The soils of the upper side are coarse textured, well drained and moderately deep (80-120 cm) with prevalent sandy clay loams on the surface horizons and clay loams at lower depths. The high sand content of these soils (of up to 49%) depicts low water holding capacity. The soils of the lower slope (2-3%) are deep (100-140 cm), brown and red, developed from weathered granulite gneiss. The soils are well drained, dominated by sandy clay loam texture on the surface and consequently have low moisture holding capacity.

The fertility status of the site is rated very low, and the soils are classified as Oxic Rhodustalf (according to USDA Soil Taxonomy) and Ferric Luvisol (according to FAO/UNESCO System) (SARI, 1995). Detailed site characterization is shown in Appendix 2.

3.2.2 Experimental Design and Layout

The experiments established on these sites were as follows:

Runoff Measurement (Kisangara, Morogoro)
Runoff Farming (Kisangara, Morogoro)
Soil-Water Conservation (Kisangara)

The Runoff Measurement experiment was designed to provide data on runoff response from a small catchment area representative of within-field RWH systems. This was a plot experiment involving combinations of three factors (replicated twice at Morogoro but not replicated at Kisangara):

i) Plot size: 10 x 5m and 10 x 10m
ii) Plot slope: gentle and steep depending on natural slope
iii) Surface Condition: four treatments applied were

    (B) bare surface (i.e. kept clear of weeds)
    (BC) bare and compacted (compaction by roller)
    (V) natural vegetation
    (LMC) low management crop.

The Runoff Farming experiment was designed to provide data on crop response to varying levels of enhanced water supply. The crop was maize in a pure stand in 50 m^2 plots. This experiment involved three factors (replicated):

(i) Catchment size: 0.50 m^2, 100m^2, 200m^2 with Catchment:Basin Area Ratio of 0:1, 1:1, 2:1 and 4:1

ii) Plot slope: gentle and steep depending on natural slope

iii) Tillage treatment: staggered ridge or flat cultivation.

Maize (Zea mays) was planted on plots with TSP applied at a rate of 40kg P/ha. At 6th leaf stage N was applied at a rate of 40kg N/ha at Morogoro. At Kisangara, however, N was either applied at 40kg N/ha (FP) or not applied (NF) for each catchment size at 3% slope at 6th leaf stage.

The soil-water conservation experiment at Kisangara was conducted on 125 m^2 plots at 8% slope. The treatments, replicated three times, consisted of:

(ZT) zero tillage (locally known as Kitang'ang'a)

(FC) flat cultivation with hand hoe to a depth of 10-15cm

(CR) contour ridging at 5m spacing with hand hoe cultivation

(SB) stone bunds at 5m spacing with hand hoe cultivation

(LB) live barriers (as above) of vetiver grass and local plant called "Iduri".

The layout of the sites at Morogoro and Kisangara is shown in Figures 15, 16 and 17. It can be seen that the Kisangara site also included two additional demonstration plots in which runoff was collected from external catchments under natural vegetation and spread on maize cropped plots.

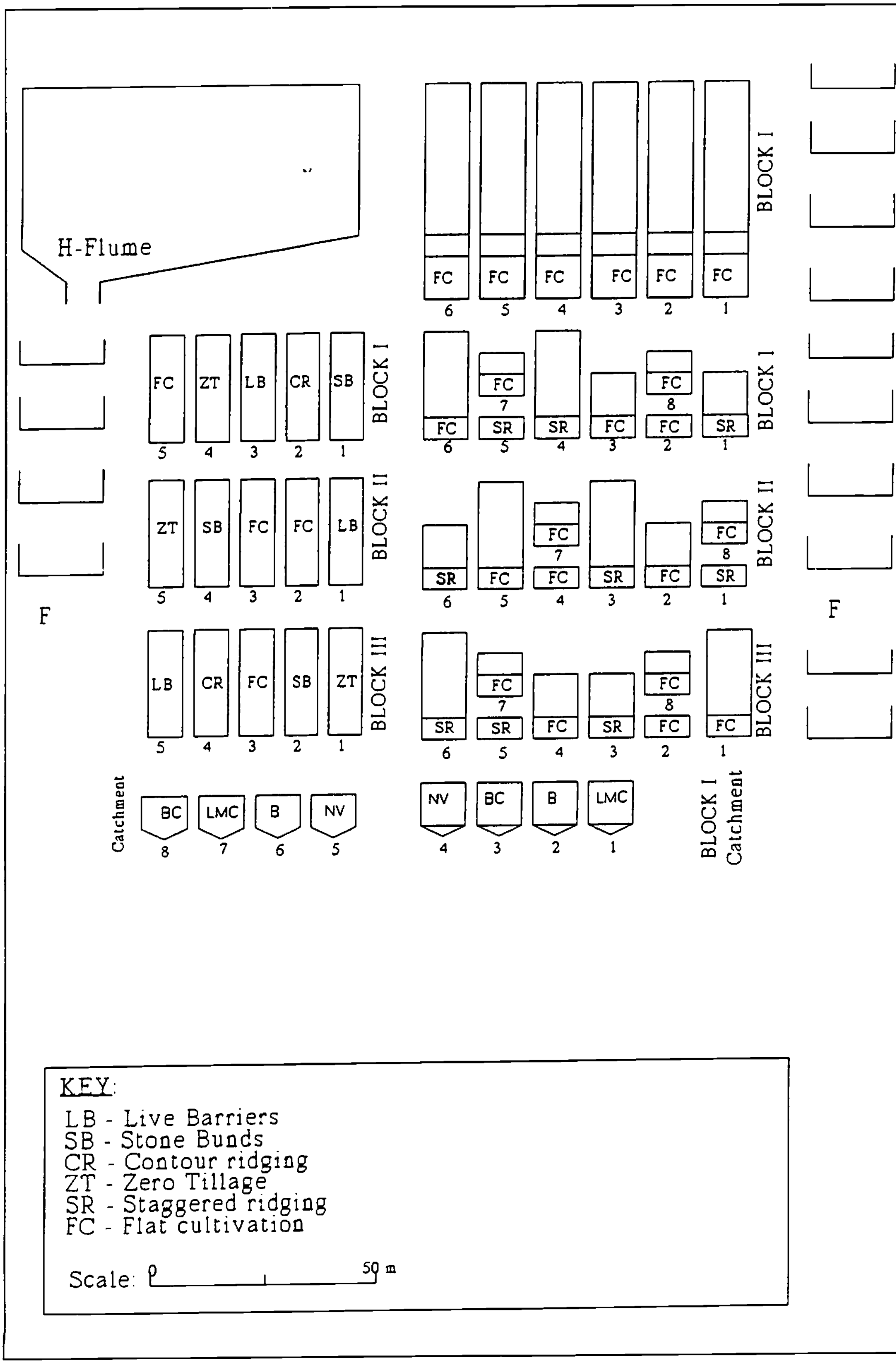


Figure 15: Layout of the experiments in 8 % slope Kisangara

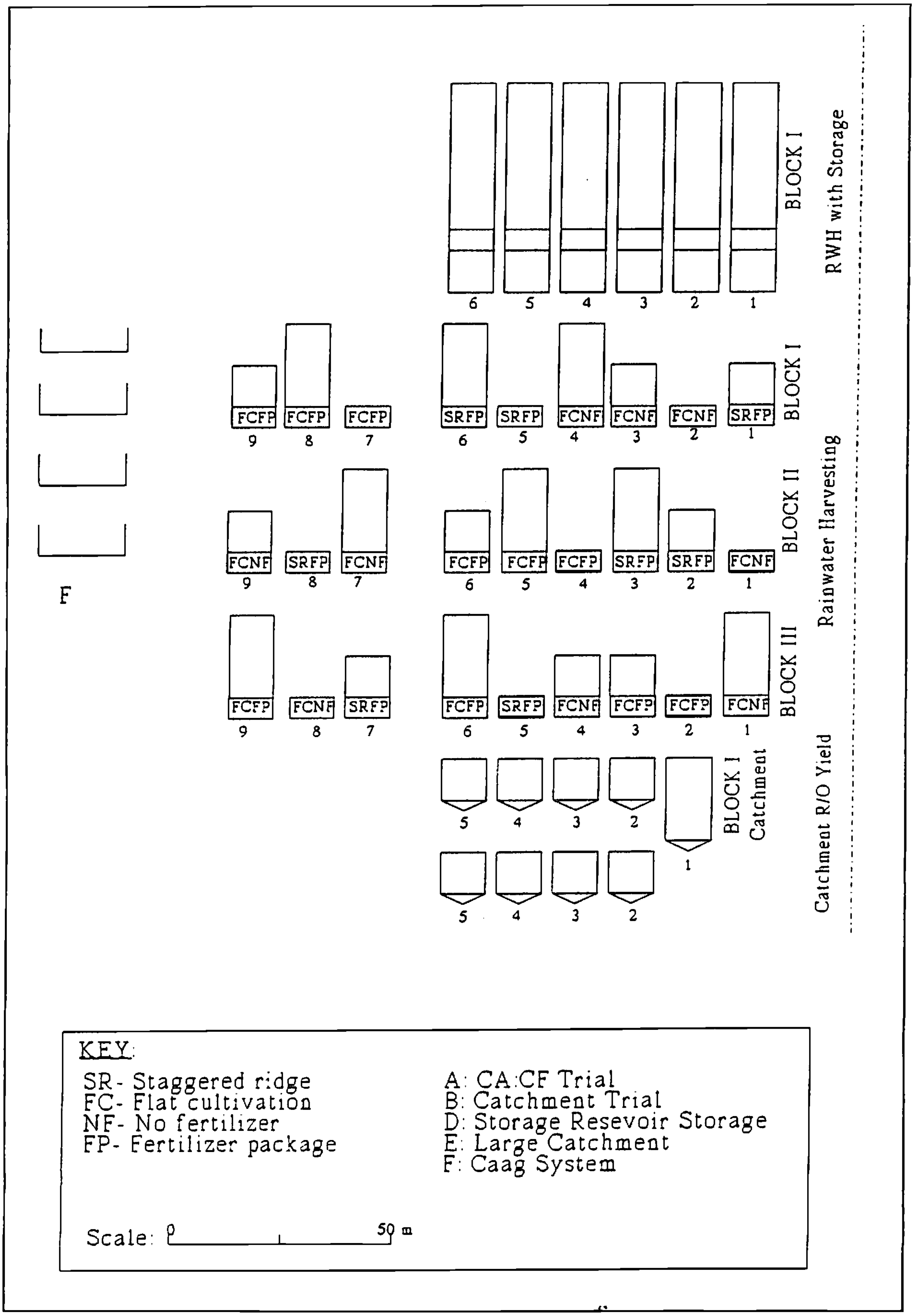


Figure 16: Layout of the experiments in 3 % slope Kisangara

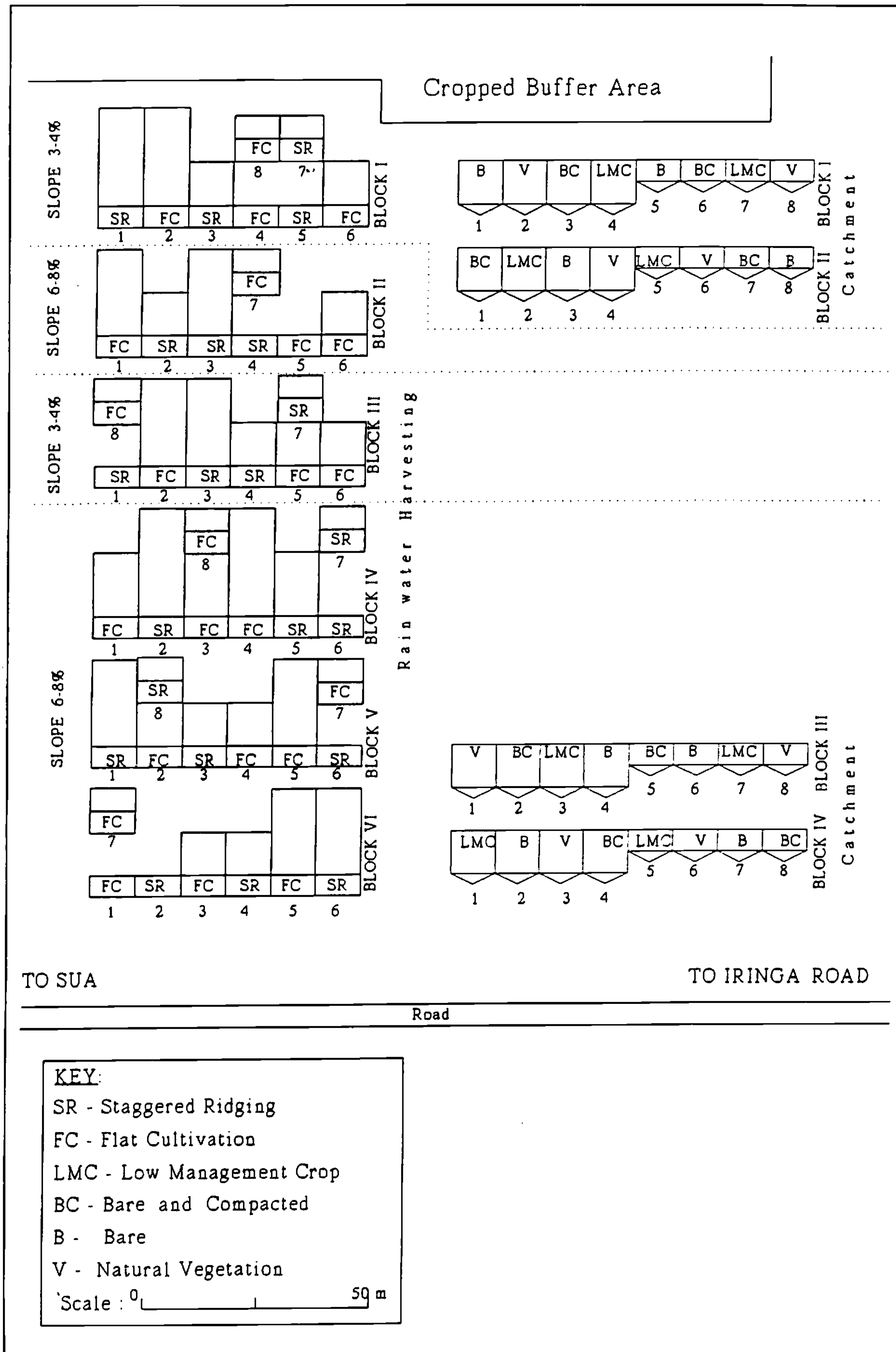


Figure 17: Experimental layout of Morogoro site

3.2.3 Soil and Plant Measurements

3.2.3.1 Soil physical properties

Soil bulk density, total porosity, soil moisture, cumulative infiltration, saturated hydraulic conductivity and soil-water release characteristics were determined using standard procedures according to Klute (1986).

3.2.3.2 Runoff

The runoff collection system consisted of a divider drum with 15 outlet pipes of diameter 1.91 cm. The central pipe was connected to the collector drum by a hose pipe. The overflow pipes of the divider drum were adjusted such that the overflow volume draining into the collector drum was between $^{1}/_{12}$ and $^{1}/_{18}$ of the total overflow. Calibration of the runoff collection system was done in order to obtain the actual ratio of the overflow that drained into the collector drum. This ratio was used to calculate the total runoff from the catchment area. A depth to volume calibration curve was established for all the drums. After each rainfall event the depth of runoff collected in 200 litre drums (of the runoff collection system) was recorded by a metric steel rule.

3.2.3.3 Crop measurements

Dates for various agronomic operations and crop growth stages for Kisangara are shown in Table 2. Seedling emergence of maize was determined by counting the number of seedlings in each plot that had emerged everyday until no further emergence occurred. Biomass accumulation during the growing season was monitored by taking above ground biomass (plant) samples at 6th leaf, silking stage and at harvest (physiological maturity). Dry matter yield was measured after oven drying the harvested green mass at a temperature of 60°C until constant weight was obtained.

At maturity all the maize plants in each plot (except those in guard rows) were cut at ground level. Ears were then harvested and shelled and grain yield recorded. One hundred seeds were randomly counted from the grain mass of each plot, weighed and then dried in the oven at 60°C until constant weight was obtained for grain moisture determination.

3.2.3.4 Contribution to model development

The data from the experiments contributed to the validation of the model in four main areas; namely

- The climate generator: The necessary climatic data was assembled, digitized and transferred to Newcastle. The following data sets were transfered:
  - Morogoro: 1971-1987 & 1993-1995
  - Same: 1958-1992
  - Dodoma (Hombolo): 1992-1994

- Rainfall disaggregator: Rainfall data from Kisangara and Morogoro meteorological stations were used.

- Pedotransfer functions: Two tests were implemented at Kisangara over a period of 90 days while in Morogoro only one test was done over a period of 40 days.

- Runoff data: The data collected as described in section 3.2.3.2 was transferred to Newcastle and used to validate the model.

