SOKOINE UNIVERSITY OF AGRICULTURE

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

2nd INTERIM TECHNICAL REPORT

Hatibu, N., H.F. Mahoo, B. Kayombo and D.A.N. Ussiri

SOIL-WATER MANAGEMENT RESEARCH GROUP

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SUMMARY

1. Soil water in most of Tanzania is dependent on erratic rainfall and is therefore not adequate for crop growth. There is therefore a need for highly efficient management techniques to hold more rain water in the soil where it falls. Rain Water Harvesting is seen as one of the important tools for ensuring adequate availability of soil-water for plant growth. The policy of the Ministry of Agriculture on agricultural water supply, puts rain water harvesting as number one source of water.

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. Run-off farming is generally practised in many parts of Tanzania through the utilization of flood water collecting in valley bottoms. Thus, in many parts of the semi-arid zone, the valleys surrounded by run-off producing slopes are utilized to grow high water demanding crops such as paddy, vegetables, sugar cane and maize.

4. The main problem facing farmers and project planners is lack of a criteria for systematic design of rain water harvesting systems. The Sokoine University of Agriculture is assisting in solving this problem through a research project in rain water harvesting. The project is supported by ODA-UK through the Natural Resources Institute. The main objective of the project is to increase sustainability of productivity of flood-and-drought prone semi-arid lowlands through more effective management of rain water.

5. The research work has concentrated in studying two climatically contrasting semi-arid areas of Morogoro and Mwanga districts. The main activities which have been undertaken include:-

   - Participatory Rural Appraisal of the soil-water management strategies practised by farmers;
   - Socio-economic study of the farmer practices;
   - Climatic characterization of the two target areas;
   - Rainfall-runoff catchment experiments;
   - Runoff farming experiments.

   This report is on the results obtained from the last three activities.

6. The performance of different surface treatments on run-off yield in relation to rainfall characteristics were measured for four seasons; two short-rainy (vuli) and two long-rainy (masika) seasons.

7. The effect of different amount of run-off added to cropped basin, on the growth and yield of maize (Zea mays L.), was measured over the four seasons. Further, the performance of different conservation tillage practices on maize yields, was measured on a sloping (8%) land in Kisangara.

8. The main characters of the climate of the study area are:

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

9. In general the run-off generation in the study area is controlled by rainfall characteristics. However, treatment of the catchment by clearing and compaction, significantly increased run-off yield coefficient. Therefore, due to low run-off yielding capacity of the rainfall, run-off yield optimization require some treatment (such as compaction) of the catchment.

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

i) During Vuli run-off farming significantly ($P=0.01$) increased grain yield by 420 kg/ha on the 8% slope. The increase on the 3% slope was 118kg/ha and significant at $p = 0.05$.

ii) During Masika run-off farming significantly ($P=0.05$) increased grain yield by between 185-642 kg/ha.

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

ACKNOWLEDGEMENTS

This work is 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 valuable and 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.

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Our collaboration with John Gowing and Guido Wyseure 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.

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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. INTRODUCTION

1.1 Background

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 1.1 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.

The 1988 census showed that the population of mainland Tanzania was 22.5 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 2.25 million farm families,each operating on average 2 hectares 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. 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. 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. 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 (Figure 1.2).

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. In the 1970's the government tried to shift people to Morogoro and Tabora, but these efforts failed to solve the problem because few people accepted the idea of settling in new areas so far from their birth places.

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.

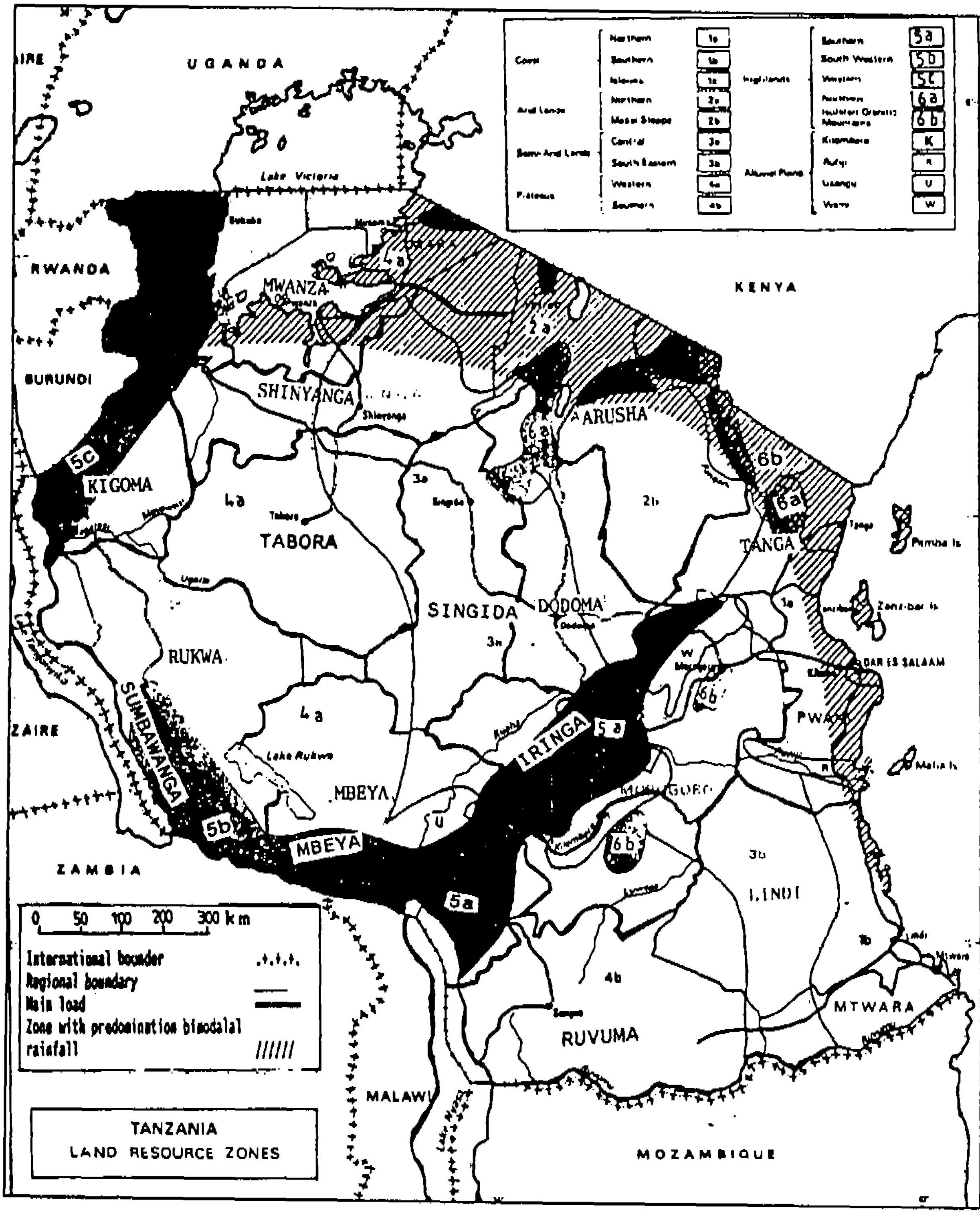
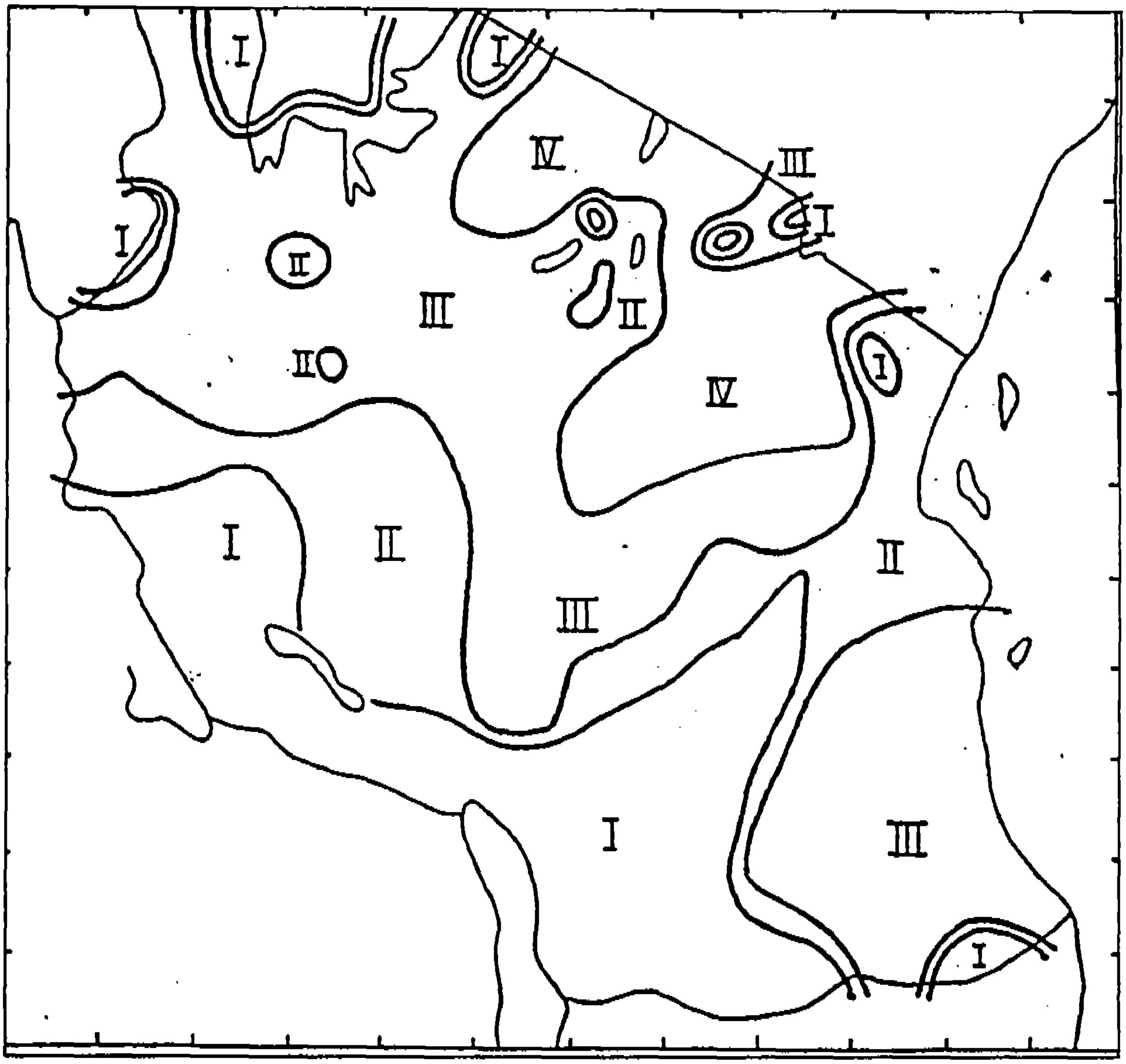


Figure 1.1 Tanzania, agrogeological zones



Zone I: There is a chance of obtaining 80% of the local maximum yields of maize in eight out of ten years;

Zone II: There is a chance of obtaining 70% of the local maximum yields of maize in seven out of ten years

Zone III: There is a chance of obtaining 60% of the local maximum yields of maize in six out of ten years

Zone IV: There is a chance of obtaining 50% of the local maximum yields of sorghum in five out of ten years

Figure 1.2 Tanzania, rainfall reliability classification

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 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. Rain water harvesting (RWH) is expected to be one of the important tools which can be used to manage the scarce rainfall.

The National Agriculture and Livestock Research Master Plan, MoA (1991), states that research should be seen as one important step in the general rehabilitation of the economy of Tanzania as foreseen in the economic recovery program. The master plan identifies the following areas of agricultural research as having top priority:

- o cash crops: coffee, tea and cotton
- o food crops: rice only
- o livestock: animal health and diseases, and ruminant milk and meat production
- o **soil and water management**
- o agro-forestry
- o farming systems research
- o agricultural economics

Under soil and water management the assessment of techniques to conserve and utilize soil moisture for crop production are accorded high priority.

Therefore, the Sokoine University of Agriculture (SUA) in attempting to assist in meeting the objectives of the National Agricultural and Livestock Research Master Plan, has started a program of research in soil and water management. The project is being carried out with funding provided through a contract between the Sokoine University of Agriculture (SUA) and Natural Resources Institute (NRI) of UK. The Semi-Arid Systems research programme at NRI manages funds for strategic research on behalf of the Natural Resources and Environment department of ODA. The focus of the programme is improved soil moisture and soil fertility for small holder farmers in semi-arid sub-Sahara Africa. The current research project, "The evaluation and promotion of rain water harvesting in semi-arid areas of Tanzania" is one of a project of research programme into soil and water management carried out by SUA. The other project "Evaluation of soil-water management in semi-arid Tanzania" was funded by the International Development Research Centre (IDRC) of Canada, up to December 1994 (Hatibu et al. 1995).

1.2 The Problem and Research Objectives

Rainfed agriculture is the most important component of Tanzania's overall economy. Because of low and unreliable rainfall in over half of the land, it is crucial that every effort be made to conserve and efficiently utilize the scarce rain water. This requires improved soil management techniques that maximize the holding of water in the soil, coupled with cultural practices which ensure the most optimum use of the available soil-water by plants. Better management of rain-water where it falls, apart from enhancing plant production, is also necessary in the protection of the environment. This is because poor management allow wasteful run-off to occur, causing erosion, downstream flooding and siltation. Soil-water management, especially in the semi-arid areas is therefore, 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.

Therefore, the overall objective of the Soil and Water Management Research Programme of the Sokoine University of Agriculture 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 aim of the research project "Evaluation and promotion of Rain-Water Harvesting" is to increase sustainability of productivity and population carrying capacity of flood-and-drought prone semi-arid lowlands through more effective management of rain-water.

The following are the specific objectives of the research:

i) To appraise and describe farming systems and indigenous soil-water management and conservation in the semi-arid areas of Tanzania.
ii) To review past research work in rain-water harvesting with particular attention to Tanzania.
iii) To assess the technical, economic and social potential for rain-water harvesting, in semi-arid areas of Kilimanjaro region in Tanzania.
iv) To develop and validate a structured model of rain-water harvesting.