The results of model validation are described in another report (Gowing and Young, 1996).

Table 2: Dates for various agronomic operations at Kisangara

		SEASONS				
ITEM/PRACTICE		Vuli 93/94	Masika 94	Vuli 94/95	Masika 95	Vuli 95/96
Cultivation		October	11-10/3	Early Oct.	1-10/3	4-15/10
Ridging		Nov.	11-14/3	Late Oct.	11-14/3	1-16/11
Planting & TSP application		3/12	17/3	11/11	15/3	11/11
Gap filling		16-17/12	27/3	20/11	28/3	8-10/12
Thinning		28/12	14-18/4	3/12	4-6/4	27-28/12
	1st Weeding		31/3 - 5/4	6/12	8-11/4	
	2nd Weeding		24-27/4	9/1	1-6/5	
	3rd Weeding		7-14/6		25/6 - 4/7	
Top dressing			26/4	4/12	15/4	
Plant Protection			21-22/3	26/12		
1st Biomass Sampling			2/5	13/12	22/4	
2nd Biomass Sampling			23/5	18/1		
Final Harvest			19/7		19/7	3/5

4. RESEARCH OUTPUTS

4.1 Climatic Characterization

4.1.1 Rainfall

4.1.1.1 Short rainy season [Vuli]

Rainfall for Vuli is unreliable at all the three stations; Morogoro, Same and Kisangara. The seasonal total rainfall with 70% probability is only 231, 257, and 178 mm for Morogoro, Kisangara and Same, respectively (Table 3). Vuli rainfalls are also very variable from season to season. The difference between maximum and minimum seasonal amounts is 448, 829 and 430 mm for Morogoro, Kisangara and Same, respectively. The usefulness of the rainfall is also affected by poor distribution. For example, in both Morogoro and Same, every month during Vuli has a chance of receiving no rainfall at all. At Kisangara the month of November may receive at least 18 mm of rainfall. At all the three stations, the length of the longest dry spell with 30 % probability of occurrence is at least 14 days in every month (Table 3).

4.1.1.2 Long rainy season (Masika)

Masika rains are higher in general and vary between 348-758, 163-1,185, and 141-721 mm, for Morogoro, Kisangara and Same, respectively. The variability is therefore very high at Kisangara site. The 70% probability rainfalls are 498, 327, and 246 mm for Morogoro, Kisangara and Same, respectively. Further, in Morogoro rains are always received in the months of March, April and May. At the other stations, only the months of March and April receive rainfall each year. Except for April, the rest of the months suffer a dry spell of more than 14 days at 30% chance at both Kisangara and Same. Thus there is a high possibility of crop damage by stress during the season (Table 3).

4.1.2 Other Weather Parameters

4.1.2.1 Vuli

Results of analysis show that the minimum temperature during Vuli varies between 18-22°C and 14-20°C, for Morogoro and Same, respectively. The maximum temperature vary between 27 - 34°C for Morogoro and 24 - 35°C for Same (Table 4).

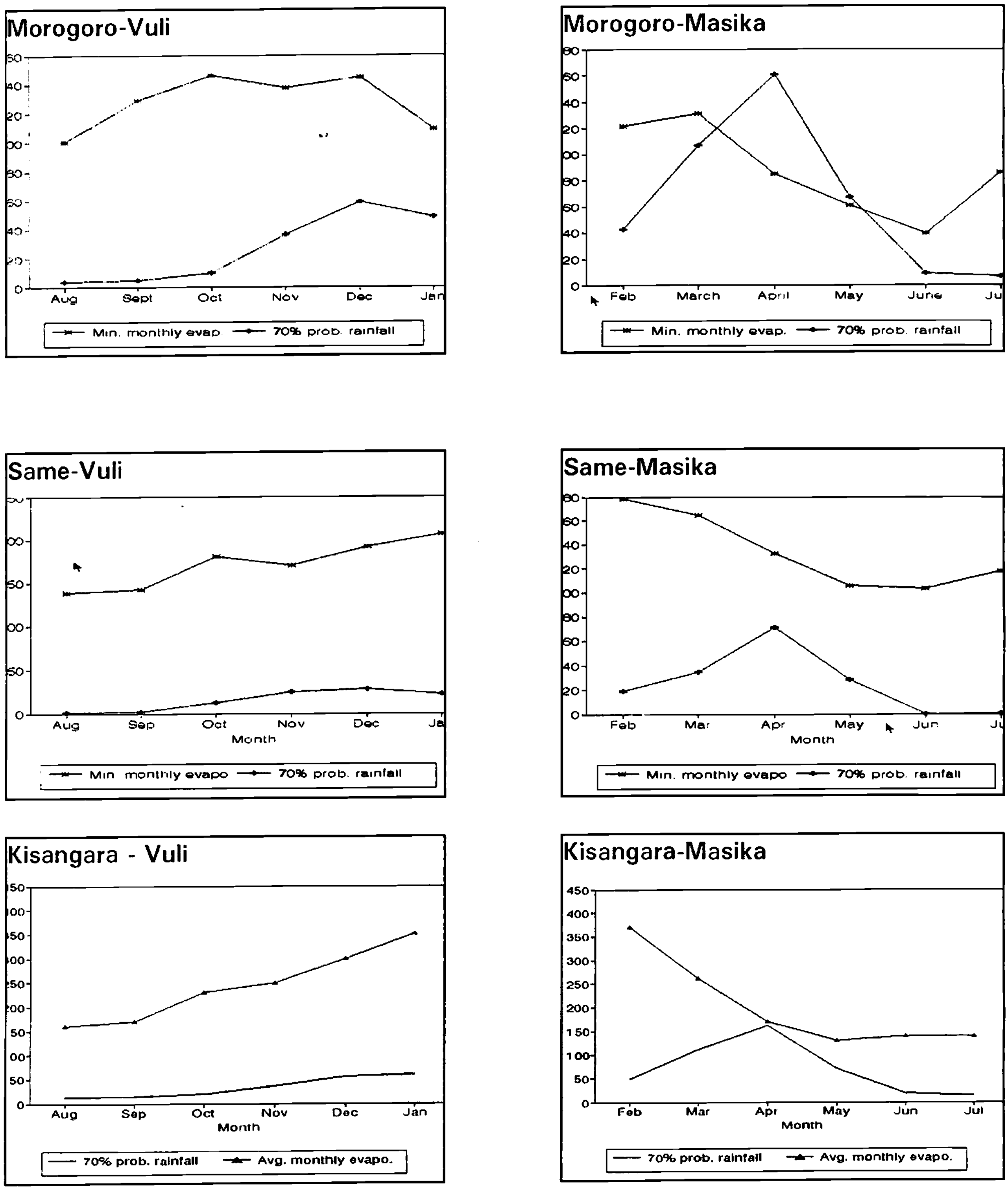
Evaporation during Vuli varies between 786 - 1,326 mm, and between 1,119 - 1,611 mm for Morogoro and Same, respectively (Table 4). Evaporation rates in Kisangara are similar to those of Same. During Vuli, long term average minimum evaporation exceeds the 70% probability rainfall in all years at both Morogoro and Same (Figure 18).

Table 3: Summary of long term rainfall characteristics

SITE	Parameter		Aug	Sep	Oct	Nov	Dec	Jan	Vuli - Season	Feb	Mar	Apr	May	Jun	Jul	Masika Season
MOROGORO	RAINFALL	Min	0.1	0.0	0.0	1.4	0.8	10.8	124.3	0.7	41.2	87.1	12.7	0.0	0.0	348.0
		Mean	8.7	9.5	30.5	65.9	109.9	96.8	321.7	85.4	126.4	188.4	87.0	17.2	15.2	504.9
		70%	3.7	4.8	10.0	36.7	58.9	48.3	230.9	42.6	106.8	161.2	67.3	9.5	7.0	498.2
		Max	31.2	22.4	105.0	175.7	262.4	287.7	572.0	257.9	229.1	296.4	157.7	61.4	61.1	757.6
	WET DAYS	3mm'	1	1	2	4	6	6		4	8	13	8	2	1	
		5mm'	0	1	2	3	5	5		3	6	11	7	1	1	
		10mm'	0	0	1	2	3	3		3	4	7	3	0	0	
	LONGEST DRY SPELL	min	13	12	10	6	7	3		3	3	2	5	11	11	
		30%	31	30	25	20.5	14	19.5		18	12	8	13	30	31	
		Mean	24	24	20	16	12	15		16	9	6	10	23	22	
		Max	31	30	31	30	21	28		28	22	12	22	30	31	
KISANGARA	RAINFALL	Min	0.0	0.0	0.0	18.7	0.0	0.0	121.3	0.0	25.4	31.7	0.0	0.0	0.0	163.7
		Mean	4.7	10.6	38.03	141.0	109.0	64.0	355.78	47.2	159.3	160.3	65.4	6.5	5.80	444.5
		70%	0.0	0.0	8.0	78.0	52.0	18.0	257.0	22.0	77.0	102.5	34.0	0.0	0.0	318.00
		Max	32.0	55.0	130.0	424.0	385.0	212.8	950.0	161.3	451.0	423.0	203.0	47.0	33.0	1185.0
	WET DAYS	3mm+	1	1	3	7	13	3	28	7	7	11	9	1	1	36
		5mm+	1	1	2	6	4	2	16	5	6	6	7	1	0	25
		10mm +	0	0	2	4	4	2	8	3	5	4	5	0	0	17
	LONGEST DRY SPELL	Min	10	14	4	5	4	9		9	8	4	5	13	14	
		30%	31	30	27	15	14	20		24	17	14	15	30	31	
		Mean	26	26	20	11	13	17		20	15	11	13	26	24	
		Max	31	36	31	30	35	31		30	31	30	31	33	39	
SAME	RAINFALL	Min	0.0	0.0	0.3	0.3	0.0	0.0	84.5	0.0	2.3	17.7	2.3	0.0	0.0	141.9
		Mean	9.7	14.6	39.3	60.2	63.9	55.4	243.1	43.7	82.8	117.0	66.9	10.9	5.3	326.6
		70%	1.0	1.7	11.9	24.5	28.2	22.4	178.3	18.7	34.6	70.9	28.2	0.3	0.4	246.0
		Max	70.3	89.9	137.5	230.4	175.1	152.9	514.3	159.0	326.1	300.2	217.3	73.9	37.6	721.2
	WET DAYS	3mm'	1	1	3	4	5	3		2	5	6	4	1	0	
		5mm'	0	1	2	3	3	3		2	4	5	4	1	0	
		10mm	0	1	1	3	1	2		1	2	3	2	0	0	
	LONGEST DRY SPELL	min	16	11	8	6	6	7		7	3	4	7	12	13	
		30%	31	30	23	20	20	23		23	18	12	16	30	31	
		Mean	27	25	21	16	17	19		19	17	11	17	26	28	
		Max	31	30	31	30	31	31		29	31	28	31	30	31	

Table 4: Mean monthly evaporation, minimum and maximum temperature

Site	Parameter		VULI							MASIKA						
			Aug	Sep	Oct	Nov	Dec	Jan	Season	Feb	Mar	Apr	May	Jun	Jul	Season
MOROGORO	Mean monthly evaporation	Min	100.7	129.1	75	137.8	144.8	104.0	786.2	121.9	131.5	85.2	61.0	39.6	85.9	549.9
		Mean	145.4	163.9	160.8	219.5	228.7	173.9	1091.8	185.5	175.4	130.6	90.7	80.1	109.7	772.0
		70%	119.4	157.0	183.6	177.3	179.7	168.4	1008.8	162.9	156.8	105.7	9.16	92.1	98	718.0
		Max	190.0	198.6	246.0	301.2	312.6	242.8	1325.6	284.0	268.4	176.0	120.4	120.6	133.5	1817.7
	Minimum Temperature	Min	20.4	20.3	20.2	19.5	17.9	20.4		20.3	20.2	19.5	17.9	14.3	13.9	
		Mean	15.7	16.7	18.2	18.2	21.1	21.1		21.1	20.8	20.5	18.9	15.8	15.2	
		Max	17.2	17.8	19.3	20.5	22.1	22.3		22.2	21.8	21.4	19.8	16.9	16.6	
	Maximum temperature	min	26.8	28.6	30.2	30.6	29.7	29.3		30.3	29.7	28.3	27.6	26.4	25.9	
		Mean	28.0	29.8	31.3	32.0	31.6	31.4		30.7	31.6	29.7	28.6	27.7	27.4	
		Max	28.9	30.9	32.5	33.6	34.1	33.7		34.4	33.4	31.0	29.7	28.7	28.8	
SAME	Mean monthly evaporation	Min	138.2	142.7	179.5	169.6	190.9	206.0	1119.0	178.2	164.5	132.2	105.9	103.9	117.7	871.8
		Mean	180.6	182.1	224.8	249.6	280.8	192.1	1266.8	259.0	262.6	178.0	139.1	155.1	157.1	1117.0
		70%	151.3	184.5	200.8	205.8	239.3	270.8	1231.2	235.2	246.6	164.6	120.2	132.2	138.6	1018.9
		Max	222.9	221.4	270.0	329.6	370.6	398.7	1610.9	339.7	360.6	223.8	172.3	206.2	197.0	1325.5
	Minimum temperature	min	13.0	14.2	15.4	17.4	17.4	16.7		17.4	16.6	16.7	16.4	14.2	13.2	
		Mean	15.2	15.6	17.2	18.6	19.2	19.2		19.2	19.3	19.0	17.6	15.8	15.2	
		Max	18.0	16.9	18.4	19.5	20.1	20.3		20.4	20.3	20.3	18.8	17.1	16.4	
	Maximum temperature	Min	24.3	26.6	28.1	28.8	28.9	27.6		30.0	27.2	26.1	25.2	24.2	24.4	
		Mean	26.4	28.3	29.9	30.5	30.4	31.4		32.3	31.8	29.2	26.7	26.0	25.7	
		Max	27.8	30.9	31.3	34.7	32.9	33.9		33.9	33.7	31.9	30.1	28.3	27.2	
KISANGARA	Mean monthly evaporation	Min	111.6	75.0	1124.0	775.00	1155.0	155.0	695.6	0.0	68.2	15.0	21.7	60.0	46.5	211.4
		Mean	189.1	243.0	238.7	2246.0	384.4	440.2	174.2	210.0	337.9	414.7	105.4	129.0	133.3	1062.6
		70%	232.5	255.0	248.0	2255.0	356.5	356.5	1703.5	268.8	310.0	618.0	124.0	165.0	155.0	1202.8
		Max	297.0	360.0	1358.5	1360.0	1815.5	2108.0	15277.0	378.0	1240.0	1375.0	186.0	255.0	235.5	2636.5
	Minimum Temperature	Min	11.0	13.6	13.0	13.6	16.2	16.7		17.0	17.2	10.1	15.0	12.5	10.5	
		Mean	16.2	17.7	18.4	17.9	19.4	19.7		19.6	19.9	18.6	18.1	14.7	14.6	
		Max	22.0	22.0	30.0	22.0	22.5	23.5		21.5	21.5	20.0	20.0	18.0	18.0	
	Maximum Temperature	Min	25.0	27.0	28.0	27.0	29.0	16.7		26.0	27.0	20.0	20.0	24.5	22.0	
		Mean	30.0	32.2	31.2	32.2	31.4	19.7		32.6	32.1	29.1	26.8	26.6	27.5	
		Max	33.2	35.0	33.2	35.0	33.2	23.5		35.0	35.0	31.5	31.5	35.0	29.0	



Vuli

Masika

Figure 18 Average monthly minimum evaporation and 70% probability rainfall at Morogoro, Same and Kisangara

4.1.2.2 Masika

In Masika, temperatures are also high and the monthly mean minimum temperature varies between 14 - 22°C in Morogoro. For Same the monthly mean minimum temperature ranges between 13 - 20°C. The maximum temperatures range between 26 - 34°C in Morogoro and between 24 - 34°C for Same. Therefore, in terms of temperature there is no much difference between the two sites.

The seasonal evaporation is between 550 - 1,817 mm in Morogoro and vary between 872 - 1,325 mm in Same. Therefore, even during masika where some cloud cover is expected the rates of evaporation are also high. In Morogoro, the 70% monthly rainfall expected exceed long term minimum evaporation only during the month of April. For Same, the situation is worse as the 70% probability rainfall is exceeded by minimum expected evaporation throughout the season (Figure 18).

4.1.3 Crop Water Requirements

The long term average crop water requirement for maize calculated using 70% probability evaporation is higher than rainfall in almost all Vuli seasons in Morogoro and Kisangara (Figure 19).In Morogoro only six out of twenty four Vuli season had rainfall above or just below the seasonal crop water requirement. In only two years did the rainfall exceed seasonal crop water requirement. Therefore, the chance of harvesting during the vuli season is only one in four seasons. In Kisangara, the crop water requirement for vuli is higher and therefore adequate rainfall is obtained in only one in six years. However, it must be mentioned that Same evaporation data was used to estimate ET_{Crop} for Kisangara and there are indications that this may be an overestimation.

The Masika season in Morogoro receives adequate amount of rainfall for maize in almost all years. In Kisangara however, the crop water requirement during Masika is exceeded by rainfall in only 1 out of two years (Figure 19).

The relationship between seasonal rainfall and crop water requirements during the research period are given in Figure 20. Vuli 1994/95 was a good year in Kisangara and similarly Masika 1994 in Morogoro.

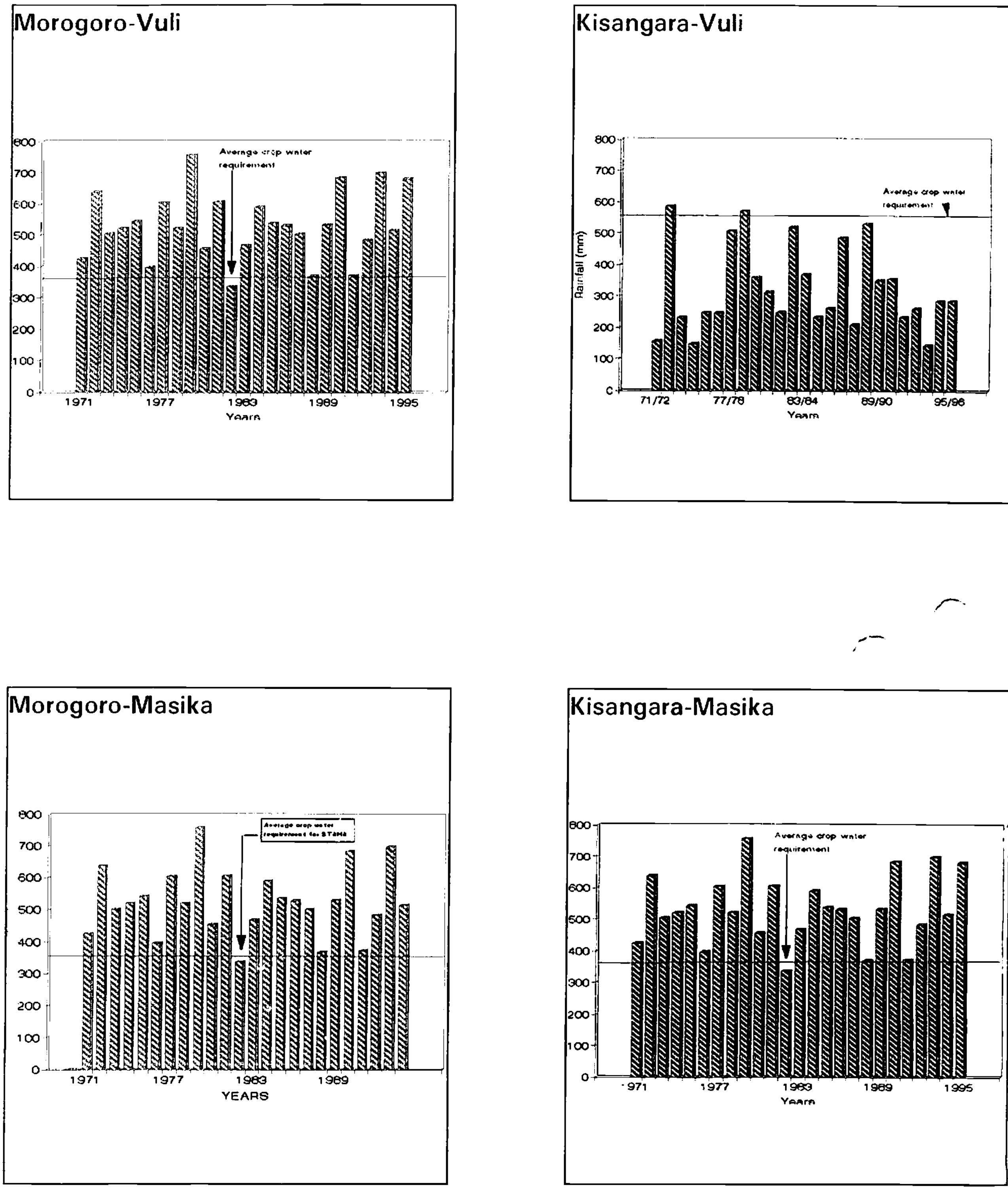
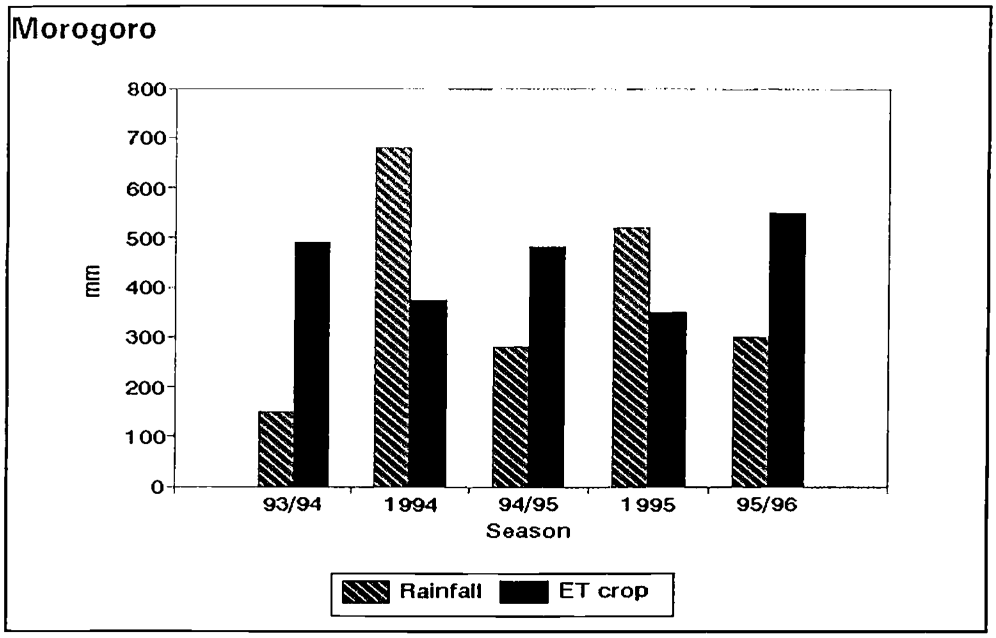


Figure 19: Comparison of historical rainfall and average maize water requirement, in Morogoro and Kisangara



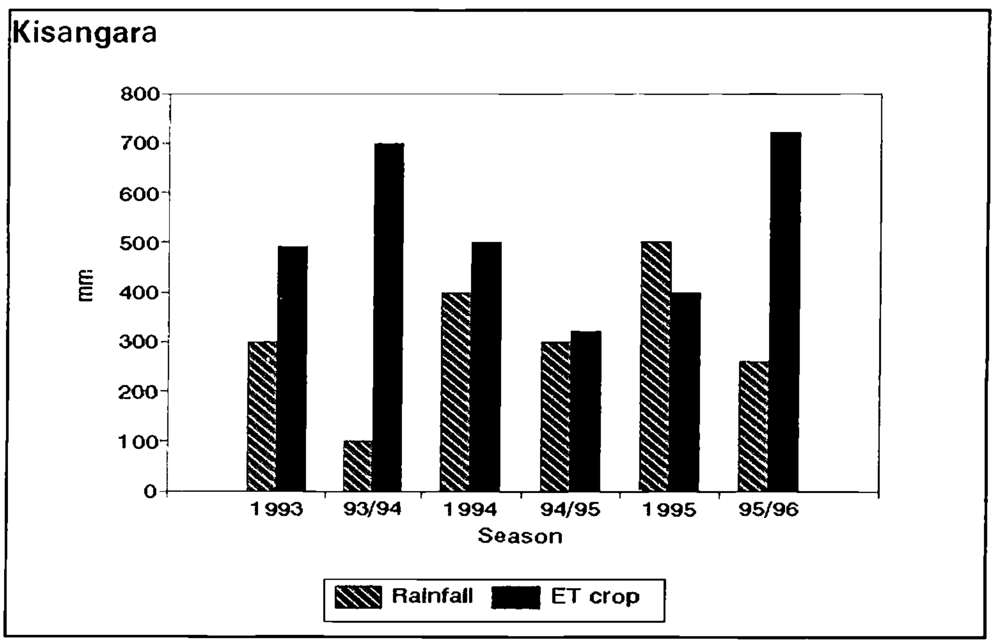


Figure 20: Comparison of seasonal rainfall and ETcrop (maize) during the research period

4.1.4 Analysis of Rainfall During the Experimental Years

(a) Vuli

The experiment was conducted over 2 Vuli seasons at the Morogoro site and 3 at Kisangara site. The two Vuli seasons at Morogoro had contrasting rainfall. The 1993/94 season received low and poorly distributed rains. The 1994/95 season received rainfall which was above 70% probability rainfall but also badly distributed, with more than half falling at the end of the season (Table 5). In 1993/94 only 143.7 mm were received with only 7 wet days and a very long (40 days) dry spell in November/December. In comparison, 285 mm were received in 1994/95 with 26 wet days. At Kisangara the Vuli season were slightly better. However, the rainfall amount was above 70% probability during only the 1994/95 season.

(b) Masika

At Kisangara, all seasons except 1993, received rainfalls above the 70% probability. These rainfalls were well distributed over the month of February - May with almost 40 wet days and longest dry spells of at most 14 days. the 1993 rainfall was below the 70% probability and the number of rainy days varied between 18 - 32.

At Morogoro, the amount of Masika rains is adequate for maize production in most of the years. Even the distribution of the masika rains in Morogoro is not very bad, with the maximum length of dry spells during the months of March, April and May, not exceeding three weeks.

In comparison, the Vuli season is more reliable at Kisangara than Morogoro. Kisangara has better 70% probability rainfall in the months of October, November and December, while at Morogoro, vuli rains are only better in December and January, i.e towards the end of the season. This trend was clearly demonstrated by the vuli 1994/95 rainfalls. In Morogoro nearly all the rain fell in January, while in Kisangara the rainfall was distributed over October, November and December. However, from the point view of the length of dry spells there is no much difference between the two sites.

Therefore, from the point of view of both seasonal amount and distribution of rainfall, the Vuli seasons are not favourable for maize production at both Morogoro and Kisangara, without interventions.

In Kisangara, the pattern of Masika rains begins in March and are only reliable for the two months of March and April. This coupled with long dry spells in the months of May and June, make maize production very risky, without interventions.

Table 5: Summary of rainfall characteristics during the research period

	Parameter		VULI							MASIKA						
			Aug	Sep	Oct	Nov	Dec	Jan	Season	Feb	Mar	Apr	May	Jun	Jul	Season
MOROGORO	RAINFALL (mm)	1992/93								167.2	117.8	296.4	100.8	12.7	5.4	700.3
		1993/94	3.2	2.1	45.8	37.4	0.8	54.0	143.7	134.6	80.1	168.8	88.2	8.2	37.0	519.9
		1994/95	18.7	5.7	26.0	43.5	49.2	142.3	285.3							
	WET DAYS	1992/93								5	6	18	8	1	0	38
		1993/94	0	0	3	2	0	2	7	9	8	13	10	1	3	44
		1994/95	2	1	4	6	7	6	26							
	LONGEST DRY SPELL (days)	1992/93								9	14	12	11	26	31	
		1993/94	31	30	21	14	40	21		6	8	9	11	21	25	
		1994/95	20	24	11	16	7	10								
KISANGARA	RAINFALL (mm)	1992/93								47.5	74.1	99.7	43.8	0.0	0.0	225.1
		1993/94	0.0	0.0	45.4	18.7	90.8	14.0	168.9	66.0	189.6	36.5	88.0	1.0	0.0	381.1
		1994/95	0.0	10.0	18.5	51.1	246.0	3.0	328.6	61.5	196.5	149.5	102.1	0.0	3.0	512.6
		1995/96	11.5	3.0	10.0	2.0	115.0	69.5	211.0							
	WET DAYS	1992/93								2	5	6	5	0	0	18
		1993/94	0	0	5	3	9	1	18	4	9	6	12	0	0	31
		1994/95	0	1	2	7	14	1	25	5.0	6.0	11.0	9.0	0.0	1.0	32.0
		1995/96	3	1	1	0	5	2	12							
	LONGEST DRY SPELL (days)	1992/93								20	8	8	16	30	31	
		1993/94	31	30	18	23	13	16		11	9	12	10	30	31	
		1994/95	31	21	27	6	5	28		39.0	13.0	7.0	13.0	31.0	30.0	
		1995/96	32	23	33	33	6	12								

4.2 Hydrological Analysis

4.2.1 Changes in Soil Physical Properties

Bulk Density

The variation of the bulk density at Kisangara during the growing season of 1995/96 showed a decreasing trend for the 0-20 cm soil depth of the LMC treatment for both the 8% and 3% slopes. The decreases in bulk density were 3.2% and 3.6% for the 8% and 3% slopes respectively. As expected, the B and BC treatment increased slightly. However, on the 8% slope the BC treatment decreased sharply by 13.1% at 5-10cm soil depth. This can be taken as a localised situation where probably there was a high concentration of dead sisal roots. The NV treatment plots showed a relatively high bulk density on both slopes. The major reason for this was primarily due to initial clearing which left plots bare and vulnerable to compaction by rainfall impact. Generally, low bulk density values were observed in the 5-10 cm soil depth profile when compared to both the 0-5 and 15-20 soil depth profiles, except in the BC treatment on the 3% slope. This was probably due to a high network of sisal roots at this depth.

Table 6: Bulk density (g/cm^3) for different treatments at Kisangara site

Site Slope (%)	Treatment	Depth (cm)	BD (g/cc)
8	LMC	0 - 5	1.24
		5 - 10	1.23
		15 -20	1.20
	B	0 - 5	1.38
		5 - 10	1.35
		15 - 20	1.54
	BC	0 - 5	1.52
		5 - 10	1.32
		15 - 20	1.51
	NV	0 - 5	1.37
		5 - 10	1.30
		15 - 20	1.48
3	LMC	0 - 5	1.36
		5 - 10	1.25
		15 - 20	1.31
	B	0 - 5	1.40
		5 - 10	1.35
		15 - 20	1.44
	BC	0 - 5	1.55
		5 - 10	1.60
		15 - 20	1.57
	NV	0 - 5	1.58
		5 - 10	1.51
		15 - 20	1.69
Before Treatments		0 - 5	1.39
		5 - 10	1.37
		15 - 20	1.50

Cumulative Infiltration

In both Morogoro and Kisangara sites cumulative infiltration (cm) after 150 minutes was on average highest for the NV treatment and the lowest for BC treatments although in some cases the B treatment recorded the lowest cumulative infiltration. (Morogoro:25.95 cm and Kisangara: 38.0 cm). (Table 7). A little difference in cumulative infiltration was observed between Morogoro and Kisangara site. At Morogoro site, the cumulative infiltration after 150 minutes varied between 18.45 - 149.70 cm, while in Kisangara the values were 20 -183 cm. The NV and LMC treatments recorded among the highest cumulative infiltration values in both masika and vuli seasons (Table 7).