1.3 The Research Approach

The approach being followed is mainly that of an adaptive research, implemented by a multidisciplinary team with agricultural engineer, hydrologist, agronomist, agricultural economist and sociologist. The research is using four research tools as follows:

i) Researcher managed on-site trials designed to maximize the production of quantifiable data on the interactions between soil, topography, climate, RWH systems, and agronomy relative to crop production and yields.
ii) On-farm trials designed to test crop and farmer response to RWH crop systems, under farmer management. Efforts are made to ensure that the farmers understand the background of RWH and participate in designing the trials in order to create research partnership.
iii) Rapid Rural Appraisal (RRA) carried out to provide significant information to assess the biophysical and socio-economic conditions of the target areas. RRA will also provide the necessary farmers views regarding RWH for soil water management.
iv) Socio-economic monitoring of farmers which is aimed at obtaining the essential detailed information regarding inputs, outputs, soils and cash flow.

1.4 The Report

This report describes the results of the research activities during the first four seasons of the project, from September 1992 to March 1995. These include two short rainy ("Vuli") seasons and two long rainy ("Masika") seasons. This report superceedes the 1st 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 include the following: Rapid Rural Appraisal of Mwanga District (Hatibu et al., 1993); Bibliography of literature related to Rain-Water Harvesting Research in Tanzania (SWMRP, 1993); Field and laboratory manual (SWMRP, 1993); Proceedings of the Second Farmers Seminar (Mahoo et al., 1995); and the 1st Interim Technical Report (Hatibu et al., 1993).

2 PRINCIPLES OF RAIN WATER HARVESTING FOR CROPS (Runoff Farming)

2.1 Introduction

2.1.1 Definitions

Rainwater harvesting is defined as any system that encompasses methods for collecting, concentrating and storing various forms of run-off for various purposes (Myers, 1975)

Many definitions of rain water harvesting have been given by different authors. For purposes of clarity it is therefore necessary to set out the definitions which will be used in this report.

Run-off may occur when rain falls on any surface which is not capable of absorbing all the rainwater, these include:

- rooftops
- rock outcrops
- roads
- shallow or compact soils

Rain water harvesting is the process of collecting, storing and using this run-off near to where it occurs. The collected run-off can be used for several purposes; for example to supply:

- soil-moisture for plants
- livestock water
- domestic water
- ground water recharge.

Rain water harvesting involves three subsystems; the source, storage and use subsystems. The different categories of sources, storage and use are depicted in Figure 2.1. The main characteristics of rain water harvesting are:

- Dependency upon local rainfall, and does not include the storing and use of river water resulting from rain falling many kilometres away,
- Involvement of the movement and concentration of water, and
- The intermittent character of the runoff.

When the harvested runoff is used for providing the soil-water required for plant growth the system is called runoff farming[1]. This is defined as the induction, collection, storage and conservation of local runoff for plant growth, especially in the arid and semi-arid areas. The four aspects interact as shown in Figure 2.2.

[1]The term "farming" is used in its broadest sense-to include crops, trees, agroforestry, rangelands, etc.

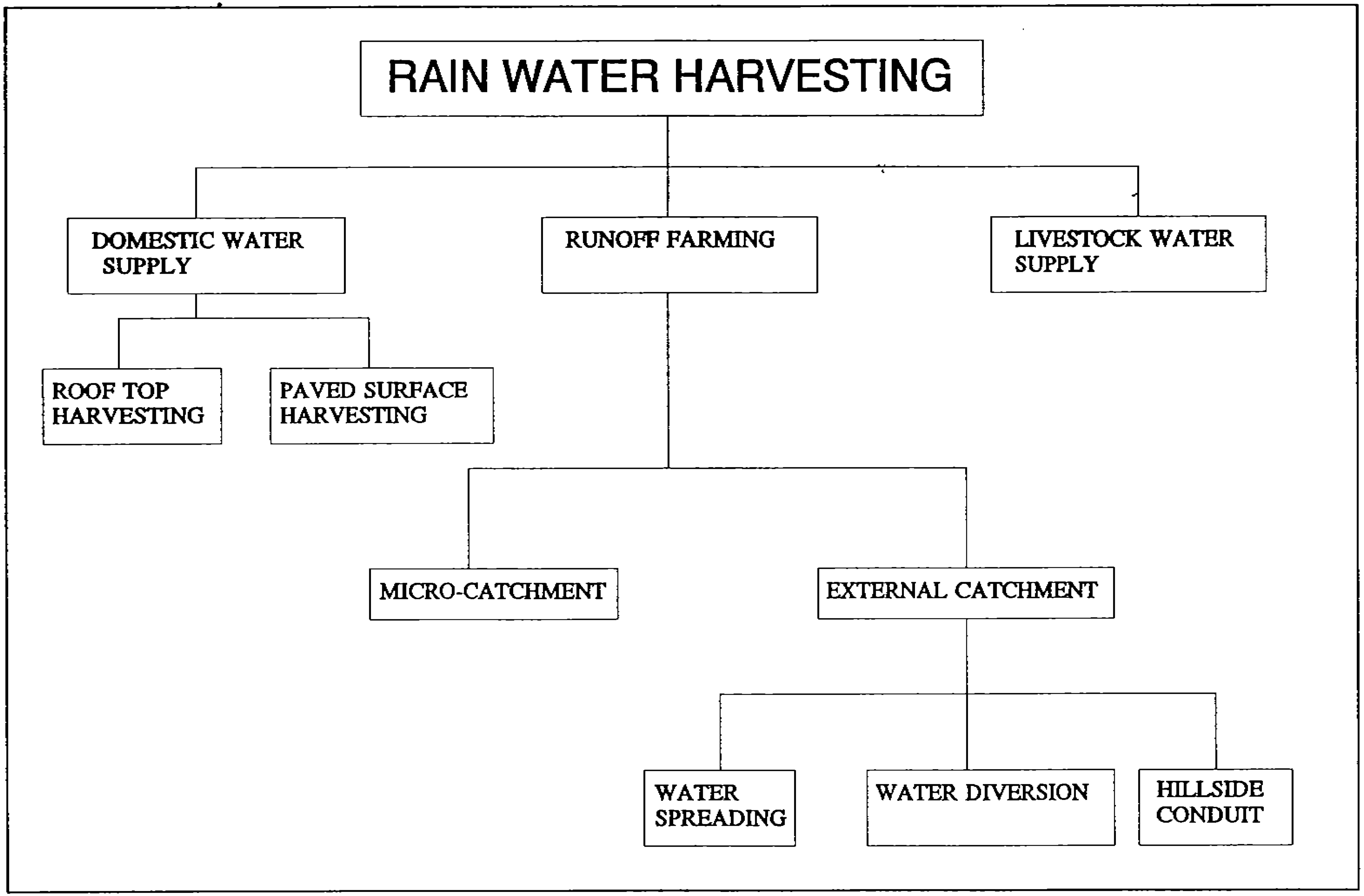


Figure 2.1: Sources of runoff for the three main uses of rain water harvesting

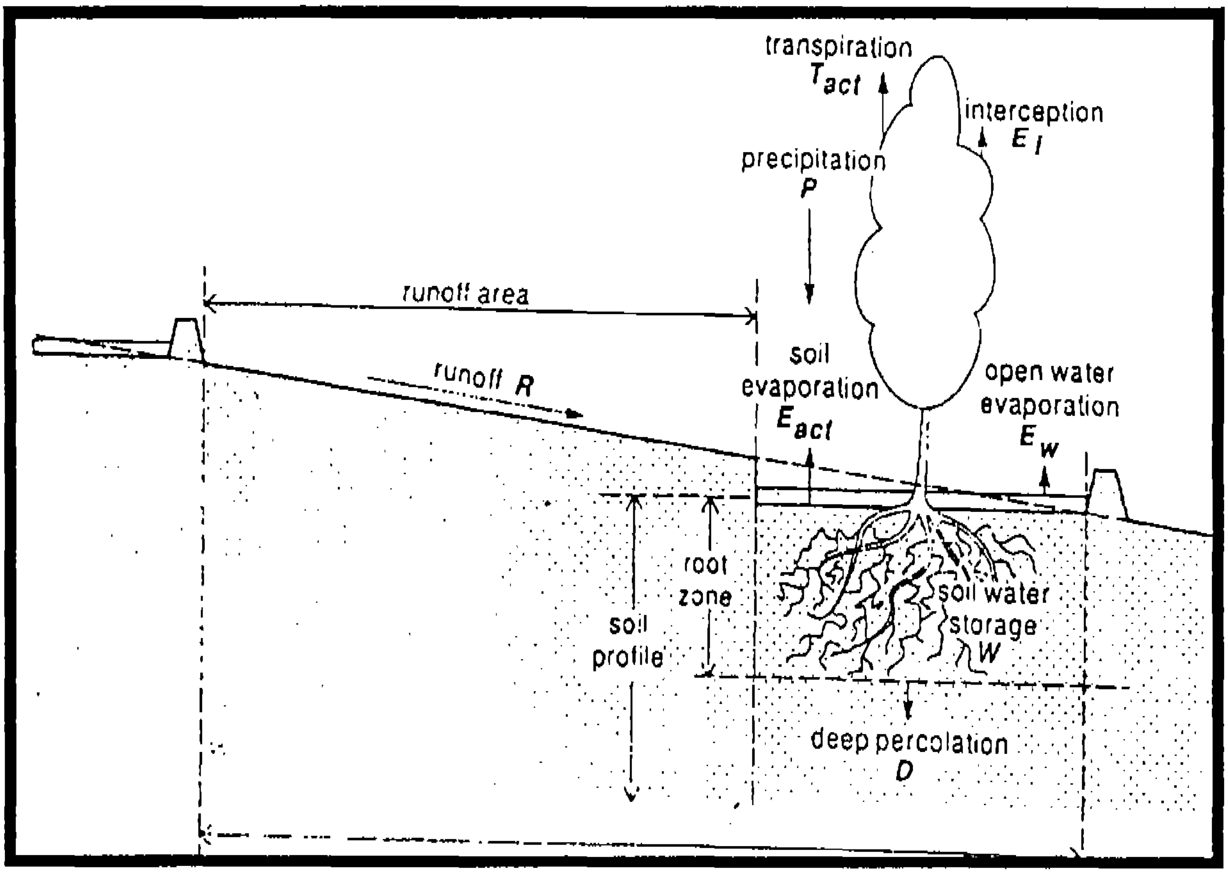


Figure 2.2: Rainfall induces runoff on the catchment area and the water collects in the basin area at the bottom of the slope

Run-off farming may be divided into two main categories (Figure 2.3):

- **Micro-catchment rain water harvesting:** In this system, within-field catchments of the order of a few square metres are used. The ridge and furrow, planting pits and contour ridges are good examples of this system. The maximum flow distance of water in a micro-catchment should not exceed 100 m.

- **External catchment system:** This involves the collection of water from large catchment areas, where the flow distance is more than 100 m. In many cases channels, dams or diversion systems are used to collect flash floods and water from ephemeral streams. Examples of this system include:

  - Water spreading: Where a series of low check dams is used to spread water from ephemeral streams onto plants for plant water supply,
  - Water diversions: Where water is forced to leave its natural course, and conveyed to a nearby location suitable for crop production, and
  - Hill side conduit system: Where run-off water from middle and upper part of a hill side is harvested and directed by channels onto storage reservoirs for later use in supplementary irrigation.

2.1.2 Inducement and Storage of Run-off

2.1.2.1 Inducement

The main variable of any rain water harvesting system, is the quantity of water that can be harvested from an area under given climatic conditions. The amount of run-off a catchment can yield depends on several factors. One of these factors is the quantity of rainfall required to initiate run-off. This amount of rainfall is called threshold retention capacity of the catchment and it depends on surface storage, rainfall intensity, infiltration capacity and soil water holding capacity. For every catchment, a coefficient of run-off is defined in equation 2.1.

$$\textit{Runoff Coefficient } (e_R) = \frac{\textit{Runoff}}{\textit{Rainfall}} mm\ mm^{-1} \qquad (2.1)$$

Runoff may be obtained from natural surfaces such as rock slopes or granite outcrops. However, in many cases induction of run-off requires the treatment of the catchment to reduce the threshold retention. The main methods of catchment treatment are vegetation removal, mechanical treatment of catchment surface, soil modification, and surface covering with impermeable materials.

- **Vegetation removal:** A summary of studies conducted throughout the world indicates that in areas with an annual precipitation of more than 280 mm, runoff can be increased by the removal of vegetation (Cooley et al., 1975). With this method, runoff efficiency is low, and may vary greatly per storm, season or year. The method is usually applied in combination with mechanical surface treatments (Hillel, 1967). The main effect of vegetation removal is that it reduces the infiltration capacity. Therefore, it is beneficial where infiltration capacity is the dominant factor reducing runoff efficiency.

- **Mechanical treatment of surfaces:** such as rock clearing, smoothing and compacting increase runoff. The main effect of surface treatment is that it reduces surface storage. Like vegetation removal, mechanical surface treatment is relatively inexpensive and may last for a long time. Where the dominant factor reducing runoff efficiency is a high infiltration capacity, vegetation removal is more effective than mechanical surface treatment. Where surface storage is the dominant factor, mechanical surface treatment will be more effective.