Table 7: Effects of surface treatments on cumulative infiltration

Site	Season	Slope(%)	Treatment	Cumulative infiltration (cm)				
				30 min	60 min	90 min	120 min	150 min
Morogoro	Masika 1995	3	NV	18.23	34.20	50.60	65.15	79.78
			LMC	7.05	11.13	14.93	18.25	21.13
			B	7.13	14.13	18.3	19.33	25.95
			BC	9.90	19.33	25.33	28.03	35.58
		6	NV	37.65	67.68	89.93	112.15	149.70
			LMC	5.63	9.50	12.83	15.78	19.15
			B	10.45	16.28	21.95	26.70	31.80
			BC	5.28	8.70	12.20	15.40	18.45
Kisangara	Masika 1995	3	NV	31.80	43.95	49.90	53.65	58.15
			LMC	28.90	43.10	51.48	61.63	67.28
			B	13.55	25.15	32.65	37.45	41.05
			BC	6.45	10.95	14.20	18.00	20.00
		8	NV	22.20	31.60	37.45	42.40	47.40
			LMC	20.60	35.70	43.15	48.85	53.90
			B	10.15	21.35	27.25	33.40	38.05
			BC	8.10	12.60	15.70	19.10	20.80
	Vuli 1995/96	3	NV	38.00	63.75	88.95	112.85	127.05
			LMC	51.40	78.25	100.85	112.75	120.50
			B	31.50	49.15	63.50	73.55	80.95
			BC	19.45	26.75	32.50	37.30	41.80
		8	NV	61.05	98.45	134.35	165.35	183.05
			LMC	36.65	59.30	74.05	87.90	100.95
			B	11.00	18.65	25.95	33.20	38.00
			BC	18.60	12.05	43.20	53.55	61.10

Hydraulic Conductivity:

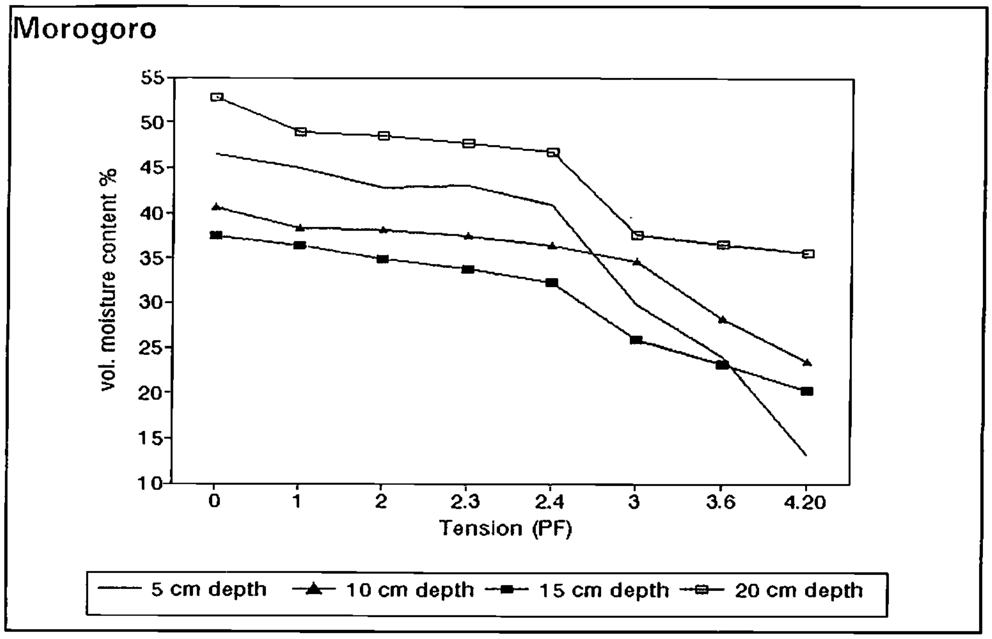
The saturated hydraulic conductivity for both Morogoro and Kisangara sites did not show consistent trend as would have been expected. (Table 8). However, the LMC treatment at both sites and slopes showed higher values compared to the other treatments. Generally when the two sites are compared, Kisangara had higher value of saturated hydraulic conductivity than Morogoro.

Table 8: Saturated hydraulic conductivity for Morogoro runoff catchments

Slope (%)	Catchment Treatment	Hydraulic conductivity (m/day)	
		Morogoro	Kisangara
3	NV	0.35	0.46
	LMC	0.73	0.56
	B	0.47	
	BC	0.23	0.27
8	NV	0.07	
	LMC	0.18	1.51
	B	0.27	0.67
	BC	0.07	0.35

Water release characteristics:

At Morogoro site, the combined results from all the plots showed that available moisture is about 25% (v/v) at 5 - 10cm depth. However, the value decreases to about 20% (v/v)at 15 - 20cm depth (Figure 21). At Kisangara site, the NV and LMC treatments showed little changes in their water release at pF ranging from 0-2.4 for the 0-20cm depth. For the NV, the moisture content ranged from 36-45 percent (v/v). Beyond pF 2.4, the water released at all depth decreased drastically for all the treatments. For the B and BC treatments, there were large differences in the moisture released between the 5cm soil depth and the rest (5,10 & 15cm depths). Whereas in B treatment the difference in moisture content varied from about 33% (v/v) to 50% (v/v) between the 5cm depth and the 10cm depth, in BC the variation was from about 40% to 52% (v/v) for pF values ranging from 0-2.4. As expected, water released decreased with increasing depth and tension except for the 15cm depth in B treatment which increased in moisture content at pF 3.6. In the NV treatment a similar increase was observed for 20cm depth at pF 3.6 (Figure 21).



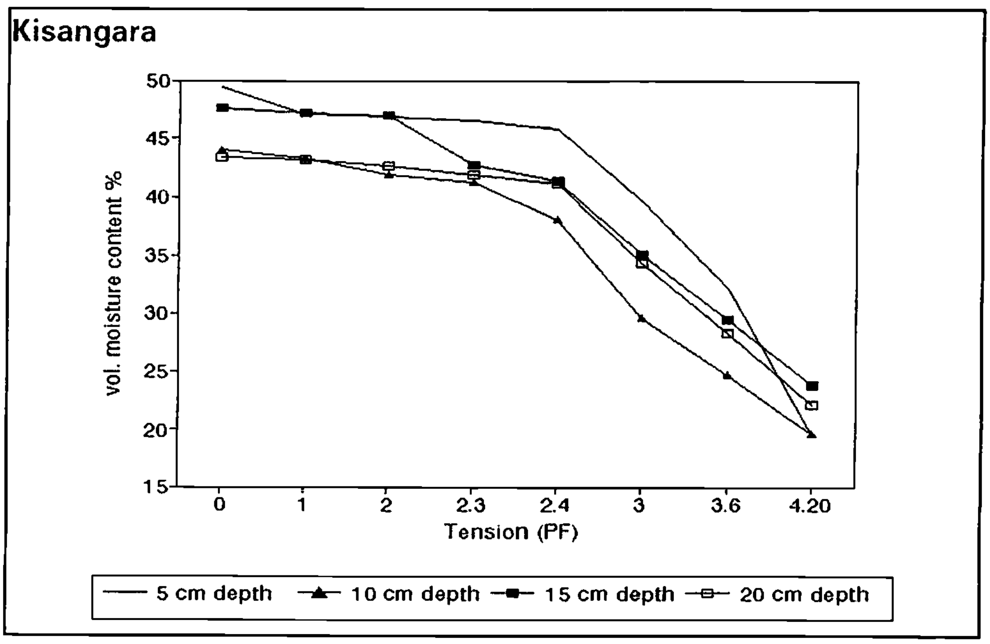


Figure 21. Effects of soil depth on Moisture release characteristics

4.2.2 Soil Moisture Changes

i) Vuli: conservation tillage

During the Vuli season of 1993/94, the LB treatment showed relatively higher water content at full crop emergence and crop development stages compared to the other treatments (Table 9). However, at tussling, the lowest water content was observed in ZT treatment. At maturity, the water content showed little seasonal variation in all the treatments. For the 1994/95 Vuli season, there was higher soil moisture at crop development stage than at full-emergence. At tussling the soil moisture was between 151-177 mm but slightly increased at crop maturity stage. Comparing the two vuli seasons, (i.e 1993/94 & 1994/95) there was more soil moisture down the profile during the 1993/94 Vuli than the same period in 1994/95.

ii) Masika: conservation tillage

During the Masika season of 1994, the highest moisture content down the profile was observed in the FC treatment (255 mm water) followed by LB (228mm) and immediately by SB (227mm water). A similar pattern was observed during the tussling stage. For the Masika season of 1995, the highest soil moisture was observed in the CR treatment (227 mm), followed by FC (223mm), SB (217 mm) and LB (206mm) at crop development stage. However, at tussling stage, LB and SB treatments recorded the highest soil moisture, with the lowest (126mm) being observed in FC treatment.

Comparing the two masika seasons, and considering tussling as the critical stage of the crop growth, the 1995 season had more soil moisture down the profile than in 1994. This is also reflected in terms of crop yields as is shown in section 4.3.1.

iii) Vuli 1993/94 & 1994/95 Runoff Experiment (8%)

During the Vuli season of 1993/94 on the 8% slope, the 2:1 CBAR treatment had relatively higher soil water content almost throughout the season (Table 4 a). At tussling and maturity stages the soil water content down the profile was 213 mm and 233 mm, respectively. On the other hand, the 4:1 CBAR treatment had lower water content at full emergence (182 mm) and crop development (178mm) stages. This could be due to too much runoff which damaged the bunds and escaped as surface runoff.

The soil moisture status during the Vuli season of 1994/95 was slightly different from the previous one. The 2:1 CBAR treatment was least superior in storing soil moisture between full emergence and tussling stages. As expected the 4:1 CBAR treatment had the highest stored moisture during the season. For example, at maturity, the stored water down the profile was 210mm. Although, during the 1994/95 Vuli season, there was much soil moisture at crop development stage, at tussling stage it reduced substantially. For the 2:1 and 4:1 CBAR treatments, the reductions were 22.4% and 21.8%, respectively. On the 3% slope, the 2:1 and 4:1 CBAR treatments unexpectedly had lower soil moisture content at full crop development stage than the 0:1 CBAR treatment. At tussling, however, the 2:1

CBAR treatment out performed the rest with 215 mm soil moisture followed by 0:1 (213mm) and 4:1 (199mm). Compared to the 8% slope, there was substantially more moisture in the soil during tussling in all the treatments during the 1994/95 Vuli season. This is expected as the runoff had more time to infiltrate into the soil due to the gentle slope.

iv) Masika 1994 & 1995

On the 8% slope, all the treatments for the Masika season of 1995 showed higher soil moisture in the soil profile at tussling than the 1994 season. A similar pattern was also observed at maturity stage. As expected the 4:1 CBAR treatment showed higher soil water content in both seasons but the soil moisture at tussling for the 1995 season was higher by 17.1%. For the 2:1 CBAR treatment, the soil moisture was higher by 20.4% in 1995 than 1994 season at tussling. Results on the 3% slope show that there were little differences in the amount of soil moisture in the profile at tussling stage in both seasons. In the 1994 Masika season, the soil moisture varied from 228-249 mm while in the 1995 season, it varied from 231-250mm for all the treatments at tussling stage.

Table 9: Effect of treatment and growth stage on soil moisture

Slope (%)	Treatment	Water content (mm) down to 100 cm depth															
		Vuli 1993/94				Masika 1994				Vuli 1994/95				Masika 1995			
	CBAR	FE	CD	T	M	FE	CD	T	M	FE	CD	T	M	FE	CD	T	M
8	0:1	185	190	184	234	211	191	177	161	220	204	163	178	.	222	228	182
	1:1	187	204	211	188	186	177	188	162	180	221	190	170	.	194	248	183
	2:1	202	199	213	233	229	.	183	149	205	196	152	197	.	214	230	180
	4:1	182	179	213	225	179	193	203	170	195	220	172	210	.	231	245	186
3	0:1	191	214	213	215	243	.	249	170	189	201	185	216	176	233	245	196
	2:1	195	190	215	186	227	.	229	155	185	210	204	195	176	229	251	193
	4:1	176	199	199	233	222	.	228	168	194	213	182	202	182	240	231	184
Conservation tillage 8	FC	186	173	228	229	255	204	203	188	175	200	168	191	.	223	216	193
	ZT	158	176	166	237	213	181	188	165	177	215	169	180	.	194	237	190
	LB	190	191	196	234	228	194	200	163	167	206	173	186	.	206	245	190
	SB	170	164	210	238	227	197	194	157	169	206	177	197	.	217	240	174
	CR	168	173	207	214	219	189	190	166	153	186	151	183	.	227	233	186

FE:Full emergence CD:Crop developement T:Tasseling M:Maturity

4.2.3 Rainfall-runoff Analysis

Data is available for two seasons (1994 and 1994/95) for Morogoro and four seasons (1994 - 1995/96 for Kisangara. The processed data is in Appendix 3. The effect of slopes, plot length and catchment surface cover were analyzed statistically using only the Morogoro data. This is because the runoff experiments at Kisangara were not replicated to reduce the cost associated with runoff measurement.

Analysis of the Morogoro data from the two seasons show the following:

- The amount of runoff produced on the two slopes (3% & 8(%) differed significantly only when the rainfall amount was lower than 9mm. Above this amount of rainfall, the runoff yield of the two slopes were not significantly different. There are several reasons for this trend, one being that at high rainfall amount the catchment moisture content become more important factor than the amount of rainfall, in the generation of runoff.

- No significant different runoff yield was observed in relation to the catchment length. However, the 5m long catchments produce about 10% higher runoff compared to the 10m long catchments.

- The most important significant difference was noted in relation to the surface characteristic of the catchment. The cultivated and vegetated plots produced significantly low runoff as compared to bare and bare compacted plots. This is consistent with findings by other researchers who have found that for a given rainfall, vegetation cover has an overriding effect on runoff generation (Othieno & Laycock, 1977; Elwell & Stocking, 1976: and Snyman et al, 1985).

Table 10: Seasonal Runoff at Kisangara site

Season	Rainfall	Slope (%)	Seasonal runoff as % of seasonal rainfall			
			NV	LMC	B	BC
Masika 1994	381.1	8	4.3	1.2	6.2	10.3
		3	3.8	0.7	5.0	7.8
Vuli 1994/95	328.6	8	11.2	3.5	22.9	22.0
		3	8.8	1.2	17.6	23.3
Masika 1995	509.6	8	5.9	4.3	17.3	24.8
		3	7.2	5.8	19.2	29.7
Vuli 1995/96	211.0	8	2.4	4.9	19.7	33.8
		3	3.8	7.5	14.1	28.1

The runoff data for Kisangara site is summarized in Table 10. It can be seem that the 8% slope plots generally produced higher runoff (%) except during Masika 1995 when the seasonal rainfall amount was very high. This is consistent to the observation made on the basis of Morogoro data. Similarly, the effect of vegetation/cultivators is clearly seen where the % from the NV and LMC treatments varied between 0.7 - 8.8% as compared to the range for B and BC treatments, which was 5-34%.

The importance of the amount of rainfall is shown by the fact that, % runoff was high (2.4 - 33.8%) during the seasons with the lowest and the highest rainfall amount as compared to the average rainfall (0.7 - 23.3%) (Figure 22).

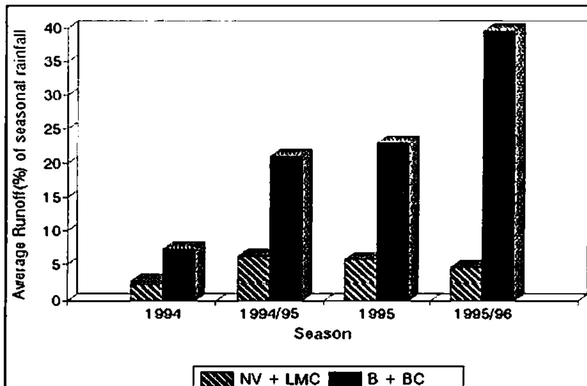


Figure 22 Surface treatment and seasonal effect on run-off generation

On average during years of very low rainfall. It is possible to obtain runoff of 20 % of the seasonal rainfall. This is important because it means RWH with CBAR of 2:1 will lead to higher effective rainfall on the cropped area of 1.4 times the direct rainfall. For example, the 211 mm seasonal rainfall received during Vuli 95/96 enabled the cropped area in a 2:1 arrangement to receive 295 mm of effective rainfall. This may lead to significant improvement to crop performance.

However, the dependence of run-off amount on the bareness of the land indicate a risk of catchment degradation. It is necessary therefore, to explore further the threshold vegetation cover which will allow adequate run-off yield without excessive erosion.

4.3. Performance of Runoff Farming

4.3.1 Treatment Effects on Yield

Grain was harvested in 5 out of 6 seasons in Kisangara (viz. Masika 1993, Masika 1994, Vuli 1994/95, Masika 1995 and Vuli 1995/96) and 2 out of 4 seasons in Morogoro (viz. Masika 1993 and Masika 1994). Effects of runoff farming on yield at Morogoro site are shown in Table 11. Effects of runoff farming and soil-water conservation tillage on yield at Kisangara site are shown in Table 11 and Figure 24.

4.3.1.1 Masika seasons

At Morogoro, the highest biomass yield (11950 kg/ha) in Masika 1993 was obtained from 4:1 treatment whereas in Masika 1994 the highest biomass yield came from the 2:1 treatment. In terms of grain yield, there were no significant differences between treatments in both Masika season, with the overall mean yields being 4057.9 and 4805.9 kg/ha for 1993 and 1994, respectively.

At Kisangara, the highest biomass yield (7457 kg/ha) was recorded in 1993 for the 2:1 treatment. The 4:1 treatment recorded highest biomass yields of 9,478 and 11384 kg/ha in 1994 and 1995, respectively, at 8% slope. The 4:1 and 2:1 treatments produced the highest biomass yields in 1994 and 1995, respectively, at 3% slope. There were no significant differences in biomass yield between soil-water conservation tillage treatments at 8% slope (Table 12a). The highest significant grain yields for 2:1, 4:1 and 2:1 treatments were 2173, 4226 and

3872 kg/ha, respectively for 1993, 1994 and 1995 at 8% slope. Similar results were recorded at 3% slope. There were no significant differences in grain yield between soil-water conservation tillage treatments in 1993. In 1994 and 1995, however, CR (3113 kg/ha) and SB (3947 kg/ha) recorded the highest significant yields, respectively (Table 12 b). High significant yields, in these and above mentioned treatments are due to heavier grains as shown by the 100 seed weight (Table 12c).