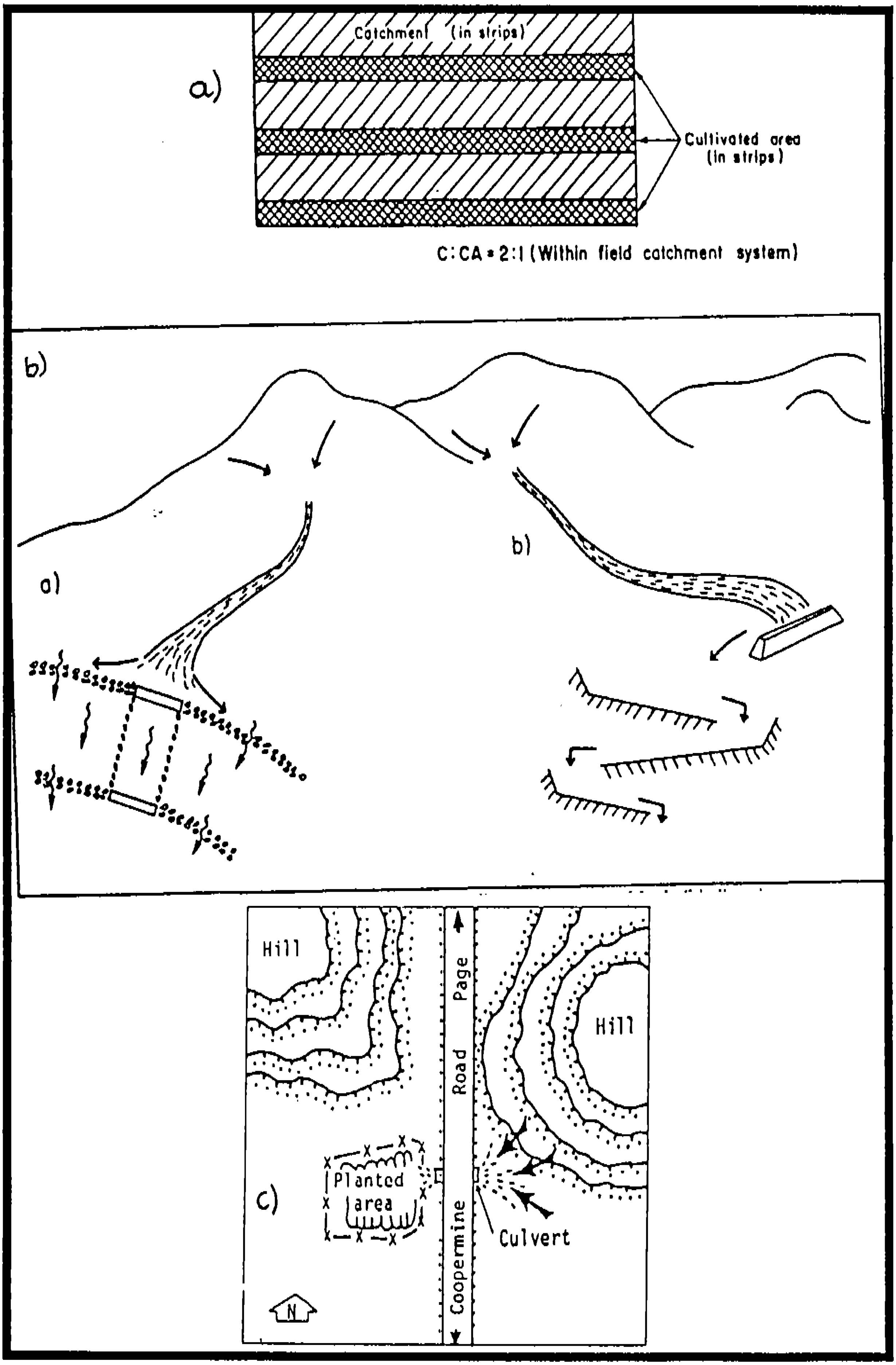


Figure 2.3: Main types of runoff farming systems

- **Soil modifications:** treatments involve chemicals applied to the soil surface by spraying or mixing to reduce or stop water infiltration. However, it is necessary to match the treatment with specific soil and climatic characteristics. Bitumen or asphalt have been widely tested as soil modification treatment and it is best suited for use on fine sandy soils and has a projected effective life of 2 - 5 years. Salt treatment is potentially the cheapest soil modification technique. This treatment consists of mixing a water-soluble sodium-based salt at a rate of about 11 t ha^{-1} into the top 2 cm of soil. After mixing the salt with the soil, the area is wetted and compacted to a firm, smooth surface. However, for this treatment to be effective the soil should be made up with 20% or more of kaolinite or illite clay. The sodium salt disperses the clay, plugs the soil pores and reduces the hydraulic conductivity. Another soil modification involves water-repellent treatments. For example, if molten paraffin wax is sprayed on soil surface, it coat the soil particles rendering them water-repellent (Fink et al., 1973). This treatment is best suited to soils containing less than 20% clay. The wax does not provide significant soil stabilization, and the treatment can be damaged by water erosion.

- **Surface covering:** In some cases impermeable or waterproof sheeting or membrane can be used as catchment covering. Many conventional construction materials can be used. These materials are relatively expensive, but when properly installed and maintained are durable, and may be the best treatment for some locations. Several types of plastic and other thin sheeting have been investigated as potential soil coverings for water-harvesting catchments. Unfortunately, most of these thin film coverings were found to be susceptible to mechanical damage and sunlight deterioration. Wind damage potential can be reduced by placing shallow layer of clean gravel on the sheeting after it has been positioned on the catchment surface. The sheeting is the waterproof membrane, and the gravel protects the sheeting from mechanical damage. This treatment requires periodic maintenance to ensure that the sheeting remains covered with the gravel. Wind-blown dust trapped in the gravel layer provides a seedbed for plants and has been a minor problem. This treatment is relatively inexpensive if clean gravel is readily available.

2.1.2.2 Water Storage

Storage, as surface water or soil water, is an integral part of water harvesting (Myers, 1975). The decision on how to store water depends in the first place on how the water is to be used. For crop production, surface reservoirs have been used or proposed in a few cases, but soil-water storage is far more common. Figure 2.4 shows Area A, which produces an annual volume of runoff equal to e_RPA. In general, when the runoff volume is large and requires a large storage capacity, surface reservoirs are used. Otherwise soil-water storage is less expensive.

(a) Root zone storage

The soil-water storage of the root zone W (mm) can be expressed as shown in equation 2.2.

$$W = \int_{|z_r|}^{0} \theta dz \tag{2.2}$$

Where θ_{FC} is the volumetric soil-water content (-), z is the vertical coordinate from the basin area positive up wards, and z_r is the depth of the root zone (Figure 2.4).

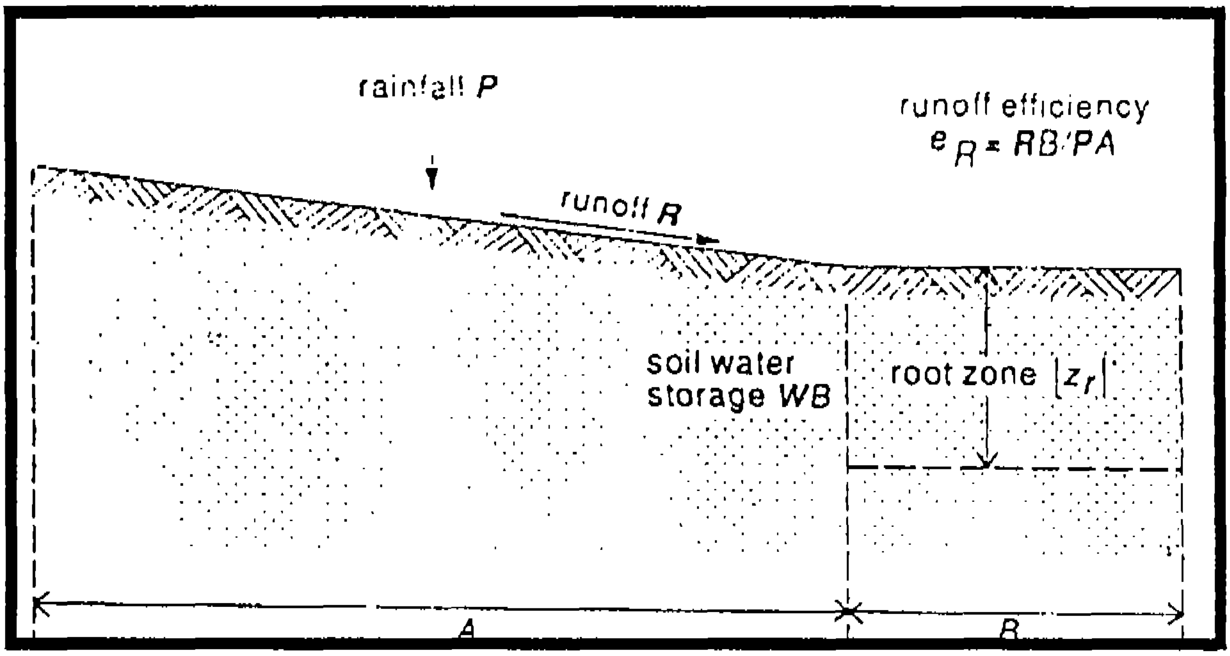


Figure 2.4: Factors determining the volume of surface runoff and soil-water storage (After Boers and Ben-Asher 1982)

For the purpose of water harvesting, the maximum possible soil-water storage in the root zone W_{max} mm can be approximated by equation 2.3

$$W_{max} = (\theta_{FC} - \theta_{WP})|Z_r| \tag{2.3}$$

Where θ_{FC} and θ_{WP} are the volumetric soil-water contents at field capacity and at permanent wilting point, respectively. The annual runoff volume from Area A results in a runoff depth on Area B as given in equation 2.4.

$$e_{R\,ann} = \frac{RB}{PA} \tag{2.4}$$

This leads to infiltration, I. If I $\leq$ W_{max}, soil-water storage within the root zone depth is possible, but if I > W_{max}, water may be lost by deep percolation below the root zone. If I >> W_{max}, surface water storage should be considered.

Any root zone storage of soil require optimum conservation of the harvested water by minimizing losses caused by soil evaporation and deep percolation. Methods have been developed to reduce direct evaporation losses from soil water. In general, the deep storage of soil water and a loosening of the top soil are the best methods to reduce soil evaporation losses. The case of $I > W_{max}$, when deep percolation losses occur, may be due to either large I or to a coarse-textured soil (small W_{max}). The best way to reduce deep percolation losses is by maximizing z_r (i.e. by allowing deep root development).

(b) Reservoir storage

In this case water is collected and stored in a reservoir or pond away from the basin area, permitting its later application to the crop through some form of irrigation. When strategically timed during dry spells in the rainy season or used to extend the growing period into post rainy season, supplemental irrigation markedly reduces the risks involved in rainfed agriculture and improves crop yields.

However, unlined earthen pits or ponds are usually not satisfactory methods of storing water for supplemental irrigation. Unless seepage losses are naturally low, the soil is sealed with chemicals or the losses are controlled by liners of plastic or artificial rubber.

Since storage system is generally an expensive method of supplying water, controlling evaporation losses is an important factor, and should be an integral part of any water storage facility. Floating covers are effective means of controlling evaporation.

2.1.3 Design Requirements

2.1.3.1 Calculation of crop water requirement

The design of runoff farming systems is based on an assessment of the water requirement of the crop to be grown. Crop water requirement is mainly influenced by four climatic factors (Table 2.1).

The highest crop water needs are thus found in areas which are hot, dry, windy and sunny. Crops grown in different climatic zones will have different water needs. Therefore, the water requirements of a given crop is calculated as shown in equation 2.5.

Table 2.1: Effect of major climatic factors on crop water needs

Climatic factor	Crop water need High	Crop water need Low
Sunshine	sunny (no clouds)	cloudy (no sun)
Temperature	hot	cool
Humidity	low (dry)	high (humid)
Wind speed	windy	little wind

$$ET_{crop} = K_c \cdot ET_o \qquad (5)$$

Where: ET_{crop} = the water requirement of a given crop in mm per unit of time e.g

mm/day, mm/month or mm/season.
K_c = the "crop factor"
ET_o = the "reference crop evapotranspiration" in mm per unit of time

While conventional irrigation strives to maximize the crop yields by applying the optimal amount of water required by the crops at well determined intervals, this is normally not possible with run-off farming when reservoir storage is not used. It is, therefore, a common practice to only determine the total amount of water which the crop requires over the whole growing season. However, since the values of ET_o are normally measured or calculated on a daily basis (mm/day), an average value for the total growing season has to be determined and then multiplied with the average season crop factor K_c. For example K_c values for maize grown in Kisangara will be as given in Figure 2.5. However, since water is the most important limiting factor especially under rainfed agriculture in the semi-arid areas, this method has shortfalls and is site-specific. It is therefore necessary to develop models which can estimate crop water requirement in a more dynamic manner.