4.3.1.2 Vuli seasons

At Morogoro, only biomass was harvested during 1993/94 and 1994/95 due to prolonged drought. The highest biomass yield was recorded from the 2:1 treatment in both seasons (Table 11). There were, however, no significant differences in biomass yield between treatments and slopes.

At Kisangara, the highest biomass yields were recorded for the 4:1 (4093 kg/ha), 2:1 (4540 kg/ha) and 4:1 (5142.3 kg/ha) treatments in 1993/94, 1994/95 and 1995/96, respectively,at 8% slope. Similar results were observed at 3% slope (Table 12a). Except for the ZT treatment which generally recorded the lowest yields, there were no significant differences in biomass yield between the other soil-water conservation tillage treatments. No grain yield was recorded in 1993/94 season due to prolonged drought. The 2:1 and 4:1 treatments recorded 1247 and 1730 kg/ha during 1994/95 and 1995/96 seasons, respectively. These were the highest significant grain yields at 8% slope. A similar trend was observed at 3% slope. As for the soil-water conservation tillage experiments, no significant differences between treatments were observed. The very significant grain yields from 2:1 and 4:1 treatments were attributed to high 100 seed weight (Table 11c).

4.3.2 Seasonal Effects on Yields

At Morogoro, runoff farming could not induce the production of maize grains for two Vuli seasons (viz. 1993/94 and 1994/95). This may partly be explained by the general characteristic of Vuli rains, which tend to fall towards the end of the season. Runoff farming works better when there is runoff generating rainfall at the beginning of the rainy season. There are no conspicuous differences in grain yield between treatments when the 1993 and 1994 Masika seasons are compared. The overall mean grain yields, for instance, were 4057.9 and 4805.9 kg/ha for 1993 and 1994, respectively. This is because Masika rainfall at Morogoro is adequate in amount and distribution.

At Kisangara, average maize grain yields are markedly higher in Masika seasons than in Vuli (Table 11d)The importance of runoff farming is verified during Vuli seasons (of unreliable rainfall regimes) by enabling a crop to grow until grain harvest. For each Vuli season of 1994/95 and 1995/96, a crop of maize was harvested at Kisangara. Compared with Morogoro, there is runoff generating rainfall at the beginning of the rainy season at Kisangara.

Grain yield results show that the optimum CA:BA ratio is 2:1, as very little yield increase is achieved by increasing this ratio to 4:1. At Kisangara, for example, the average grain yields for 2:1 and 4:1 were 2818.5 and 4023 kg/ha in Masika 1994 and 3320 and 3250.5 kg/ha in Masika 1995, respectively at 8% slope. Respective values for Vuli seasons were 903 and 1033 kg/ha in 1995/96 (Figure 23). In some instances, as shown by grain yield values for Masika 1995, there was a reduction in yield mainly due to water logging occurring after each rainfall event. Similar results have been found in Hombolo (Hatibu et al., 1995). The importance of RWH intervention during Vuli is substantiated by results of 30 year simulations reported by Gowing and Young (1996) for conditions typical of Kisangara and neighbouring areas. These results show that there is little overall increase in Masika yield due to RWH, whereas the introduction of RWH causes increased variance in Vuli season yields and a significant overall increase.

4.3.3 Site Effect on Yield

The two sites (viz. Morogoro and Kisangara) are significantly different during Vuli seasons. Morogoro site has very poor Vuli seasons (as earlier illustrated by its complete failure to produce a grain crop during 1993/94 and 1994/95 seasons) compared to Kisangara site. During Masika, the performance of the Morogoro site was better than that of Kisangara. The average maize grain yields (of the runoff farming experiment) for Masika 1993 and 1994 seasons were 1544 and 3211 kg/ha (Kisangara) and 4134 and 4635.1 kg/ha (Morogoro), respectively, at 8% slope (Tables 11, 12 b).

Table 11 Effects of runoff farming on yield for Morogoro site

Slope	Treatment		Total biomass at harvest				Grain weight (kg/ha)		100 seed weight (g)	
	CA:BA ratio	BA Surface	Masika 93	Vuli[1] 93/94	Masika 1994	Vuli 1994/95[2]	Masika 1993	Vuli 1993/94	Masika 1993	Masika 1994
3%	0:1	FC SR	10324.2 9752.6	224.7 571.1	7777.8 6746.0	239.5 315.4	4529.9 3958.3	5634.9 4831.3	38.93 36.50	38.00 34.17
	1:1	FC SR	- -	273.9 561.7	8313.5 8571.4	339.3 342.0	- -	5476.2 5654.8	- -	36.33 35.00
	2:1	FC SR	9416.3 9329.4	879.6 936.7	9027.8 12599. 2	837.4 413.5	3915.0 3893.2	5039.7 5218.3	35.30 32.90	31.67 35.33
	4:1	FC SR	11785.6 8504.6	369.1 162.2	7025.8 5754.0	131.3 62.1	4136.1 3459.0	4543.7 3415.0	36.00 31.00	31.17 24.00
	Mean		9852.2	439.6	8226.9	341.8	3981.9	4976.7	35.10	33.20
6%	0:1	FC SR	10803.1 9835.2	142.7 377.9	6150.8 6904.8	354.9 348.0	4129.9 4236.3	4285.7 3888.9	36.40 35.80	32.67 30.57
	1:1	FC SR	- -	324.4 583.8	6329.4 8839.3	377.5 386.4	- -	4484.1 5138.9	- -	34.17 35.67
	2:1	FC SR	9758.7 9159.5	2329. 3 856.8	8115.1 6467.1	373.7 381.3	3736.6 4341.8	5357.1 5138.9	34.67 36.13	32.33 31.50
	4:1	FC SR	11950.8 10536.2	167.3 146.6	7440.5 5714.3	263.3 148.7	4366.2 3993.2	5079.4 3708.3	34.77 35.30	35.83 23.66
	Mean		10340.6	576.9	6995.2	329.2	4134.0	4635.1	35.50	32.15
	Overall mean		10,098. 9	508.2	7,611. 0	335.5	4057.9	4805.9	35.30	32.10

1 Biomass harvested 15/2/94, 65 days after emergence
2 Biomass harvested 13/2/95, 96 days after emergence.

Table 12 (a): Efects of runoff farming and soil- water conservation tillage on biomass yield at Kisangara

Experiment and slope	Treatment		Biomass yield at harvest (kg/ha)					
	CA:BA ratio	Tillage	Masika 1993	Vuli 1993/94	Masika 1994	Vuli 1994/95	Msika 1995	Vuli 1995/96
8% Runoff farming	0:1	FC	3593.0	1650.0	7303.6	3920.0	10730.0	3047.4
		SR	6000.0	1790.0	6242.1	1436.0	10090.2	1448.3
	1:1	FC	-	1926.0	7718.3	3975.0	11570.0	2137.8
		SR	-	2461.3	7285.7	3850.0	9340.8	3127.3
	2:1	FC	7457.0	3885.3	6649.6	4540.0	9190.4	1763.6
		SR	5665.0	3254.0	6958.3	3900.0	9160.8	3358.1
	4:1	FC	5135.0	4093.0	9158.7	4050.0	7520.0	2952.2
		FC	5059.0	3618.7	9748.0	4191.0	11380.4	5142.3
	Average		5034.8	2834.8	7633.0	4098.3	9870.6	2872.0
3% Runoff farming	0:1	FC	-	388.2	6798.2	3480.0	10170.9	1280.2
		SR	-	252.8	5532.1	2780.0	7980.8	1422.7
	2:1	FC	-	715.3	5988.1	3153.0	8460.1	2661.5
		SR	-	260.4	6222.0	2920.0	11000.0	743.0
	4:1	FC	-	1121.5	8254.8	2893.0	9080.1	2841.3
		SR	-	461.8	6958.3	2600.0	10330.5	2413.7
	Average			533.3	6625.0	2971.0	9500.7	1893.7
8% Conservation tillage		ZT	1401.0	300.0	3979.6	2093.0	6230.2	1123.2
		FC	3332.0	270.6	4180.0	3063.5	12580.1	1928.6
		CR	3296.0	330.6	5953.4	2688.5	12980.6	2126.7
		SB	3429.0	258.6	5336.6	2723.0	11730.6	1651.3
		LB	3206.0	228.6	4550.5	1950.0	11940.9	862.0
	Average		2932.8	277.7	4799.9	2503.6	11090.7	1538.4

1. Biomass haversted 102 days after plating due to drought

Table 12 (a): Effect of runoff farming and soil-water conservation tillage on grain yield of maize at Kisangara

Experiment treatment			Grain yield (Kg/ha)				
Slope	CA:BA ratio	Tillage	Masika 1993	Masika 1994	Vuli 1994/95	Masika 1995	Vuli 1995/96
8% Runoff farming	0:1	FC	1761ab	2784bc	507c	3122b	137d
		SR	1047d	2675bc	597bc	2965b	297cd
	1:1	FC	-	3518abc	613bc	3437ab	380bcd
		SR	-	3030abc	683bc	2965b	547abcd
	2:1	FC	2173a	2417c	1247a	3872a	1673ab
		SR	1359bcd	3220abc	571bc	3203b	1160abcd
	4:1	FC	1599bc	3820ab	963abc	3197b	1730a
		SR	1223cd	4226a	1103ab	3304b	1467abc
		AVERAGE	1544	3211	787	3241	924
3% Runoff farming	0:1	FC		2822ab	668abc	2764b	133b
		SR		2188b	553bc	2953ab	191ab
	2:1	FC		2920ab	962a	3120a	436ab
		SR		2204b	423c	3096a	310ab
	4:1	FC		3519a	847ab	2879ab	507a
		SR		2901ab	780abc	3027ab	364ab
		AVERAGE		2759	700	2956	324
8% Conservation tillage		ZT	187de	1287cde	683de	2567bc	70e
		FC	559de	1756bcd	430de	2747bc	120e
		CR	712de	3113a	560de	3427ab	200e
		SB	650de	2797ab	405de	3947a	210e
		LB	679de	2377abc	448de	3420ab	120e
		AVERAGE	558	2378	505	3221.3	144

Grain yield followed by the same letters are not significantly different at 5% probability by DMRT.

Table 12 (a) Effect of runoff farming and soil-water conservation tillage on 100 seed weight at Kisangara

Experiment and slope	Treatment		100 seed weight (g)				
	CA:BA ratio	Tillage	Masika 1993	Masika 1994	Vuli 1994/95	Masika 1995	Vuli 1995/96
8% Runoff farming	0:1	FC	26.06	22.63		10.6	17.4
		SR	24.52	24.03		9.3	11.4
	1:1	FC	-	23.41		9.5	10.0
		SR	-	27.70		9.9	9.5
	2:1	FC	26.06	27.93		11.4	21.4
		SR	23.38	25.23		10.4	20.9
	4:1	FC	24.90	30.26		10.6	21.3
		FC	24.85	31.73		10.5	23.0
	Average		24.96	26.62		10.3	16.9
3% Runoff farming	0:1	FC	-	26.53	18.18	8.9	8.9
		SR	-	28.32	19.44	10.5	11.4
	2:1	FC	-	19.36	18.00	10.1	20.3
		SR	-	25.62	18.65	7.4	8.0
	4:1	FC	-	32.97	17.66	19.3	19.9
		SR	-	30.95	20.39	10.6	16.0
	Average		-	27.29	18.72	23.1	14.1
8% Conservation tillage		ZT	20.12	19.80		13.1	12.5
		FC	20.56	24.90		19.2	21.0
		CR	22.78	24.80		20.4	31.5
		SB	21.78	24.80		15.7	22.4
		LB	21.32	23.30		14.3	16.7
	Average		21.31	23.52		16.54	20.82

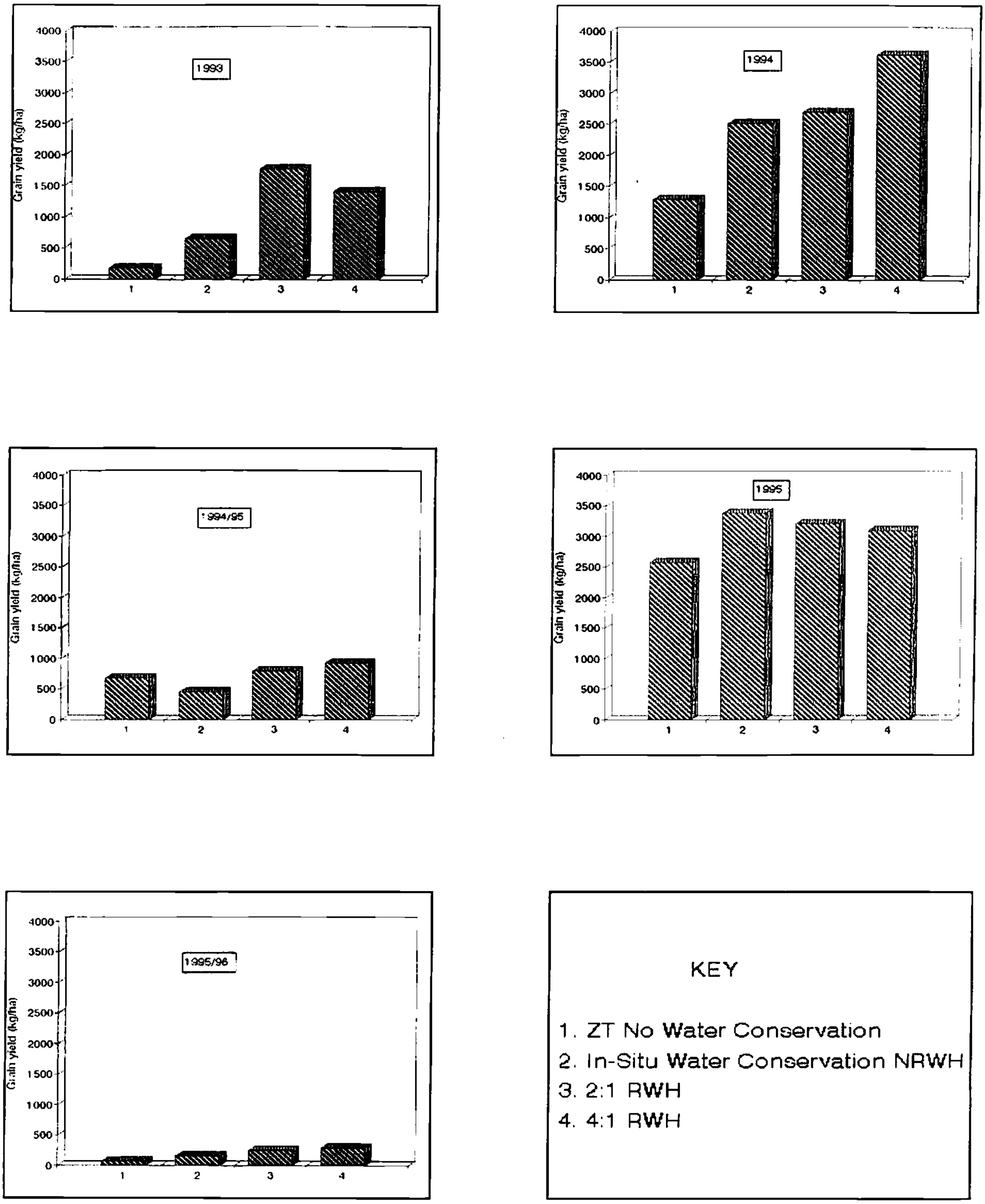


Figure 23. Treatment and Seasonal Effect on grain yields

4.4 Model Simulation and Performance

The run-off model was shown to predict the daily runoff well, with most of the values of R^2 above 0.5. The prediction improved when made on seasonal basis, where R^2 become 0.85 [Gowing & Young, 1996].

The model enabled a simulation of Kisangara crops over 30 years. The benefits were shown to be optimum with CBAR of 2:1 (i.e 1/3 of the field planted). Further, the simulation showed that RWH gives larger impact during Vuli compared to Masika (Figure 24).

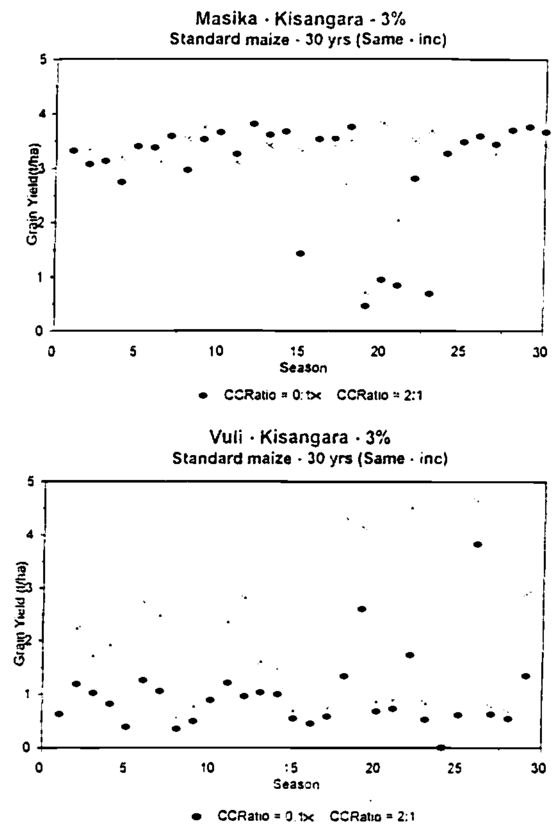


Figure 24: Typical simulation results for 30 years (After Gowing and Young, 1996)

The model was tested by potential users at a workshop conducted in Morogoro towards the end of 1996. The performance was found to be encouraging but several shortfalls were noted. However, the major ones were found to be with PARCH rather than THIRST. For example, it was found out that PARCH uses sorghum 'cultivar' parameters instead of maize. Further, Leaf Area Index was found to reach maximum too early in the model. Therefore, there is a need for up-dating relevant parameter files so as to improve the performance of the model. The runoff model was found to have problems associated to inconsistencies in the rainfall-runoff data. Furthermore, the model was negatively affected by low performance of Pedotransfer Functions.