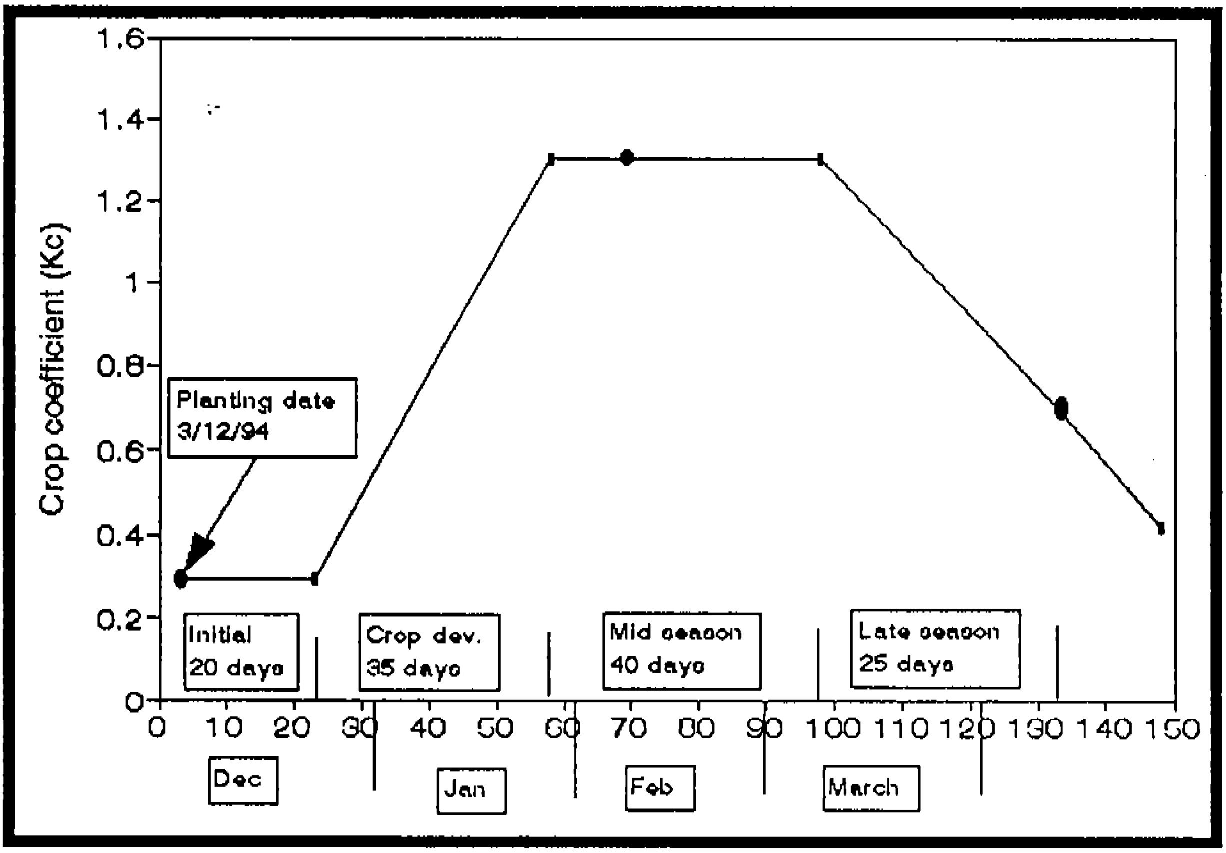


Figure 2.5 Maize crop coefficient curve for vuli 1993/94 Kisangara

2.1.3.2 Soils

The physical, chemical and biological properties of the soil affect the yield response of plants to extra moisture harvested. Generally the soil characteristics for water harvesting should be the same as those for irrigation. Ideally the soils in the catchment area should have a high runoff coefficient while the soil in the basin should be deep and fertile. The selection of a run-off farming site should, however, be made on the basis of the conditions of the cultivated basin.

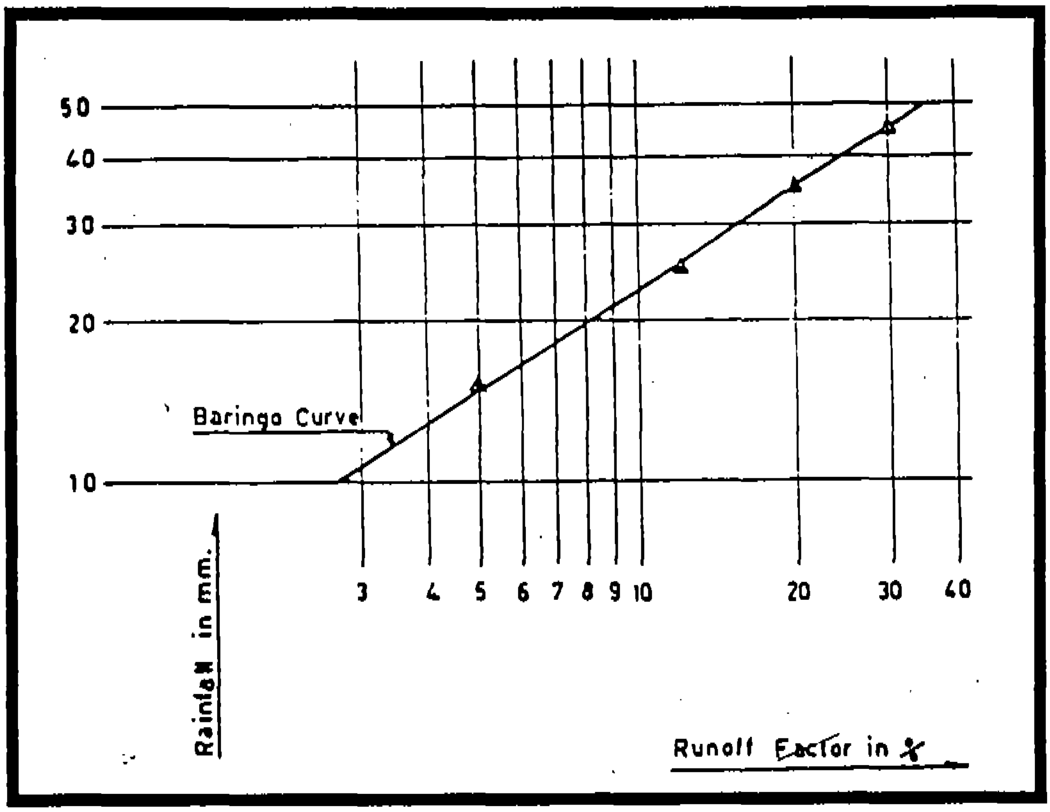


Figure 2.6: Rainfall-runoff relationships (After Finkel 1987)

A much better relationship is obtained if in addition to rainfall depth the corresponding rainstorm intensity, the rainstorm duration and the antecedent soil moisture were also measured (Figure 2.7).

These measurements are achieved by establishing runoff plots in the project area. The size and physical characteristics of the run-off plot should be representative of the site(s) where rain water harvesting schemes are planned. It is advisable to construct several plots in series in the project area which would permit comparison of the measured runoff volumes and to judge on the representative character of the selected plot sites. However such experiments are expensive, site specific and time consuming. Therefore, physical modelling approach can allow the application run-off plots data from one locality in another.

2.1.3.4 Catchment size

The most important design in run-off farming is the relationship between the sizes of the catchment area and basin (cultivated) area. For an appropriate design of a system, it is necessary to determine the ratio between catchment area (CA) and Basin area (BA).

The calculation of the Catchment to Basin Areas Ratio (CBAR) is based on the concept:

EFFECTIVE WATER HARVESTED = EXTRA WATER REQUIRED

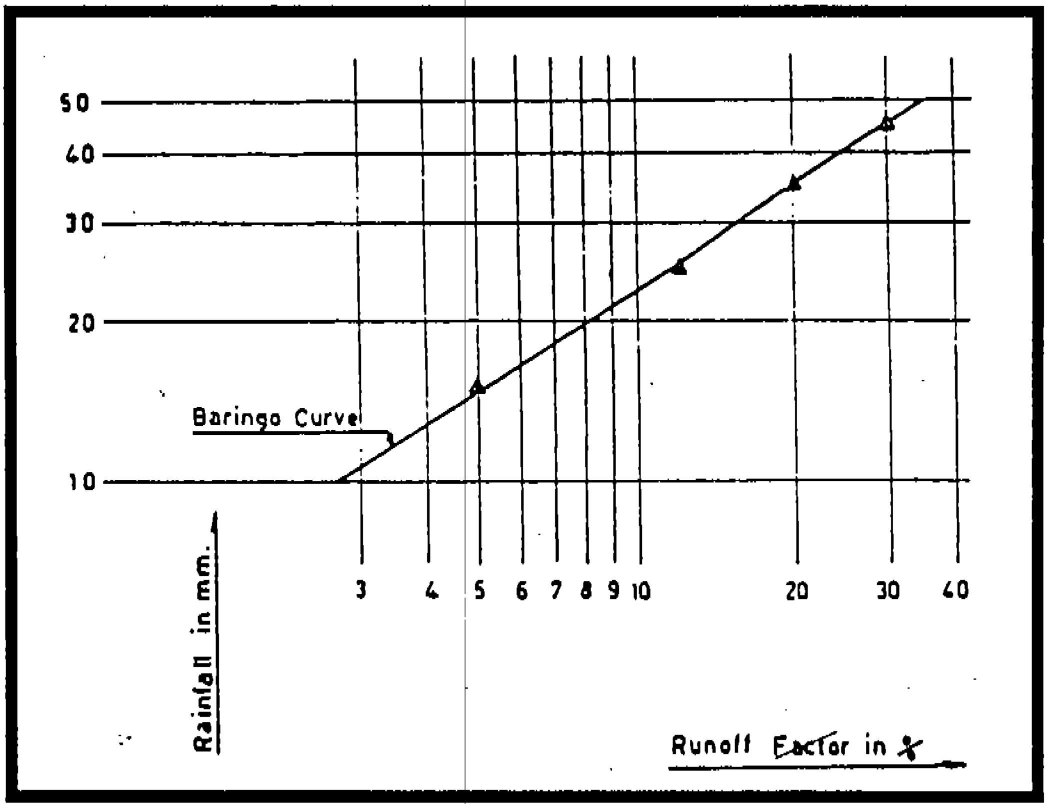


Figure 2.6: Rainfall-runoff relationships (After Finkel 1987)

A much better relationship is obtained if in addition to rainfall depth the corresponding rainstorm intensity, the rainstorm duration and the antecedent soil moisture were also measured (Figure 2.7).

These measurements are achieved by establishing runoff plots in the project area. The size and physical characteristics of the run-off plot should be representative of the site(s) where rain water harvesting schemes are planned. It is advisable to construct several plots in series in the project area which would permit comparison of the measured runoff volumes and to judge on the representative character of the selected plot sites. However such experiments are expensive, site specific and time consuming. Therefore, physical modelling approach can allow the application run-off plots data from one locality in another.

2.1.3.4 Catchment size

The most important design in run-off farming is the relationship between the sizes of the catchment area and basin (cultivated) area. For an appropriate design of a system, it is necessary to determine the ratio between catchment area (CA) and Basin area (BA).

The calculation of the Catchment to Basin Areas Ratio (CBAR) is based on the concept:

EFFECTIVE WATER HARVESTED = EXTRA WATER REQUIRED

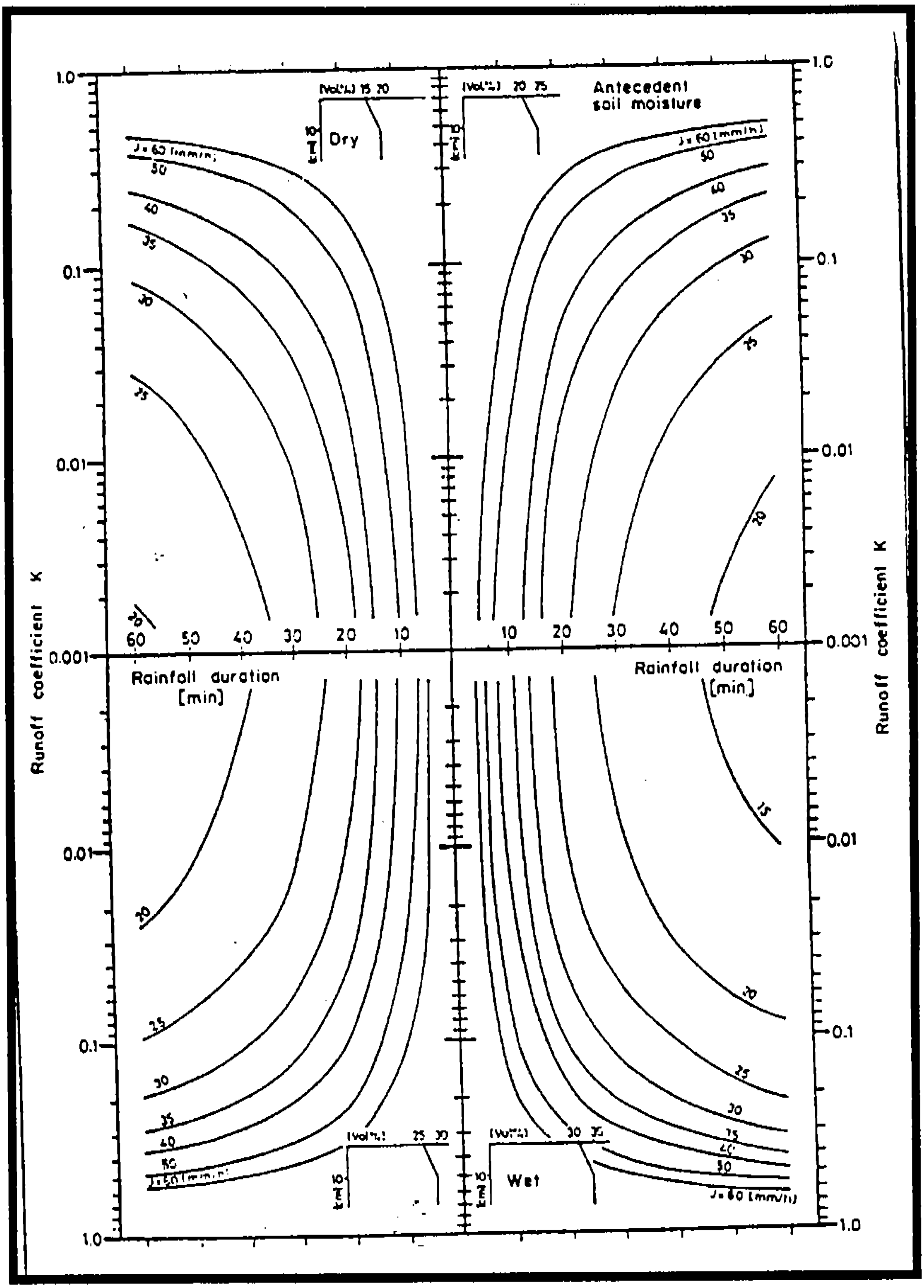


Figure 2.7: An example of the presentation of runoff coefficients in relation to rainfall intensity, rainfall duration and antecedent soil moisture (After Siegert 1978)

The amount of effective water harvested from the catchment area is a function of the amount of runoff created by the rainfall on the area. The runoff, for a defined time scale, is calculated by multiplying a "design" rainfall (P_D) with the runoff coefficient of the catchment. However, since all runoff can not be effectively utilized (because of losses), it must be additionally multiplied with an efficiency factor (e_B) to determine the effective water harvested.

$$EFFECTIVE\ WATER\ HARVESTED = CA \cdot P_D \cdot e_R \cdot e_B$$

The amount of extra water required is obtained by multiplying the size of the cultivated basin (BA) with the total water requirement less the assumed "design" rainfall.

$$EXTRA\ WATER\ REQUIRED = BA \cdot (ET_{CROP} - P_D)$$

Therefore,

$$CBAR = \frac{CROP\ WATER\ REQUIREMENT - DESIGN\ RAINFALL}{DESIGN\ RAINFALL \cdot RUNOFF\ COEFFICIENT \cdot EFFICIENCY\ FACT}$$

However, it should be noted that calculations are always based upon parameters with very high variability. Rainfall and runoff are characteristically erratic in the semi-arid areas. It would therefore, sometimes be necessary to modify an original design in the light of experience, and often it will be useful to incorporate safety measures, such as cut-off drains, to avoid damage in years when rainfall exceeds the design rainfall. This process can be improved by the use of simulation techniques whereby the input parameters may be easily changed while observing the outputs.