5. CONCLUSIONS

5.1 Findings

1. The main characteristics of the climate of the study area are:

   - low seasonal rainfall amount which for vuli seasons is less than seasonal crop-water requirement for maize;
   - low intensity storms which are interspaced with long dry spells;
   - high potential evapotranspiration rates.

2. In general the run-off generation in the study area is controlled by rainfall characteristics. However, treatment of the catchment by clearing and compacting significantly increased run-off yield coefficient. Therefore, to optimise run-off yield generation there is need to treat the catchment.

3. In Kisangara run-off farming is technically feasible during both Vuli and Masika.

   i) During Vuli, run-off farming significantly (P=0.05) increased grain yield by 775 kg/ha on the 8% slope. The increase on the 3% slope was 147kg/ha and significant at P = 0.05.

   ii) During Masika, run-off farming significantly (P=0.05) increased grain yield by between 153-183 kg/ha.

   iii) The CBAR of 2:1 was found to be optimum under most conditions.

5.2 Contribution to Science

Through the conduct of research, this project has contributed to science as follows:

- Analysis of long-term historical weather records has facilitated the characterization of climate in the study area (viz. amount of rainfall in Masika and Vuli seasons, length and occurrence of dry spells, start and end dates of rains, etc) which is being used for agricultural planning in Mwanga district and other areas with similar semi-arid conditions.

- A better understanding of the rainfall-runoff relationship has highlighted the need to optimize runoff yield generation by treating the catchment (to some extent) due to the low runoff yielding capacity of rainfall.
- There is found to be little overall increase in Masika grain yield due to RWH, whereas the introduction of RWH causes increased grain yield in Vuli season.

- Publications produced include:

i) Hatibu, N., H.F. Mahoo, B. Kayombo, D. Ussiri & P. Lameck (1996). Effects of Micro-Catchment Rain Water harvesting on Growth and Yield of Maize in Semi-Arid Areas of Morogoro and Kilimanjaro Regions. Proceedings of University of Dar es Salaam Workshop on Research on Sustainable Agriculture in Semi-arid Tanzania, 1995: (In press)

ii) Hatibu, N., & H.F. Mahoo (1996). Performance of supplementary irrigation using harvested rain water. Proceedings of National Rainwater Harvesting Workshop, Dodoma. pp: 26-28.

iii) Kamugisha, S.S & N. Hatibu (1996). Simulation of the effect of rain water harvesting on soil water content and crop growth in semi-arid Tanzania. In: Mattee A.Z.et al. (eds): Meeting the Farmers' Needs Through Agricultural Research: Proceedings of the 1st Faculty of Agriculture Research Conference, Morogoro): 286-303.

iv) Luswema, S.P & N. Hatibu (1996). Performance evaluation of rainwater harvesting and storage for supplementary irrigation. In: Mattee A.Z.et al. (eds): Meeting the Farmers' Needs Through Agricultural Research: Proceedings of the 1st Faculty of Agriculture Research Conference, Morogoro): 270-285.

v) Hatibu, N., H.F. Mahoo, E.M. Senkondo, T.E. Simalenga, B. Kayombo, & D. Ussiri (1994). Strategies for soil-water management for dryland crop production in Tanzania. Proceedings of TSAE Vol. 6: 83-97

vi) Lameck P.G.M., N. Hatibu & B. Kayombo, D.A.N. Ussiri (1994). Effect of rain water harvesting on sorghum and maize yield in semi-arid Tanzania. Proceedings of TSAE Vol. 6: 98-107

vii) Mahoo, H., Gowing, J.W., Hatibu, N., Kayombo, B., Ussiri, D.A.N., Wyseure, G.C.L. and Young M.D.B., 1994. Rainfall-runoff model for rainwater harvesting design in Tanzania. Proceedings of 5th Annual Scientific Conference, SADC-Land and Water Managment Research Programme.pp. 105-118.

viii) Hatibu, N., H.F. Mahoo, E.M. Senkondo, T.E. Simalenga, B. Kayombo, & D. Ussiri (1994). Strategies for soil-water management for dryland crop production in Tanzania. In: Craswell, E.T. & J. Simpson (eds): Soil Fertility and Climatic Constraints in Dryland Agriculture. Proceedings of ACIAR/SACCAR Workshop. pp 32-38.

ix) Gowing, J.W., N. Hatibu, C.G.L. Wyseure, and M.D.B. Young, 1994. Local solutions to irrigation needs in semi-arid Africa. The agricultural Engineer-Journal and Proceedings, 49(4): 20-21. Institution of Agricultural Engineers.

x) Gowing, J.W., N. Hatibu, H.F. Mahoo, G.C.L. and M.D.B. Young D.A.N. Ussiri 1996. Sustainable systems for rain water harvesting in semi-arid Tanzania: a simulation approach. Agricultural Systems (in preparation).

5.3 Contribution to Development

Rain water harvesting for crop production is a priority issue in Tanzania and the Ministry of Agriculture has identified it as Priority 1 problem. In the National Agricultural Research Programme for the next 5 years, it is stated that:

> "The major goal of water management research is therefore to develop appropriate technologies aimed at efficient utilization of available water..."

It is further stated that:

> "Research in water harvesting will be conducted by Sokoine University of Agriculture"
>
> (MoA, 1996)

Therefore, the project has contributed to SUA's recognition as a national centre for research in Rain Water Harvesting.

The project has also contributed to increased awareness among farmers and policy makers in the semi-arid areas. In Mwanga district, for example, whereas previously rain water runoff was considered a hazard, it is now recognized as a potential valuable resource.

At national level, the results have contributed to policy making and to the on-going development of a national rain water harvesting programme which is under preparation with assistance of UNDP.

5.4 Recommendations for Further Work

Two research projects have already been designed to follow-up the results of this project. These have already started and are:

- The Project Titled "Development of improved rainfed cropping system incorporating rain water harvesting/conservation" will seek to develop a decision-support tool for design, implementation and management of RWH agrosystems. It will evaluate the transferability of the model which will be extended to allow simulation of external catchment water harvesting systems. Evaluation of factors influencing uptake of RWH amongst farmers will help identify the non-technical factors necessary for the development of a decision-support tool.

- The Project Titled "Combining systematic and participatory approaches for developing and promoting strategies for sustainable land and water management" has been started with funding from European Commission

DGXII. Through research collaboration between two European Universities and two in East Africa, improved methodologies for promoting sustainable improvement of soil-water management practices in semi-arid regions, will be developed.

REFERENCES

ADIS, 1992. Review of Agricultural Production Systems in Tanzania. Food Studies Group. University of Oxford.

Allnutt, R.B. 1942. Rice growing in dry areas. East Africa Agriculture and Forestry Journal Vol. 8 (2).

Boers, Th.M. and J. Ben-Asher 1982. A review of rain water harvesting. In: Agric. Water Management 5: 145-158.

Critchley, W.R.S. and Reij, C. 1989. Water Harvesting for Plant Production: Part 2, Case Studies and Conclusions from Sub-Sahara Africa (Draft)

Elwell, H.A. and M.A. Stocking 1976. Vegetal Cover to Estimate Soil Erosion Hazard in Rhodesia. Geoderma 15: 61-70.

Evenari, M., Shanan, L. and Tadmor, N.H. 1971. The Negev, the Challenge of a Desert. Havard University Press. Cambridge, Mass.

Gommes, R.A. and M. Houssiau, 1992. Rainfall variability, types of growing seasons and cerial yields in Tanzania. Proc. of Tech. Conf. on climate in Africa. WMO/OMM publication No. 596: 312 - 324.

Gowing, J.W. and M.D.B. Young 1996. Evaluation and Promotion of Rain Water Harvesting in Semi-Arid Areas. Final Technical Report 84 pp.

Harris, D., G.J. Fry, S.T. Miller and A. Pain 1992. Crop Production Rainfall, Runoff and Availability of Soil Moisture in Semi-Arid Botswana. 140pp.

Hatibu, N., H.F.Mahoo, B. Kayombo, E.M.Senkondo, D. Mwaseba and D.A. Ussiri 1993b. Evaluation and Promotion of rain water harvesting in semiarid areas of Tanzania Research Project. First interim Technical Report. SUA. 46 pp.

Hatibu. N., H, Mahoo., B. Kayombo., and D.A.N. Ussiri 1995a. Evaluation and Promotion of RWH in Semi-Arid Areas of Tanzania. 2nd Interim Technical Report. 79pp.

Hatibu, N., H.F.Mahoo, B. Kayombo, E. Mbiha, E.M.Senkondo, D. Mwaseba and D.A. Ussiri 1995b. Soil Water Management in Semi-arid Tanzania Research Project. Final Technical Report. SUA. 87 pp.

Hatibu, N., Kayombo, B., Mahoo, H., Ellis-Jones, J., Senkondo, E.M. and Simalenga T.E., 1993a. Rapid Rural Appraisal of Mwanga District. Evaluation and promotion of RWH in semi-arid Tanzania. SUA 52 pp.

Hatibu, N., and N.A. Mtenga, 1996. Small holder Technological Constraints in Shinyanga District, Tanzania: The Case of Bulambila Village. Participatory Base line Study. 101 pp.

Hudson, N.W. 1987. Soil and Water Conservation in Semi-Arid Areas. FAO Soils Bulletin 57. FOA, Rome. 172 pp.

Kaaya, A.K. 1989. Soil survey and land evaluation of the central part of Sokoine University of Agriculture Farm for rainfed crops. Unpubl. MSc. Dissertation Sokoine University of Agriculture.

Kanyeka Z.L., S.W.Msomba, A.N. Kihupi and M.S.Penza 1994. Rice Ecosystems in Tanzania, Characterization and Classification. Tanzania Agricultural Research and Training Newsletter Vol. 9 (1-2):13-15pp.

Klute, A., 1986. Methods of Soil Analysis, Part 1. Second Edition, ASA/SSSA, Madison, Wisc.

Land Resources Development Centre (LRDC), 1987. Tanzania: Profile of Agricultural Potential. 26 pp.

Mahoo, H.F., F. Rwehumbiza, S. Reuben, B. Kayombo, N. Hatibu, P.J. Makungu and G. Ashimogo, 1996. Rapid Rural Applisal Mpwapwa District. 21pp.

Ministry of Agriculture (MoA), 1991. National Agricultural and Livestock Research Masterplan 44pp.

Ministry of Agriculture (MoA), 1993. 1992/93 Industry review of maize, rice and wheat. 41pp.

Ministry of Agriculture (MoA), 1994. National irrigation development plan. 103pp.

Ministry of Agriculture, (MoA) 1996. National Agricultural Research Programme. NARP II. Draft Proposal. 84pp.

Mwakalila, S.S. and N Hatibu 1992. Rain Water Harvesting for Crop Production in Tanzania. Proceedings of the third annual scientific conference. SADC-Land & water Management Research Programme. pp.513 - 525

Myers, L.E. 1975. Water harvesting 2000 B.C to 1974 A.D. In: Proc. Water Harvesting Symp., Phoenix, A.Z, ARS W-zz, USDA, pp 1-7.

Othieno, C.O. and Laycock, D.H. 1977. Factors Affecting Soil Erosion within Tea Fields. Tropical Agriculture, 54:323-330.

Pacey, A. and Cullis, A. 1986. Rain Water harvesting; the Collection of Rainfall and Runoff in Rural Areas. It Publications, London, UK.

Rapp, A., L. Berry, and P. Temple (Eds). 1972. Studies of soil erosion and sedimentation in Tanzania. Geografiska Annaler 54. A(3-4): 105-379.

Seliani Agricultural Research Institute (SARI) 1995. Report on soils of Rainwater Harvesting experimental Site at Kisangara. 28pp.

Silva, G.L. 1989. Potential for Improving Rice Production in Tabora Region, Tanzania and Implications for Village Planning. ODNRI, 58 pp.

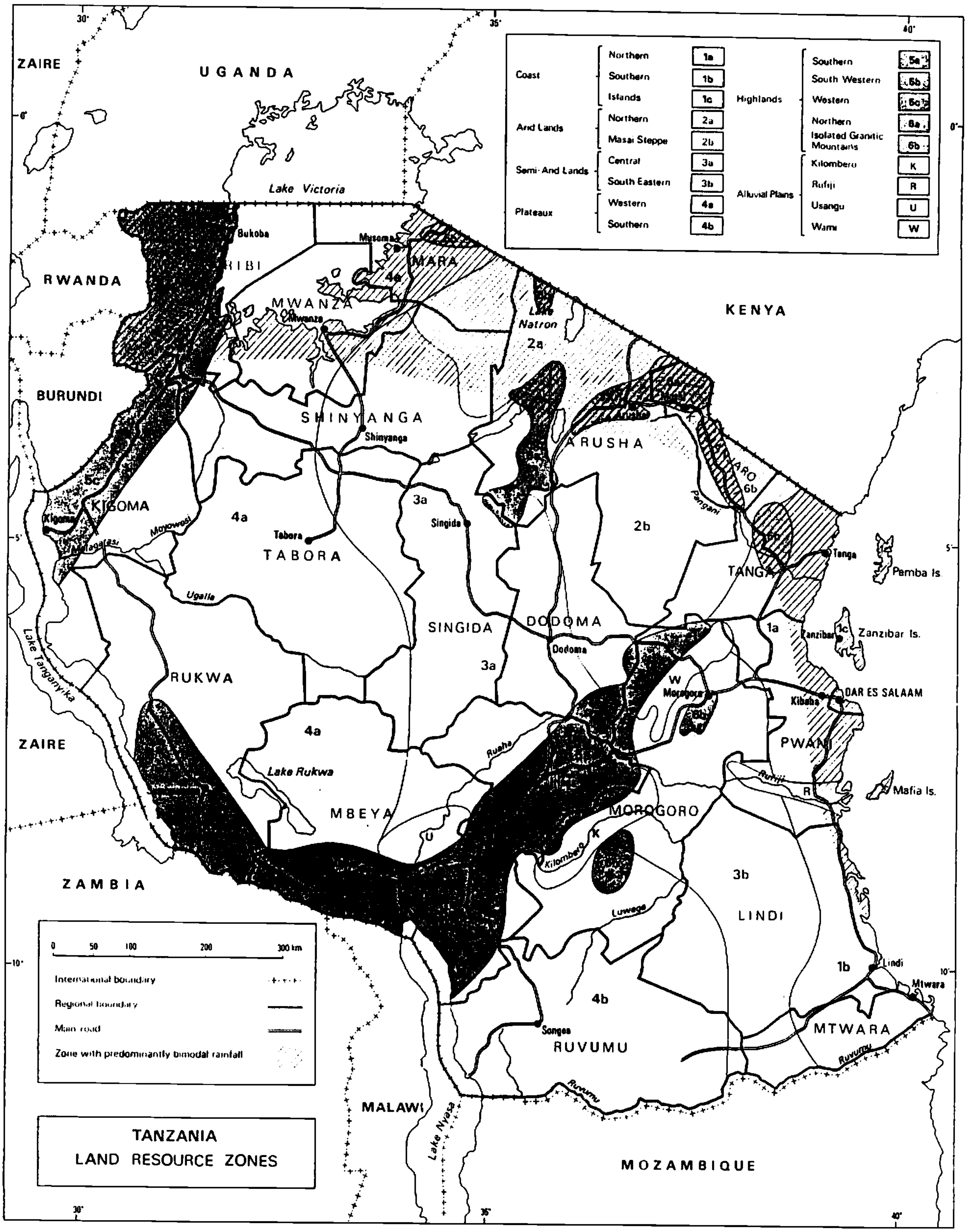
Snyman, H.A., W.L.J. Van Rensburg and D.P.J. Opperman, 1985. Soil loss and runoff measurements from natural veld with a rainfall simulator. Journal of the Grassland Society of Southern Africa 2:35-40.

Soil-water management research Programme (SWMRP) 1993a. Bibliography of the literature related to Rain water harvesting in Tanzania. SUA

Soil-Water Management Research Programme (SWMRP) 1993b. Field and laboratory manual. Sokoine University of Agriculture

Zaunderer, J. and Hutchinson, C.F. 1988. A Review of Water Harvesting Techniques of the Arid Southwestern US and North Mexico. (Draft) Working Paper for the World Bank's Sub-Sahara Water Harvesting Study.

Map 1: Tanzania, Agrogeological Zones



APPENDIX 1: MONTHLY SEASONAL RAINFALL FOR MOROGORO AND KISANGARA

(a) Vuli monthly and seasonal rainfall for Morogoro [24 years]

Year	August	September	October	November	December	January	Seasonal rainfall
1993/94	3.2	2.1	45.8	37.4	0.8	54.0	143.3
1974/75	3.6	4.4	25.0	1.4	9.5	104.1	148.0
1971/72	0.0	3.7	6.0	3.7	34.5	109.3	157.2
1987/88	8.5	0.0	43.8	36.0	28.9	93.6	210.8
1973/74	8.9	3.5	18.1	48.3	125.5	26.6	230.9
1991/92	2.9	9.6	6.7	17.7	183.8	13.4	234.1
1984/85	4.1	5.6	30.5	127.4	56.2	10.8	234.6
1976/77	3.9	28.9	7.5	7.4	61.6	136.6	245.9
1975/76	0.4	11.1	21.7	29.7	78.3	106.4	247.6
1981/82	11.8	10.7	37.5	51.3	96.8	40.0	248.1
1992/93	0.1	1.5	0.0	117.0	111.0	31.5	261.1
1985/86	9.6	0.8	13.7	59.1	44.3	134.6	262.1
1994/95	18.7	5.6	26.0	43.5	49.2	142.2	285.2
1980/81	16.1	0.3	23.9	77.9	151.9	42.5	312.6
1989/90	6.8	0.4	70.9	85.5	102.5	83.6	349.7
1990/91	7.0	30.5	6.8	158.8	67.8	85.0	355.9
1979/80	0.8	6.5	29.7	40.3	167.4	115.3	360.0
1983/84	3.2	10.5	10.0	11.5	147.8	186.1	369.1
1986/87	6.7	1.2	37.6	175.7	156.2	108.1	485.5
1977/78	9.4	22.9	50.3	45.0	167.2	212.1	506.9
1982/83	11.5	13.9	105.0	110.0	262.4	14.4	517.2
1988/89	17.6	33.4	27.5	51.7	170.1	229.0	529.3
1978/79	31.2	5.1	5.0	173.6	255.7	100.1	570.7
1972/73	14.2	22.8	83.0	71.3	107.2	287.7	586.2

(b) Masika monthly and seasonal rainfall for Morogoro

Year	Feb	March	April	May	June	July	Total seasonal rainfall
1982/83	4.4	66.1	97.2	68.4	39.3	61.1	336.5
1988/89	33.7	191.0	87.1	12.7	44.8	0.0	369.3
1991/92	0.7	74.5	201.8	66.1	2.9	26.6	372.6
1976/77	22.3	118.6	156.7	40.1	51.4	7.5	396.6
1971/72	35.0	63.8	226.7	55.4	36.5	7.4	424.8
1980/81	70.5	80.2	205.3	94.9	0.0	5.4	456.3
1983/84	57.0	106.5	113.8	132.5	24.3	34.2	468.3
1992/93	45.5	85.0	240.3	86.9	21.9	4.7	484.3
1973/74	85.7	41.2	291.0	61.3	14.7	9.6	503.5
1987/88	74.9	183.7	108.2	132.7	0.0	4.0	503.5
1994/95	134.6	80.1	168.8	88.2	8.2	37.0	516.9
1974/75	12.3	90.5	278.8	102.9	22.5	14.3	521.3
1978/79	62.0	203.8	191.9	37.0	12.1	15.0	521.8
1986/87	70.1	146.5	142.7	157.7	11.4	2.3	530.7
1989/90	7.2	146.4	250.4	112.7	11.7	3.9	532.3
1985/86	158.7	107.1	135.4	118.3	1.3	16.7	537.5
1975/76	38.0	163.3	197.7	102.7	25.2	16.7	543.6
1984/85	101.4	111.0	287.6	63.2	21.9	6.5	591.6
1977/78	218.5	151.9	123.3	84.0	2.9	23.7	604.3
1981/82	39.7	184.7	222.7	130.6	16.7	12.1	606.5
1972/73	115.4	177.0	165.9	152.8	0.0	26.1	637.2
1990/91	187.3	229.1	193.6	56.8	10.2	8.2	685.2
1993/94	167.2	117.8	296.4	100.8	12.7	5.4	700.3
1979/80	257.9	177.1	188.0	84.0	41.4	8.4	756.8

(c) Vuli monthly and seasonal rainfall (mm) for Kisangara Sisal Estate

Year	Aug	Sept	Oct	Nov	Dec	Jan	Total seasonal rainfall
1989/90	0.0	0.0	16.1	68.7	0.0	36.5	121.3
1966/67	1.0	0.0	6.0	33.0	54.0	43.5	137.5
1974/75	0.0	0.0	3.0	79.0	38.0	18.0	138.0
1975/76	0.0	32.0	0.0	83.0	0.0	34.0	149.0
1976/77	0.0	27.0	0.0	77.0	13.0	37.0	154.0
1992/93	0.0	0.0	31.1	101.6	89.6	0.0	222.3
1983/84	0.0	0.0	9.0	41.0	174.5	0.0	224.5
1968/69	2.0	6.6	11.0	96.0	123.0	0.0	238.6
1965/66	0.0	8.0	42.0	54.0	116.0	37.0	257.0
1964/65	2.0	33.0	8.0	61.0	129.0	26.0	259.0
1970/71	0.0	11.0	0.0	81.0	34.9	144.0	270.9
1987/88	25.2	0.0	0.0	122.0	100.9	37.2	285.3
1990/91	1.9	0.0	31.8	148.5	89.6	25.4	297.2
1971/72	0.0	3.0	7.0	58.5	147.5	95.0	311.0
1967/68	15.0	55.0	63.0	156.0	31.0	0.0	320.0
1969/70	17.0	3.0	86.0	166.0	26.0	26.0	324.0
1962/63	0.0	0.0	27.2	78.0	108.5	114.3	328.0
1994/95	0.0	0.0	18.5	51.1	246.0	14.0	329.6
1972/73	14.0	17.0	70.0	163.0	52.0	16.0	332.0
1973/74	8.0	0.0	7.	193.0	11.0	115.0	334.0
1991/92	15.3	10.4	32.1	96.7	164.7	17.8	337.0
1993/94	0.0	0.0	45.4	18.7	90.8	199.9	354.8
1985/86	0.0	7.0	83.2	237.7	57.4	0.0	385.3
1979/80	0.0	0.0	20.0	78.0	141.0	154.0	393.0
1981/82	4.0	0.0	51.0	148.0	117.0	101.0	421.0
1963/64	0.0	0.0	6.0	276.0	149.0	43.0	474.0
1986/87	0.0	0.0	37.5	141.0	89.6	211.8	479.9
1980/81	26.0	0.0	42.0	268.0	47.0	121.0	504.0
1982/83	5.0	29.0	169.0	296.0	28.0	0.0	527.0
1977/78	32.0	7.0	87.0	125.0	170.0	110.0	531.0
1988/89	0.0	7.6	0.0	162.5	181.1	196.7	547.9
1961/62	0.0	53.1	130.6	232.2	195.1	5.1	616.1
1984/85	0.0	9.3	26.0	286.2	217.0	141.5	680.0
1978/79	0.0	0.0	34.0	424.0	385.0	107.0	950.0

(d): Masika monthly and seasonal rainfall for Kisangara Sisal Estate

Year	Feb	March	April	May	June	July	Total seasonal rainfall
1961/62	35.1	45.5	70.4	3.6	0.0	9.1	163.7
1964/65	19.0	39.0	59.0	50.0	0.0	0.0	167.0
1974/75	11.0	28.0	79.0	52.0	0.0	14.0	184.0
1973/74	2.0	82.0	108.0	34.0	2.0	15.0	243.0
1960/61	62.2	39.1	102.9	30.0	2.0	27.7	263.9
1992/93	47.5	74.1	99.7	43.8	0.0	0.0	265.1
1988/89	5.1	25.4	206.6	36.3	0.0	0.0	273.4
1972/73	59.0	34.0	123.0	60.0	13.0	1.0	290.0
1983/84	25.0	79.3	152.0	12.0	25.0	11.0	304.3
1990/91	30.1	81.1	111.8	68.8	1.1	11.7	304.6
1968/69	38.0	77.0	177.0	25.0	1.0	0.0	318.0
1986/87	6.5	67.3	176.5	65.7	0.0	3.0	319.0
1984/85	161.3	60.3	31.7	83.6	0.0	5.0	341.9
1991/92	30.4	103.0	178.3	40.7	2.7	0.0	355.1
1975/76	89.0	84.0	122.0	51.0	14.0	5.0	365.0
1979/80	74.0	67.0	195.0	24.0	0.0	11.0	371.0
1993/94	66.0	189.6	36.5	88.0	1.0	0.0	381.1
1976/77	41.0	173.0	100.0	63.0	0.0	20.4	397.4
1965/66	44.0	139.0	140.0	77.0	7.0	0.0	407.0
1962/63	51.0	220.0	80.0	30.0	26.0	2.0	409.0
1987/88	18.9	245.4	154.7	0.0	0.0	0.0	419.0
1982/83	89.0	112.0	52.0	169.3	9.5	6.0	437.8
1963/64	65.0	153.0	211.0	20.0	1.0	0.0	450.0
1985/86	0.0	222.0	129.0	130.5	10.0	0.0	491.5
1966/67	22.0	93.0	262.0	96.0	2.0	27.0	502.0
1969/70	70.0	380.0	83.0	26.0	0.0	0.0	559.0
1989/90	39.0	227.6	281.1	25.6	0.0	1.1	574.4
1971/72	57.0	217.0	143.0	155.0	1.0	2.0	575.0
1981/82	15.0	148.0	248.0	144.0	47.0	33.0	635.0
1980/81	0.0	282.5	274.0	89.0	0.0	0.0	645.5
1970/71	2.0	356.0	356.0	53.0	17.0	3.0	787.0
1977/78	80.0	451.0	198.0	65.0	7.0	0.0	801.0
1967/68	63.0	413.0	355.0	77.0	32.0	2.0	942.0
1978/79	102.0	446.0	423.0	203.0	11.0	0.0	1185.0

APPENDIX 2: SOIL CHARACTERISTICS AT KISANGARA

Kisangara

Prior information on the soils at the site were not available and a survey was commissioned from Selian Agricultural Research Institute (Ngatoluwa *et al*, 1995). The fieldwork was conducted in October and November 1994. Seven soil pits were described and sampled for laboratory analysis. Locations were chosen to reflect the observed soil variations.

Soils are developed from weathered acid granulite and gneiss and are generally reddish sandy clay loams and sandy clays. Soil classification according to FAO-UNESCO soil taxonomy system indicates that the description is Ferric Luvisol. Fertility status is generally low and is influenced by topography with lowest nutrient levels in upper slopes.

Bulk density values vary from about 1.4 $mg.m^{-3}$ in topsoil to 1.6-1.7 $mg.m^{-3}$ in subsoil. Hydraulic conductivity values are 0.7-0.9 $m.day^{-1}$. Soil texture analyses are presented in Table 3.4. Detailed profile descriptions are as follows:-

Pit A
Soil classification
FAO: Niti Ferralic Cambisol
USDA: Oxic Ustropept

These soils have developed on weathered acid granulite gneiss bed rock materials that have been deposited at the base of escarpment. Such materials have been moved down slope by forces of gravity and surface runoff. These soils lack clay accumulation and exhibit little variation in clay content in the sub surface horizons and are classified as Cambisols.

The soils have generally the most coarse texture when in comparison with soils on lower slope positions (pit C & D). The soils are well to rapidly drained, fairly deep yellowish red in colour. Soil texture is sandy clay loam on the surface as well as on the underlying horizons. Soil fertility is low, the soils are acid in reaction with low base status and are likely to be deficient in phosphorous and nitrogen.

Pit B
Soil Classification
FAO: Acri Plinthic Luvisol
USDA: Oxic Rhodustalf

Acri Plinthic Luvisol are most extensive on the Northern part of the study area, covering nearly 10-15% of the whole area. They have developed on acid granulite gneiss bedrock with a thick plinthic layer. The soils are well drained, and moderately deep. They are uniformly coloured red to strongly brown, with very little colour horizonation. Soil texture at greater depths is clay loam with a sandy clay loam at the surface. The soils are somewhat coarse in texture with up to 49% sand content. As a consequence moisture holding capacity would also be expected to be relatively lower. The dark organic rich surface horizon is less than 25 cm thick.

Pits C and D

Soil classification
FAO: Acri Ferric Luvisol
USDA: Typic Plinthustalf

Acri Ferric Luvisols occur intensively on the middle and lower slope position (3-5%) and they account for nearly 75% of the surveyed area. Pits C and D are located on a 3% zone. Pit C is situated approximately 85 m south of pit A while pit D is located approximately 45 m west of the site's office. The development of these soils is associated with the accumulation of clay in the subsurface horizons (Bt) and exhibit little colour horizonation. These soils are virtually similar to those described for pits: F and G. However, it was noted that in pit F and G clay content tended to increase with depth while the opposite was true for pits C and D. The major difference between this order and that described for pit A is the level of soil development. In pit A there was no clear horizon formation as it was the case in pits C and D. On the other hand pit B is more or less similar to pits C & D except that pit B is associated with the presence of plinthite layer at a depth of approximately 50 cm.

The soil texture is typically Sandy Loam at the surface with Sandy Clay Loam texture at lower depths. These soils are associated with low organic matter content. The low organic matter content and high sand content cause a low water holding capacity of these soils.

Pit E

Classification
FAO: Rudi Chromic Luvisol
USDA: Oxic Haplustalf

Pit E is located on the middle slope position (3-5%) on the abandoned sisal field. These soils have developed on acid granulite gneiss parent material and they occupy less than 2% of the experimental site. The soils are lithic to shallow, well drained, reddish brown, stony, and Sandy Clay Loam in texture.

Severe erosion has resulted in shallow soil (depth to bed rock) as well as in some parts, the exposure of the underlying bedrock. Moisture holding capacity is a major limiting factor on these soils.

Pits F and G

Classification
FAO: Acri Ferric Luvisol
USDA: Oxic Rhodustalf

Pits F and G are located on the lower slope position (3%) of the site. Pit F is situated on the Southeast portion of the study area while pig G is located on the Southwest part approximately 100 m south of pit D. Soils in these two pits are more or less similar in their morphological and chemical properties. These soils have an accumulation of clay in the subsurface horizon and are classified as Luvisol (F.A.O.) or Alfisol (U.S.D.A.). Clay movements and accumulation are evident and are marked by a variation of clay content in the subsurface horizons. Clay content tended to increase substantially with increasing depth. Although the whole experimental site is rated as having low natural fertility, it appears that the lower part (3%) has relatively high natural fertility. Secondary minerals such as quartz were common throughout the profile.