2.2 Current Practices in Tanzania

2.2.1 Characteristics

Rain water harvesting for crop production is generally practised in many parts of Tanzania through the utilization of flood water collecting in valley bottoms. In many parts of the semi-arid zone, the valleys surrounded by runoff producing slopes are used to produce high water demanding crops such as paddy, vegetables, sugar cane and maize. The semi-arid zone 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. Rice production is dependent on rain-water harvesting more than any other crop.

Land which is 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 40'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).

The "Majaruba" system used by farmers in these areas can be divided into 2 categories depending on the relationship between the catchment area and the cultivated basin. The basins consist of bunds of heights varying between 25 and 100 cm with simple provisions for entry and egress of water. The categories are differentiated by the way the water is captured and directed to basins.

a) Elevated Ground Catchment (Figure 2.8 (a)): In this arrangement the contributing catchment is an elevated ground relative to the cultivated land, and contribute sheet surface flow directly. The catchment will normally be of a rocky terrain and where residential areas are located. Due to the frequent deposition of fine sediments the basin area has become very fertile. The exact CBAR is not known but may be around 10 - 15:1, and the runoff coefficient vary between 15 - 30%.

b) Flood water diversion (Figure 2.8 (b)): Under this system farmers divert water from its natural course and direct it to the cultivated basins (Majaruba). The diverted flow is conveyed through a system channels and bunds. These channels sometimes deliver water up to 2 km distance. The command catchment is large at 10 km^2 or more and the runoff coefficient is estimated to be 12%.

The construction of the bunds around the cultivated basins is completed over a period of 2-3 seasons. Most of the bund construction is done soon after the first rains. This is because during the dry season the soils are too hard to be worked and also further into the season, the soil is too sticky. The bunds are protected against erosion by planting the star grass *(Cynodon dactylon)* on them. The size of the cultivated basin ranges between 0.1 to 0.5 ha. Puddling of the soil is done after the basin is filled with water to a depth of 5-7 cm. However, during the growing season the depth of trapped water may exceed 50 cm.

2.2.2 Performance and Main Constraints

Very little research has been done to evaluate the performance of the system in relation to moisture and soil conservation. However, the results speak for themselves, since paddy rice is being produced in areas which are considered marginal even for sorghum production (Figure 1.2). However, yields under rain water harvesting are estimated to be only 1.0 t ha^{-1} as compared to lower Moshi for example, with average yields of 6.0 t ha^{-1}. Water is not the only limiting factor that reduces yields under rain water harvesting, but also low yielding varieties and poor agronomic practices. Farmers prefer the local varieties for their taste although they are low yielding.

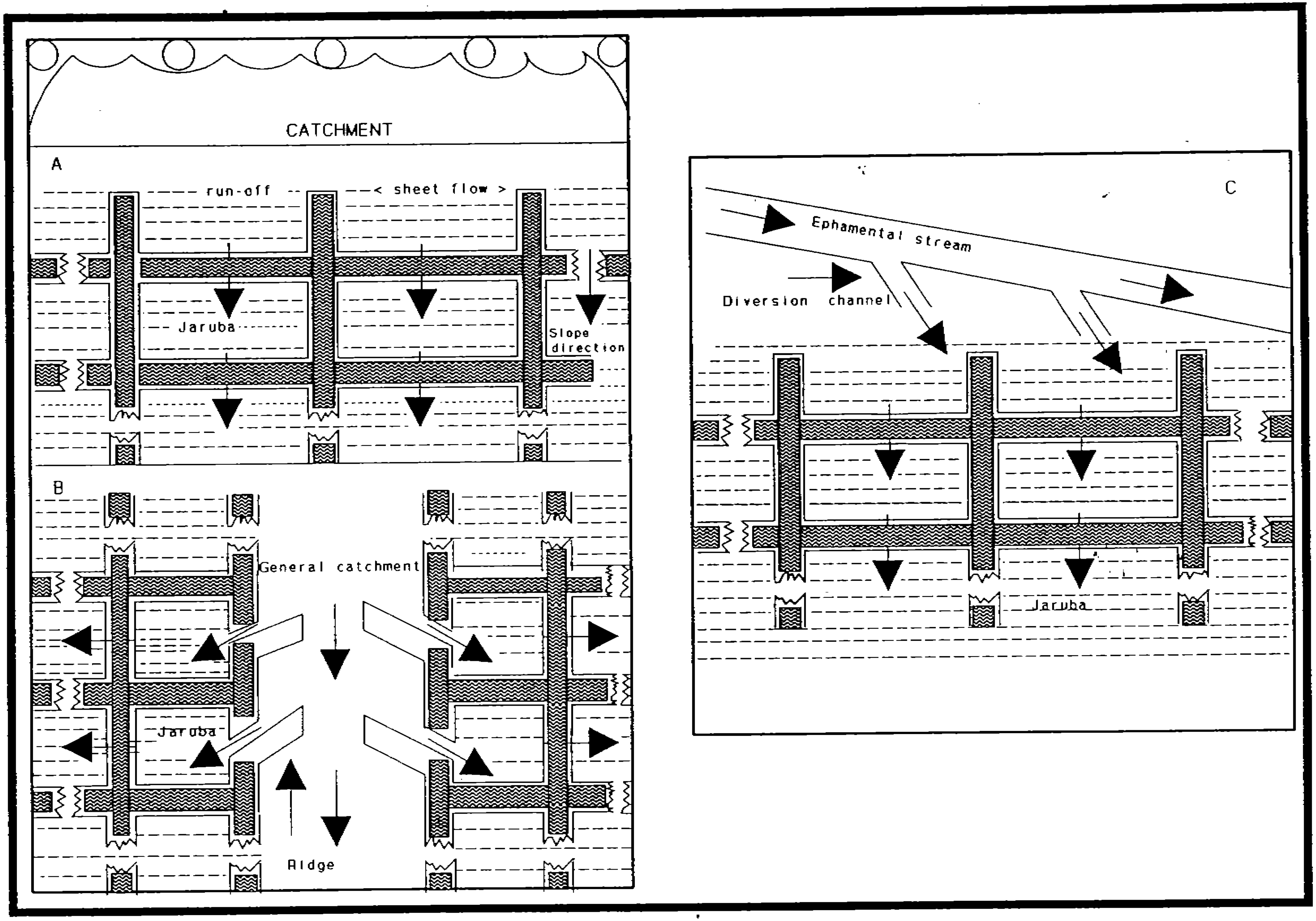


Figure 2.8: Layout of catchment and basin area for the paddy production system

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 problems early in the season.
- Low strength of the bunds due to poor construction methods, leading to flood damages 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.
- Very high loss of water by evaporation from the cultivated basin.

Reliable data concerning costs and benefits of rain water harvesting for paddy production in Tanzania, are scarce. However, the continued increase of rice production in the semi-arid areas of Tanzania, where farmers have received very little technical assistance, is a good indicator that runoff rice farming is a viable proposition. There is, therefore, an urgent need to assess the true potential of this technology.

Since farmers consider rice as a cash crop, many will choose to grow rice if the problems associated with rain water harvesting are removed. Therefore, improvement of rain water harvesting for rice production makes good socio-economic sense.

3. METHODOLOGY

3.1 Climatic Characterisation

3.1.1 Instrumentation

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

Morogoro and Same are full meteorological stations while only rainfall has been monitored in 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 thermometer have been installed at Kisangara since 1992. For long term analysis of weather, Same data is used to give a picture of what would be expected in Kisangara.

3.1.2 Rainfall

Long-term rainfall data for Morogoro and Same were obtained from the archives of the Department of Meteorology in Dar es Salaam. Daily and monthly rainfall records for Kisangara were obtained from the Karimjee Agriculture Ltd, Kisangara Sisal Estate. The following processing were conducted:

- 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_6)
  - 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
N = total number of observations used.

Longest dry spells for each month were recorded by considering a wet day with

3 mm or more rain 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.

All the analysis was done on seasonal basis, that is:

- Short rainy season (Vuli) was considered to last between August and January
- Long rainy season (Masika) was considered to last between February and July.

3.1.3 Other Weather Parameters

Long-term historical temperature and evaporation data for Morogoro and Same were obtained as for rainfall. Analysis was conducted on the same basis for the following parameters:

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

- Monthly minimum temperature
  - Minimum
  - Mean
  - Maximum

- Monthly maximum temperature
  - Minimum
  - Mean
  - Maximum

3.2 Materials and Methods

3.2.1 Location

Researcher - managed experiments are located at two sites, namely, Morogoro on Sokoine University of Agriculture (SUA) farm, and Kisangara near Mwanga township in Kilimanjaro Region.

3.2.1.1 Morogoro

Morogoro site is located within SUA farm near the main University gate. This site has been under maize cultivation for several years and then under vegetation fallow for two years prior to the initiation of the present experiments (Plate 1).

The slope of Morogoro 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 loam underline 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 Eutric regosol (FAO/UNESCO System) (Kaaya, 1989).

3.2.1.2 Kisangara

Kisangara site is located within the Karimjee Agriculture Sisal Estate in Mwanga district Kilimanjaro region (Figure 3.1). The land which was under sisal since 1975 (Plate 2) was cleared with a front mounted shear blade bulldozer to pave way for the current experiments.

The slope of Kisangara site is 2-3% on the lower part and 7-10% 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% sand) depicts low water holding capacity.

The soils of the lower slope (2-3%) are deep (100-140 cm) brown and red soils developed on 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 Kisangara 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)

3.2.2 Experiments and Layout

The layouts of the experiments in both Morogoro and Kisangara are shown in figure 3.2 and 3.3.

3.2.2.1 Runoff catchment experiment

In Morogoro the experiment was a runoff yield factorial trial of three factors, namely:

(i) Size at 2 levels: 10x5m and 10x10m

ii) Surface characteristics with four treatments;
- Natural vegetation (V) where the catchment was allowed to grow with natural vegetation of the area with minimal interference.
- Low managed crop (LMC)
- Bare surface (B)
- Bare and compacted surface (BC), where compaction was done by using a hand pushed roller passed 5 times over moist soil (Plate 3).

iii) Slope at 2 levels: 2-3% and 5-6%

The trial is replicated twice in each slope. Only the surface catchment treatments were randomized within the block. The same layout is repeated at Kisangara but the trial is not replicated.

3.2.2.2 Runoff farming experiment

In Kisangara runoff farming experiment was carried in two slopes. Treatments were four catchment sizes viz: 0:1, 1:1, 2:1 and 4:1 Catchment: Basin Area Ratio (CBAR) and two tillage practices namely staggered ridging and flat cultivation applied on basin area for each CBAR. The basin area was 10m wide and 5m long.

Maize (*Zea mays* cv TMVI) was planted with TSP at a rate of 40kg P/ha for all plots in 8%. In 3% slope treatments were 0:1, 2:1 and 4:1 and two tillage practices namely staggered ridging and flat cultivation applied on basin area for each CBAR. The basin area was 10m wide and 5m long. Maize (*Zea mays* cv TMVI) was planted with TSP at a rate of 40kg P/ha. At 6th leaf stage N was either applied at a recommended rate of 40kg N/ha (FP) or none (NF) for each catchment size in 3% slope (Figure 3.3).

In Morogoro, runoff farming experiment was carried in two slopes 2-3% and 4-6%. The treatments were four catchment to basin ratio viz 0:1, 1:1, 2:1 and 4:1 and tow tillage practices namely staggered ridging (SR) and flat cultivation (FC) on basin area for each C:B. The basin area was 5m long and 10m wide. Maize (*Zea mays* cv staha) was planted with TSP at a rate of 40kg P/ha and top dressed with 40kg N/ha at 6th leaf (Figure 3.4).

The tillage treatments were flat cultivation with a hand hoes to a depth of 10-15cm and staggered ridges were constructed at a spacing of 0.75m with staggered openings to allow both the ponding and spreading of runoff (Plate 4). All the sides of the plots were raised to form protective strong bunds to isolate each plot to ensure that no surface runoff enters or leaves the plot. In each site and each slope the plots were replicated three times in randomized complete design.

3.2.2.3 Soil conservation experiment

This was a tillage cum soil-water conservation experiment conducted in Kisangara on the 7-10% slope on 5 x 25m^2 plots. The treatments were:

- Zero tillage (Kitang'ang'a) where maize is planted without primary tillage;
- Flat cultivation with a hand hoe to a depth of 10-15cm, without any bunds to control run-on or runoff;
- Flat cultivation, as above, with contour ridging located at five metres spacing to slow down the runoff and hence improve infiltration;
- Flat cultivation, as above, with stone bunds located at five metres interval again for controlling runoff;
- Flat cultivation, as above, with live barriers of vetiver grass and local live plant called "Iduri" (Plate 5).

3.2.3 Soil and Plant Measurements

3.2.3.1 Soil bulk density

Soil core for bulk density determination were collected immediately after tillage, during mid-growing season and after crop harvest, down to a depth of 20cm in 5cm increments. The soil cores were placed in an oven at 105°C and dried until constant weight was achieved.

3.2.3.2 Total porosity

Total porosity, the volume of voids in a core sample expressed as a percentage, was calculated from the relationship between bulk density and particle density (i.e. the density of the solid material viz. 2.65 Mgm^{-3} for most mineral soils):

Where S_t = total porosity, D_B = bulk density and D_p = particle density.

$S_r = [1-(d_a/d_p)] \times 100$

3.2.3.3 Soil moisture

Soil moisture content was measured at 0-30cm depths using neutron probe model 503 DR Hydroprobe. Soil moisture was monitored at 7-10 days intervals during the dry period and after every rainfall event in runoff farming and soil conservation experiments and on a daily basis in runoff collection catchments experiment.

3.2.3.4 Infiltration of water

Infiltration of water into the soil was measured immediately after tillage, during mid growing season and after crop harvest by double ring infiltrometers with an inner ring diameter of 25.5 cm and according to Klute (1986). Infiltration measurements were terminated after 3 hours.

3.2.3.5 Saturated hydraulic conductivity

Saturated hydraulic conductivity of the soil was determined by the constant head permeameter according to Klute (1986) before tillage, immediately after tillage and after harvest by core sampling to the depth of 15 cm.

3.2.3.6 Soil water release characteristics

Soil cores for laboratory determination of water release characteristics on tension table (Clement, 1966) and pressure plate extractors (McIntyre, 1973) were taken from one replication immediately after tillage down to 20 cm depth in 5 cm increments.

3.2.3.7 Runoff and soil loss

The runoff collection system is shown in Figure 3.4. It consists of a divider drum with 15 outlet pipes of diameter 1.91 cm. The central pipe is connected to the collector drum by a hose pipe. The overflow pipes of the divider drum are adjusted such that the overflow volume draining into the collector drum is 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 and sediment collected in 200 litre drums (of the runoff collection system) was recorded by a metre steel rule. The water and sediment in the drum were thoroughly stirred for five minutes . A sample from each stirred drum was then taken and put in one litre bottle. The bottles were labelled and stored for laboratory sediment concentration determination.

3.2.3.8 Seedling emergence

Seedling emergence was determined by counting the number of seedlings that had emerged and comparing it to the total number of expected to emerge in each plot.

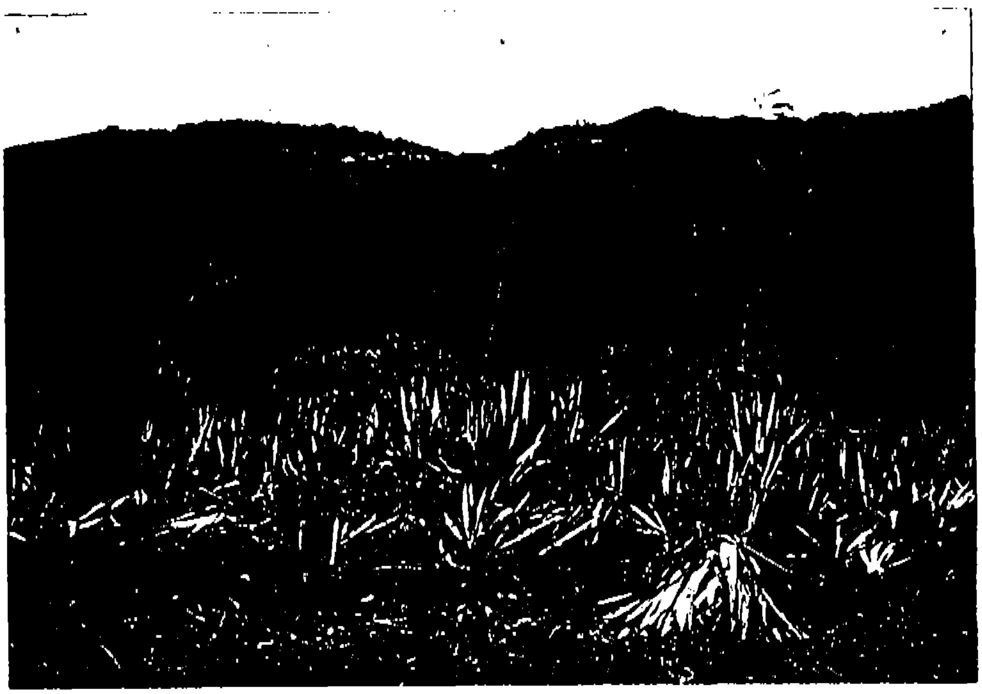
3.2.3.9 Biomass accumulation

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.

3.2.3.10 Grain yield and 100 seed weight

At maturity all the maize plants in each plot (except those in guard rows) were cut at ground level ears harvested and shelled and grain yield recorded at 10% moisture content. A 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.

a) Before clearing



b) after clearing

Plate 1: Vegetation of Kisangara site

Plate 2: Vegetation cover of Morogoro site before clearing

Plate 3: Catchment compaction by hand pushed roller

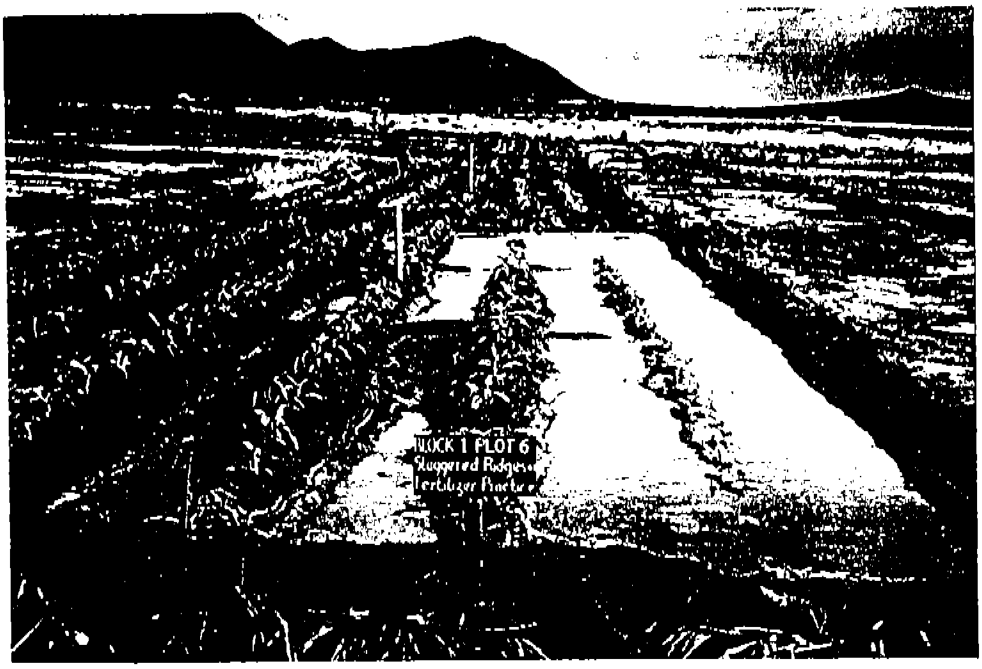


Plate 4: CA:CF arrangement: the crop id on staggered ridges

Plate 5: Soil conservation experiment, live barriers, "Iduri".

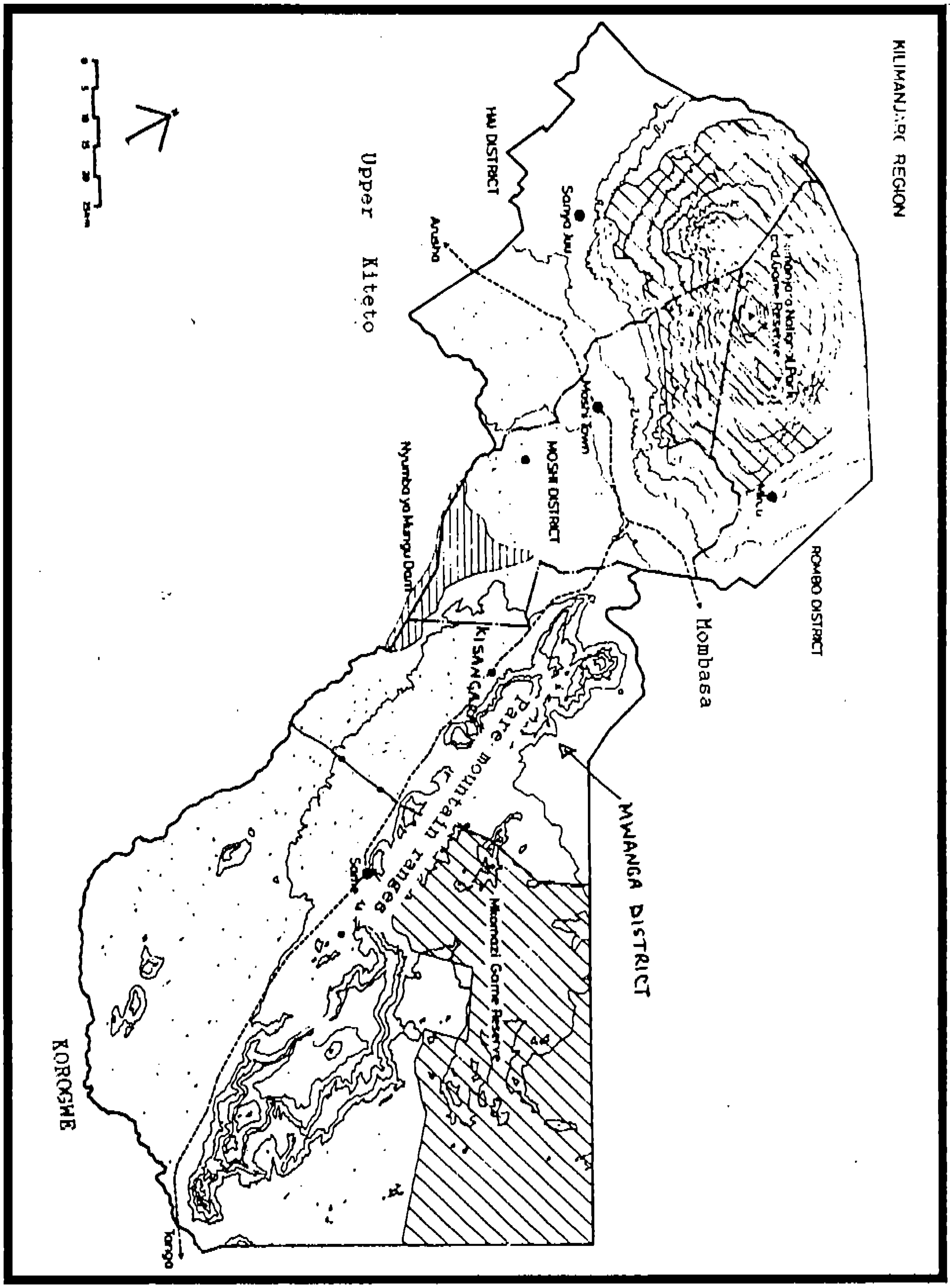


Figure 3.1 (a) Kilimanjaro region

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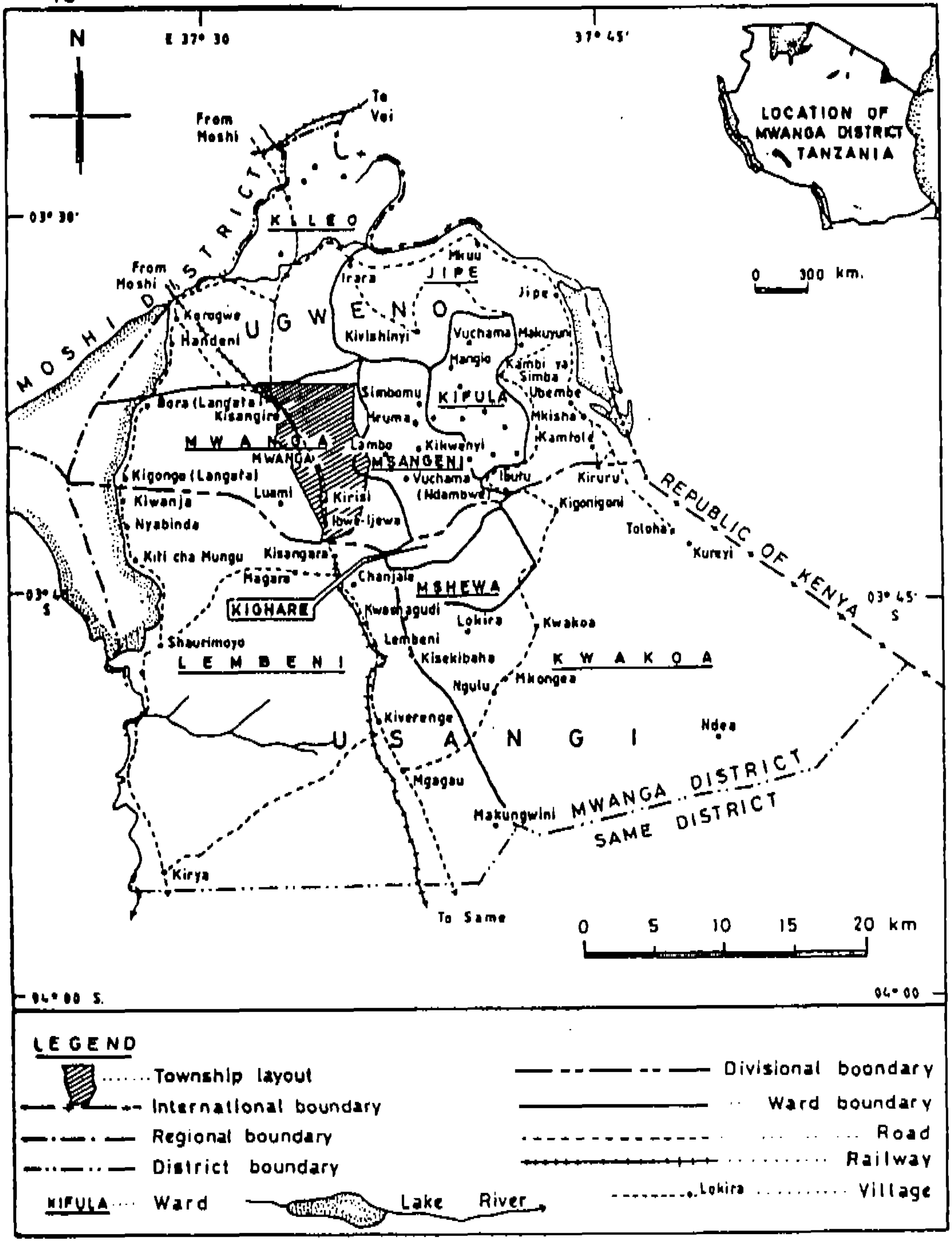