Table 3.4 Particle size analyses of Kisangara Rain Water Harvesting experimental site (without and with dispersing agent)

PHYSICAL ANALYSIS							
		PARTICLE SIZE DISTRIBUTION WITHOUT DISPERSING AGENT			PARTICLE SIZE DISTRIBUTION WITH DISPERSING AGENT (CALGON)		
Identification	Depth(Cm)	Sand %	Silt %	Clay %	Sand %	Silt %	Clay %
Pit A	0-10	56.5	17.4	26.1	54.2	16.6	29.2
	10-30	57.4	25.6	17.0	55.1	24.5	20.4
	50-75	57.2	25.7	17.1	54.8	24.6	20.5
	75-100	61.6	21.3	17.1	61.6	17.1	21.3
	100-135	62.0	16.9	21.1	62.0	16.9	21.1
Pit B	0-10	49.1	21.2	29.7	49.1	21.2	29.7
	10.30	49.4	21.1	29.5	49.4	16.9	33.7
	50-75	40.1	29.9	29.9	38.5	20.5	41.0
	75-100	54.2	18.3	27.5	49.6	16.8	33.6
	100-120	44.0	25.8	30.1	42.2	24.8	33.0
Pit C	0-10	65.7	17.1	17.1	63.0	20.6	16.4
	10-30	64.1	13.5	22.4	61.4	12.9	25.7
	50-75	48.6	38.6	12.8	48.6	21.4	30.0
	75-100	45.8	25.0	29.2	45.8	20.8	33.4
	100-150	45.5	33.5	21.0	47.5	17.5	35.0
Pit D	0-10	48.9	17.0	34.1	46.9	20.4	32.7
	10-30	45.0	21.2	33.8	43.1	16.2	40.6
	50-75	40.1	38.5	21.4	38.5	28.7	32.8
	75-100	36.0	38.4	25.6	36.0	25.6	38.4
	100-150	49.3	32.3	18.4	47.1	35.2	17.6
Pit E	0-10	58.3	25.0	16.7	60.9	17.4	21.7
	10-30	51.1	17.8	31.1	51.1	13.3	35.6
	50-75	51.1	17.8	31.1	46.9	16.4	36.7
	75-100	49.8	29.3	20.9	52.0	21.8	26.2
	100-135	66.1	21.2	12.7	66.2	16.9	16.9
Pit F	0-10	63.1	20.5	16.4	65.8	8.5	25.7
	10-30	56.3	17.5	26.2	56.3	17.5	26.2
	50-75	43.0	39.4	17.5	41.2	25.2	35.6
	75-100	40.5	34.0	25.5	40.5	25.5	34.0
	100-150	39.8	43.0	17.2	41.6	31.4	27.0
Pit G	0-10	53.2	21.3	25.5	53.2	17.0	29.8
	10-30	48.2	21.6	30.2	48.2	8.6	43.2
	50-75	39.1	32.5	28.4	39.1	16.2	44.7
	75-100	49.0	29.7	21.2	49.0	25.5	25.5
	100-150	38.6	45.0	16.4	40.2	34.2	25.6

APPENDIX 3: RUN-OFF DATA AS AFFECTED BY SEVERAL FACTORS

(a): Morogoro during Masika 1994

(i)

Date	Rainfall (mm)	Effect of slope on Runoff (mm)		Effect of length of catchment on runoff(mm)		Effect of Catchment characteristic on runoff yield			
		3 - 4% slope	6 - 8% slope	5 m	10 m	NV	LMC	B	BC
8/1/94	38.6	2.42	5.39	3.59	4.22	1.54	2.79	5.60	5.69
10/1/94	8.0	0.96	2.71	1.89	1.78	1.75	1.52	1.96	2.11
14/2/94	13.0	1.67	1.56	2.03	1.20	0.47b	0.78b	2.06ab	3.14a
19/2/94	21.0	7.38	5.53	7.38	5.57	0.07b	7.06a	9.69a	9.00a
20/2/94	6.0	0.52	1.40	0.98	0.93	0.04c	0.99b	1.21b	1.69a
26/2/94	38.1	11.47	11.73	13.28	9.92	0.38b	10.73a	17.08a	18.20a
28/2/94	10.0	0.53	0.47	0.38	0.63	0.00d	0.31c	0.60b	1.09a
4/3/94	17.9	0.53	0.56	0.55	0.54	0.26c	0.33b	0.24b	1.36a
17/3/94	6.0	0.06	0.38	0.24	0.20	0.05c	0.11bc	0.19b	0.53a
18/3/94	7.0	0.05	0.45	0.21	0.29	0.01c	0.05bc	0.21b	0.74a
22/3/94	6.0	3.81	4.33	0.23	0.21	0.23b	0.06b	0.11b	0.70a
27/3/94	12.0	0.06	0.38	0.03	0.01	0.01b	0.02b	0.02b	0.05a
6/4/94	25.0	7.45	5.24	6.84	8.85	0.41c	4.76b	13.19a	7.02a
7/4/94	47.0	10.70	8.09	9.11	9.68	0.23b	11.43a	13.41a	12.51a
11/4/94	6.0	0.02	0.03	0.24	0.22	0.00c	0.01b	0.36a	0.56a
23/4/94	7.0	0.13	0.34	0.69	1.01	0.03c	0.14c	1.11b	2.14a
24/4/94	9.0	0.91	1.25	1.03	1.25	0.02c	0.05c	1.46b	2.79a
25/4/94	15.0	0.91	1.84	1.22	1.53	0.01c	0.04c	1.38b	3.88a
4/5/94	14.0	4.50	4.44	4.18	4.76	0.04b	0.21b	8.55a	9.09a
14/5/94	8.0	1.04	1.35	1.11	1.28	0.00c	0.03c	1.63b	3.11a
16/5/94	10.0	1.35	1.35	1.08	1.62	0.00c	0.04b	2.79a	2.58a
5/7/94	17.0	0.40	0.51	0.44	0.42	0.00c	0.04bc	0.67b	1.12a
6/7/94	4.0	0.17	0.07	0.16	0.08	0.00b	0.02b	0.16a	0.28a
7/7/94	18.5	0.56	0.64	0.61	0.59	0.00c	0.15b	0.81b	1.45a

(b): Morogoro during Vuli 1994/95 season

Date	Rainfall (mm)	Effect of slope on runoff in mm		Effect of catchment length on runoff (mm)		Effect of cathment characteristics on runoff (mm)			
		3-4% slope	6 % slope	5 m	10 m	NV	LMC	B	BC
14/10/94	5.0	0.13	0.24	0.19	0.18	0.00	0.02	0.33	0.39
2/11/94	23.2	2.15	2.74	2.38	2.50	0.00	0.05	3.85	5.88
4/11/94	2.4	0.09	0.07	0.11	0.05	0.00	0.02	0.10	0.12
7/11/94	18.5	0.08	0.39	0.26	0.21	0.00	0.00	0.33	0.62
11/11/94	4.8	0.01	0.24	0.11	0.13	0.00	0.01	0.30	0.19
15/11/94	4.5	0.40	0.51	0.42	0.49	0.00	0.02	0.95	0.82
8/12/94	6.6	0.00	0.01	0.00	0.00	0.00	0.00	0.01	0.01
10/12/94	4.0	0.02	0.16	0.11	0.07	0.00	0.00	0.17	0.18
17/12/94	8.3	0.02	0.01	0.01	0.01	0.00	0.00	0.02	0.02
19/12/94	4.0	0.13	0.05	0.14	0.03	0.00	0.10	0.13	0.10
27/12/94	8.0	0.72	1.27	1.10	0.90	0.00	0.05	1.95	2.00
2/1/95	32.0	12.67	9.95	12.6	10.58	0.10	6.81	18.41	19.97
3/1/95	15.0	7.22	7.77	8.41	6.58	0.21	7.95	10.72	11.09
5/1/95	6.0	1.33	1.47	1.54	1.27	0.00	0.63	2.46	2.50
14/1/95	19.0	2.72	3.86	3.68	2.91	0.00	0.92	5.92	6.33
22/1/95	65.3	14.80	4.17	13.65	5.32	7.78	7.86	11.68	10.63

(c) Runoff collected from Kisangara 8% Runoff plots

Season	Date	Total rain mm	Runoff yield from catchments (mm)			
			NV	LMC	B	BC
Masika 1994	13/2/94	15.0	2.67	0.66	2.51	6.26
	5/3/94	19.5	4.16	0.31	3.00	6.51
	7/3/94	49.0	7.17	2.72	12.2	16.47
	24/3/94	4.0	0.13	0.04	0.13	0.26
	24/04/94	5.5	0.23	0.14	0.6	0.62
	26/04/94	9.0	0.24	0.01	0.83	0.87
	01/05/94	10.0	0.15	0.2	0.52	0.86
	12/05/94	15.5	1.49	0.48	2.72	5.93
	15/05/94	12.0	0.14	0	1.11	1.58
	Total (season)	139.5	16.38	4.56	23.62	39.36
	% of events producing runoff	36.6	36.6	33.5	36.6	36.6
	Seasonal total	381.1	4.3%	1.2%	6.2%	10.33%
Vuli 1994/95	21/10/94	9.0	0.05	0.06	1.41	1.49
	31/10/94	9.0	0.59	0.33	2.33	2.8
	11/11/94	15.0	1.36	2.02	3.78	4.42
	16/11/94	16.0	1.46	0.32	1.86	4.27
	01/12/94	52.0	1.87	0.24	2.96	5.22
	5/12/94	7.0	0.51	0.69	2.43	2.83
	6/12/94	17.0	2.1	0.45	1.93	8.67
	9/12/94	43.0	11.88	0	24.78	20.41
	14/12/94	21.0	1.33	1.16	11	6.44
	16/12/94	19.0	6.53	0.88	3.36	3.37
	17/12/94	24.0	9.21	4.25	15.77	11.38
	23/12/94	10.0	0.04	0.97	3.43	1.13
	Total	242.0	36.93	11.37	75.04	72.43
	% of events producing runoff	73.6	73.6	60.6	73.6	73.6
	Seasonal total	328.6	11.24%	3.46%	22.85%	22.04%

[1] na = data not available (recording rain gauge was out of order

(c) continue

Season	Date	Total rain (mm)	runoff yield from catchments (mm)			
			NV	LMC	B	BC
Vuli 95/96	17.10.95	0.4	0.06	0.14	0.82	1.46
	19.11.95	0.3	0.04	0.10	0.15	0.27
	01.12.95	37.0	0.74	0.14	0.15	3.82
	07.12.95	5.5	0.67	1.00	1.82	2.85
	10.12.95	1.0	0.07	0.07	0.33	0.37
	15.12.95	15.0	0.13	0.82	1.76	8.78
	19.12.95	15.0	0.64	1.49	2.90	8.78
	26.12.95	40.0	2.16	1.02	8.00	11.38
	06.02.95	35.0	0.37	1.02	2.71	18.38
	15.02.96	2.0	0.04	0.02	0.36	0.42
	18.02.96	26.0	0.17	0.43	9.33	12.00
	19.02.96	8.0	0.12	0.39	3.56	5.32
	Total season	211	5.12	10.26	41.53	71.38
	% of event producing runoff	2.4	2.4	4.9	19.7	33.8

(c) continue

Season	Date	Total rain (mm)	Runoff yield from catchments (mm)			
			NV	LMC	B	BC
Masika 1995	19.02.95	17	3.49	0.61	8.05	9.10
	02.03.95	3	0.20	0.40	0.56	0.66
	03.03.95	55	2.23	4.62	3.69	9.54
	06.03.95	7	0.00	0.06	0.56	1.16
	14.03.95	72	6.84	1.30	2.70	8.21
	15.03.95	32	1.22	0.49	1.97	1.18
	26.03.95	1.5	0.00	0.01	0.01	0.02
	29.03.95	3	0.02	0.07	0.18	0.12
	07.04.95	4	0.00	0.06	1.23	1.45
	14.04.95	5.5	0.01	0.06	0.61	1.34
	15.04.95	5.5	0.09	0.17	2.34	2.85
	19.04.95	4	0.00	0.04	0.09	0.11
	20.04.95	8.5	0.03	0.00	1.38	1.74
	23.04.95	5.5	0.01	0.22	1.50	1.72
	24.04.95	3.5	0.02	0.05	1.43	1.69
	25.04.95	39.5	4.01	3.44	13.39	17.89
	26.04.95	45.5	11.15	2.39	23.32	24.55
	29.04.95	15	0.10	0.08	1.55	6.06
	30.04.95	7	0.15	0.50	2.43	3.49
	01.05.95	2	0.00	0.00	0.04	0.24
	11.05.95	2	0.03	0.07	0.09	0.03
	17.05.95	9	0.09	0.14	2.56	3.46
	18.05.95	17	0.10	1.38	5.35	4.49
	19.05.95	23	0.10	4.61	4.34	9.58
	22.05.95	11.7	0.04	0.68	0.80	3.49
	28.05.95	13.5	0.02	0.14	2.25	4.68
	29.05.95	9	0.03	0.40	4.24	5.38
	30.05.95	5	0.02	0.01	1.39	1.93
	29.07.95	3	0.00	0.00	0.02	0.03
	05.08.95	7.5	0.00	0.00	0.00	0.08
	Total seasonal	509.6	30	22	88.1	126.3
	% of event producing runoff		5.9	4.3	17.3	24.8

(d) Runoff collected from Kisangara 3% slope Runoff plots

Season	Date	Total rain (mm)	Runoff yield from catchments (mm)			
			NV	LMC	B	BC
Masika 1994	13/2/94	15.0	2.23	0.9	1.72	3.92
	5/3/94	19.5	7.19	0.2	3.44	4.79
	7/3/94	49.0	14.36	0.5	7.57	10.53
	24/03/94	4.0	0.0	0.0	0.0	0.00
	24/04/94	5.0	0.76	0.34	1.9	2.21
	26/04/94	9.0	0.11	0.0	0.53	1.76
	01/05/94	10.0	0.11	0.07	1.37	0.75
	12/05/93	15.5	1.47	0.46	2.11	3.75
	15/05/94	12.0	0.0	0.0	0.51	1.61
	Total	139.5	14.36	2.66	19.12	29.32
	% of events producing runoff	36.6	32.4	29.9	35.6	35.6
	Seasonal total	381.1	3.77%	0.7%	5.02%	7.69%
Vuli 1994/95	21/10/94	9.0	0.2	0.18	1.09	3.52
	31/10/94	9.0	0.0	0.0	1.19	2.62
	11/11/94	15.0	2.62	0.35	2.2	4.98
	16/11/94	16.0	1.77	0.17	2.81	7.56
	01/12/94	52.0	5.87	0.19	13.87	11.9
	05/12/94	7.0	2.42	0.41	2.21	2.85
	6/12/94	17.0	2.56	0.17	5.59	4.91
	9/12/94	43.0	1.89	0.38	2.76	6.75
	14/12/94	21.0	2.45	0.02	6.57	9.68
	16/12/94	19.0	4.24	1.38	10.23	9.75
	17/12/94	24.0	4.38	0.75	8.56	7.35
	23/12/94	10.0	0.63	0.0	0.87	4.64
	Total	242.0	29.03	4.0	57.95	76.51
	% of events producing runoff	73.6	70.90	67.9	73.6	73.6
	Seasonal total	328.6	8.83%	1.22%	17.64%	23.28%

[1] na = data not available (recording rain gauge was out of order)

(d) continue

Season	Date	Total rain (mm)	runoff yield from catchments (mm)			
			NV	LMC	B	BC
Vuli 95/96	17.10.95	0.4	0.01	0.27	0.57	1.24
	19.11.95	0.3	0.01	0.01	0.05	0.14
	01.12.95	37.0	3.99	8.81	2.98	3.80
	07.12.95	5.5	0.26	0.69	1.06	1.54
	10.12.95	1.0	0.07	0.24	0.26	0.32
	15.12.95	15.0	0.27	0.73	1.77	3.89
	19.12.95	15.0	0.24	1.33	2.19	4.23
	26.12.95	40.0	2.60	1.50	4.13	8.10
	06.02.95	35.0	0.37	1.02	2.71	18.38
	15.02.96	2.0	0.00	0.00	0.05	0.31
	18.02.96	26.0	0.15	0.78	8.88	11.86
	19.02.96	8.0	0.07	0.45	5.09	5.45
	Total season	211	8.04	15.8	29.7	59.3
	% of event producing runoff		3.8	7.5	14.1	28.1

(d) continue

Season	Date	Total rain (mm)	runoff yield from catchments (mm)			
			NV	LMC	B	BC
Masika 1995	19.02.95	17.0	3.43	0.53	6.76	8.41
	02.03.95	3.0	0.00	0.00	0.00	0.02
	03.03.95	55.0	7.18	0.33	14.41	15.24
	06.03.95	7.0	0.08	0.09	0.41	1.36
	14.03.95	72.0	12.28	4.14	21.56	25.78
	15.03.95	32.0	1.34	0.84	8.00	1.02
	26.03.95	1.5	0.01	0.00	0.00	0.01
	29.03.95	3.0	0.00	0.14	0.19	0.33
	07.04.95	4.0	0.02	0.04	1.20	1.44
	14.04.95	5.5	0.12	0.15	0.30	0.87
	15.04.95	5.5	0.04	0.05	1.72	2.15
	19.04.95	4.0	0.02	0.05	0.10	0.25
	20.04.95	8.5	0.02	0.01	0.25	1.54
	23.04.95	5.5	0.09	0.29	2.01	2.51
	24.04.95	3.5	0.07	0.02	1.05	1.07
	25.04.95	39.5	4.03	0.04	3.46	8.67
	26.04.95	45.5	6.90	15.81	5.66	21.25
	29.04.95	15.0	0.09	0.03	4.00	7.46
	30.04.95	7.0	0.06	0.00	2.59	3.59
	01.05.95	2.0	0.00	0.00	0.02	0.15
	11.05.95	2.0	0.00	0.03	0.03	0.07
	17.05.95	9.0	0.04	0.05	2.14	3.44
	18.05.95	17.0	0.45	0.64	7.40	7.56
	19.05.95	23.0	0.30	4.40	4.32	14.21
	22.05.95	11.7	0.04	0.05	4.47	4.24
	28.05.95	13.5	0.03	0.00	1.77	1.98
	29.05.95	9.0	0.08	0.21	2.57	3.01
	30.05.95	5.0	0.01	0.00	1.29	1.98
	29.07.95	3.0	0.01	0.00	0.06	0.02
	05.08.95	7.5	0.00	0.00	0.00	0.02
	Total season	509.6	36.7	28.3	97.8	151.4
	% of event producing runoff		5.9	4.3	17.3	24.8