Figure 3: Mwanga district

Figure 3.1 (b) Mwanga district

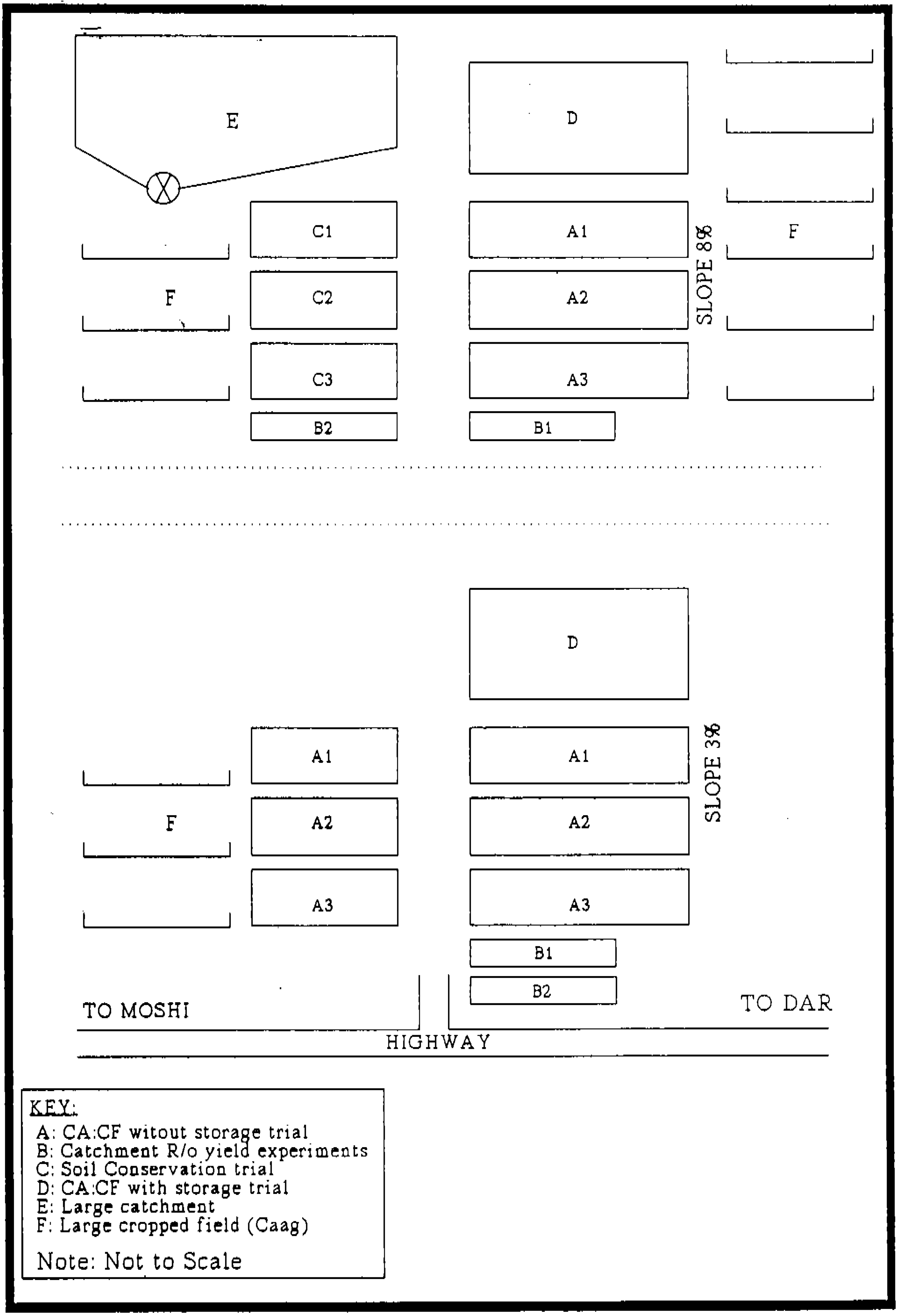


Figure 3.2(a): Layout of the experiments in Kisangara site

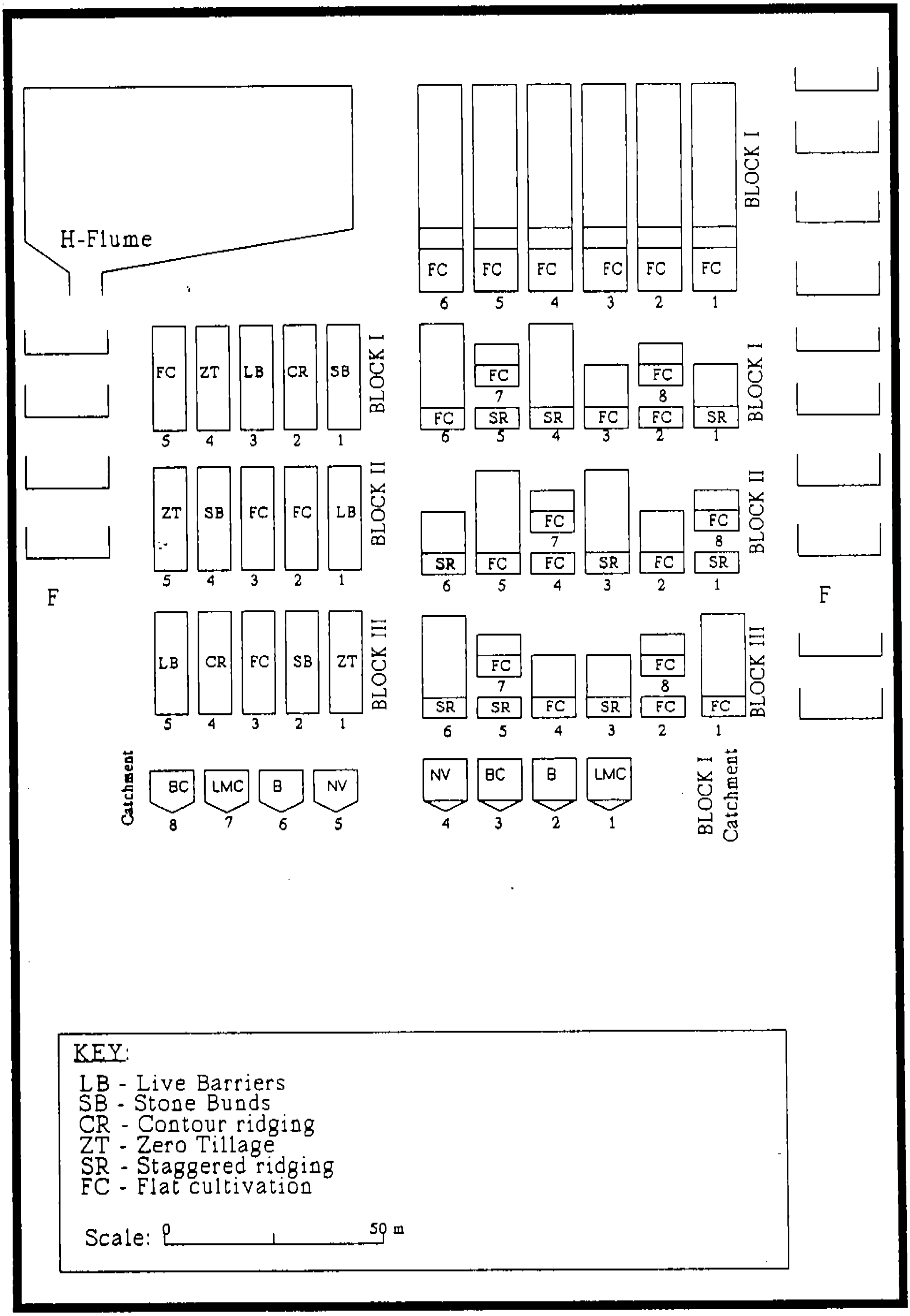


Figure 3.2(b): Layout of the experiments in 8 % slope Kisangara

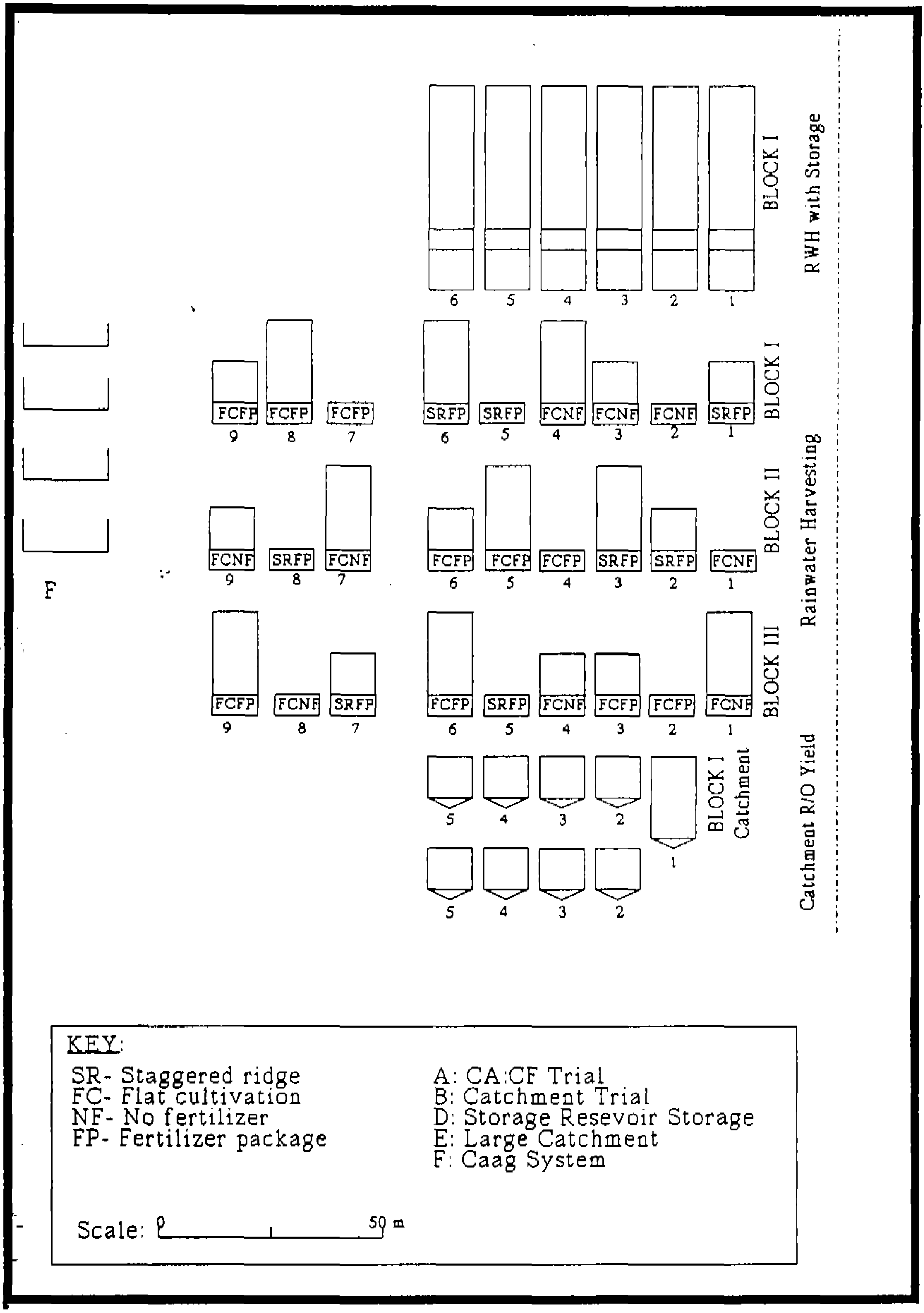


Figure 3.2(c): Layout of the experiments in 3 % slope Kisangara

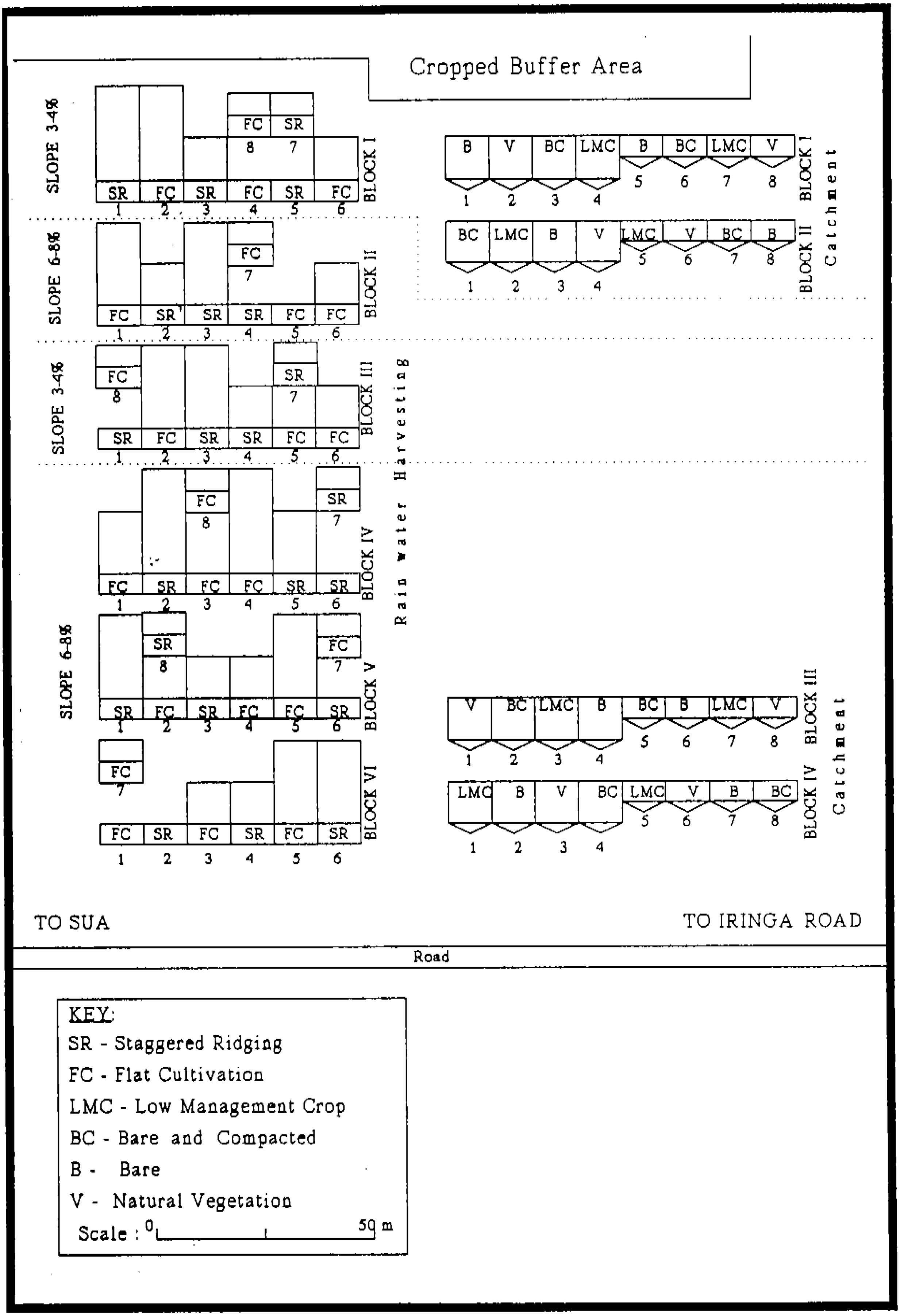


Figure 3.3: Experimental layout of Morogoro site

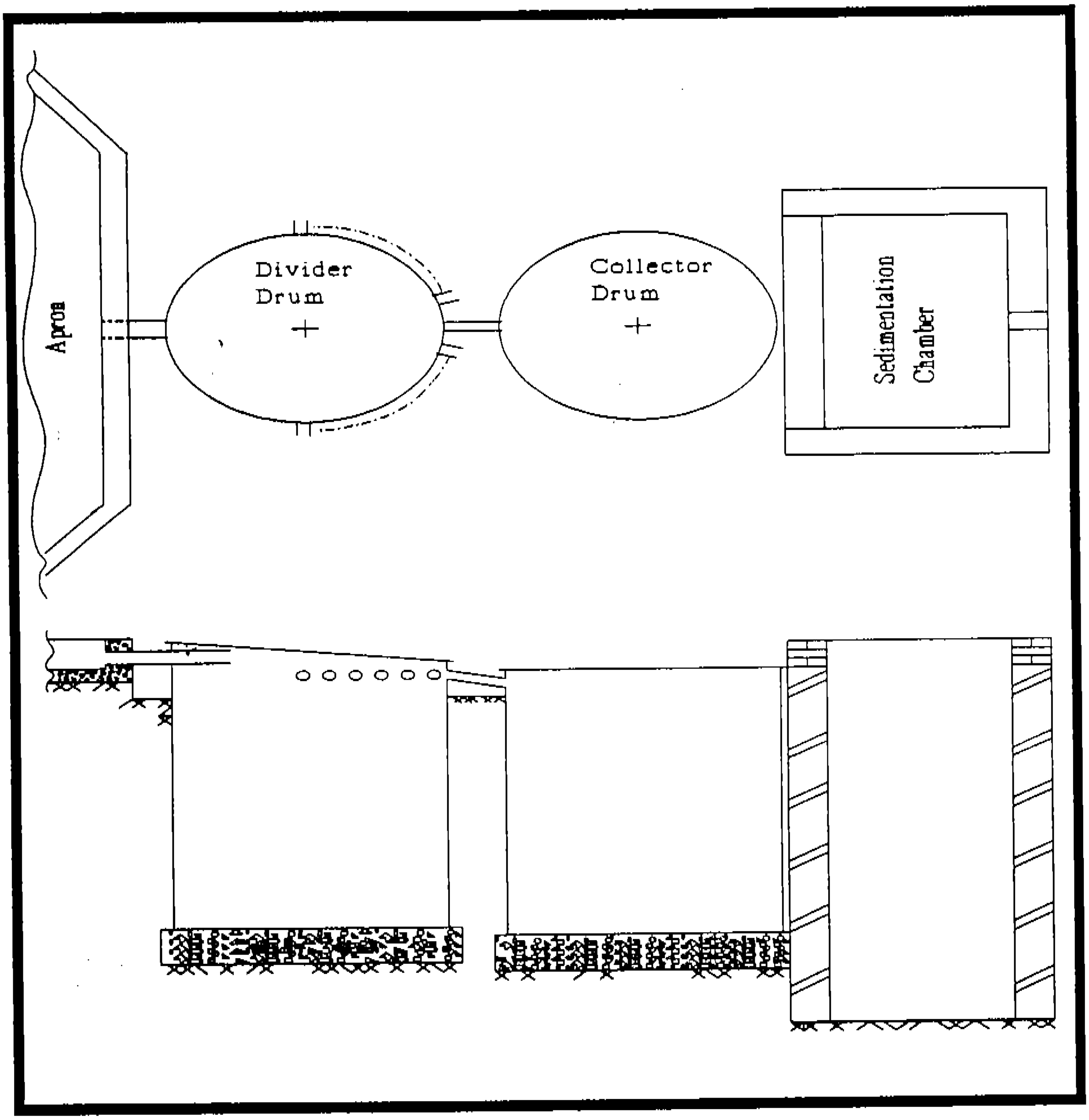


Figure 3.4: Runoff collection system

4. RESULTS

4.1 Climatic Characterization

4.1.1 Rainfall

4.1.1.1 Short rainy season [Vuli]

Rainfall for Vuli is most unreliable at all the three stations; Morogoro, Same and Kisangara. The seasonal total rainfall with 70% probability is only 230, 258, and 178 mm for Morogoro, Kisangara and Same, respectively (Table 4.1). Vuli rainfalls are also very variable from season to season. The difference between maximum and minimum seasonal amounts is 447.7, 828.7 and 429.8 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 stations, the 30% chance longest dry spell exceed 14 days in all the months (Table 4.1).

At Morogoro Vuli 1993/94 had only 143.7 mm and Vuli 1994/95 had 285.3 mm. The first is below the 70% probability rainfall while second is above. However, the 1993/94 season was affected by bad distribution where most of the rain was received towards the end of the season, in January. A similar trend was observed in Kisangara, where the 1993/94 Vuli rainfall was below 70% probability rainfall and the 1994/95 was above. The distribution was favourable in the 1994/95 season as the longest dry spells in the important growth months of November and December were only 6 and 5 days, respectively.

The long term average intensities of Vuli rains are not as high as would be expected of a tropical semi-arid area. Majority (65%) of Vuli rainfall storms in both Morogoro and Same have peak I_5 of less than 15 mm/hr. For longer duration intensity i.e. I_{30} the percentages were 80 and 85 for Morogoro and Same, respectively. Only 7.5 and 12.5% storms fell with I_5 of more than 50 mm/hr for Morogoro and Same, respectively, (Figure 4.1).

4.1.1.2 Long rainy season (Masika)

Masika rains are higher in general and vary between 336-757, 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. Only the month of April suffer a dry spell of less 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 4.1).

During the experimental period, data was analyzed for Masika 1993 and 1994. The seasonal rainfall at Morogoro was 700 and 520 mm, for 1993 and 1994, respectively. At Kisangara the seasonal rainfall was 225 and 381 mm, for 1993 and 1994, respectively. At both sites the 1994 rainfall was also better distributed with no dry spell exceeding 14 days between February and May.

The Masika rain fall with even lower intensities in both Morogoro and Same. The majority (65% and 70% for Morogoro and Same, respectively) of rain storms in Masika fell with I_6 of less than 15 mm/hr. For 30 minutes duration the intensities were even lower with 82 and 85% of the total storms recording less than 15 mm/hr for Morogoro Less than 10% of storms had I_6 and I_{30} of more than 50 mm/hr (Figure 4.2).

4.1.2 Other Weather Parameters

4.1.2.1 Vuli

Results of analysis show that the minimum temperature during Vuli vary between 17.9 - 22.3°C and 14.2-20.3°C, for Morogoro and Same, respectively. The maximum temperature vary between 26.8 and 34.1°C for Morogoro and 24.3 and 34.7°C for Same.

Evaporation during vuli varies between 786 and 1,325.6 mm, and between 1,119.0 to 1,610.9 mm for Morogoro and Same, respectively. Evaporation rates in Kisangara would be expected to be similar to those of Same. During Vuli long term average minimum evaporation exceeds the 70% probability rainfall in all years in both Morogoro and Same (Figure 4.3).

4.1.2.2 Masika

In Masika temperatures are also high and the monthly mean minimum temperature vary between 13.9 and 22.2 in Morogoro. For Same the monthly mean minimum temperature ranges between 13.2 and 20°C. The maximum temperatures range between 25.9 and 34.4°C in Morogoro and between 24.4 and 33.9°C for Same. Therefore, in terms of temperature there is no much difference between the two sites or the two seasons.

The rates of evaporation is between 550 and 1,817 mm in Morogoro and vary between 872 and 1,325 mm in Same. Therefore, even during masika where some cloud cover is expected the rates of evaporation are also high. In Morogoro monthly rainfall expected 70% of the time 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 4.4).

4.1.3 Crop Water Requirements

4.1.3.1 Long term average

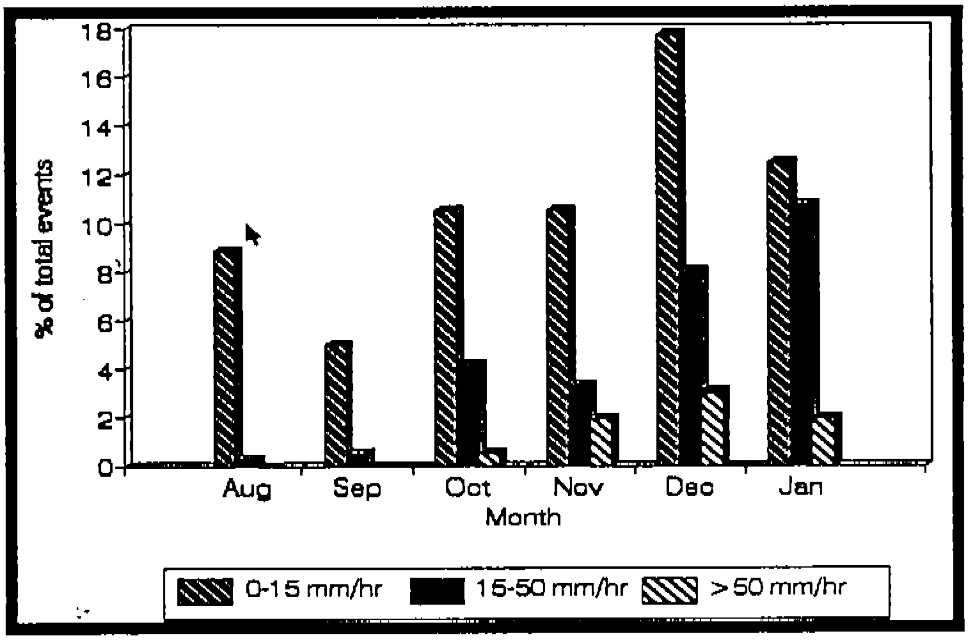
The long term average crop water requirement for maize calculated using 70% probability evaporation is higher than rainfall in almost all Vuli seasons in Morogoro and Kisangara (Figure 4.5).In Morogoro only six out of twenty four Vuli season had rainfall above or just below the seasonal crop water requirement. 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 4.6).

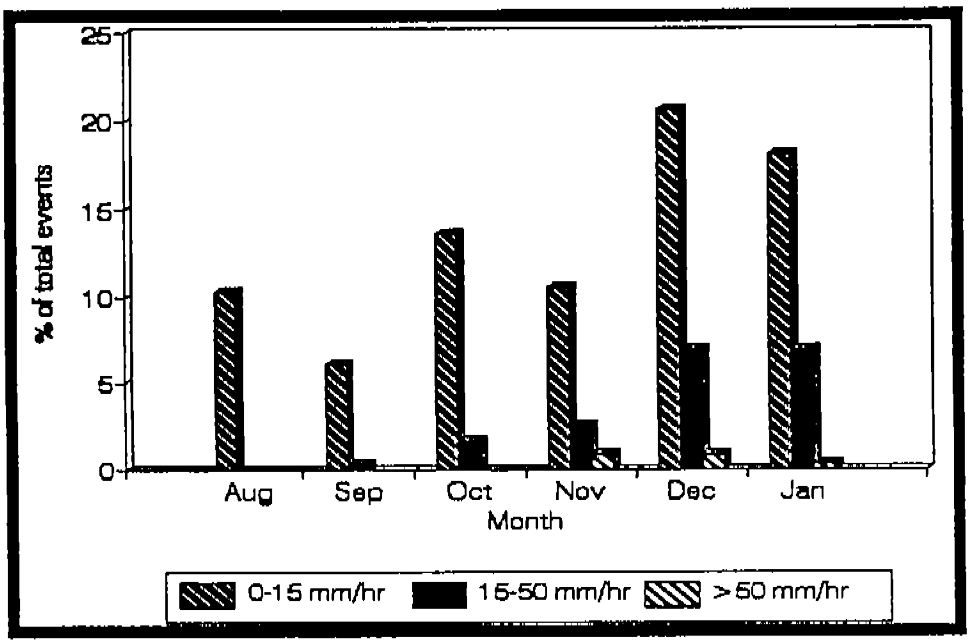
The relationship between seasonal rainfall and crop water requirements during the research period are given in Figure 4.7. Vuli 1994/95 was a good year in Kisangara and similarly Masika 1994 in Morogoro.

a) Morogoro

(i) 5 minutes intensity

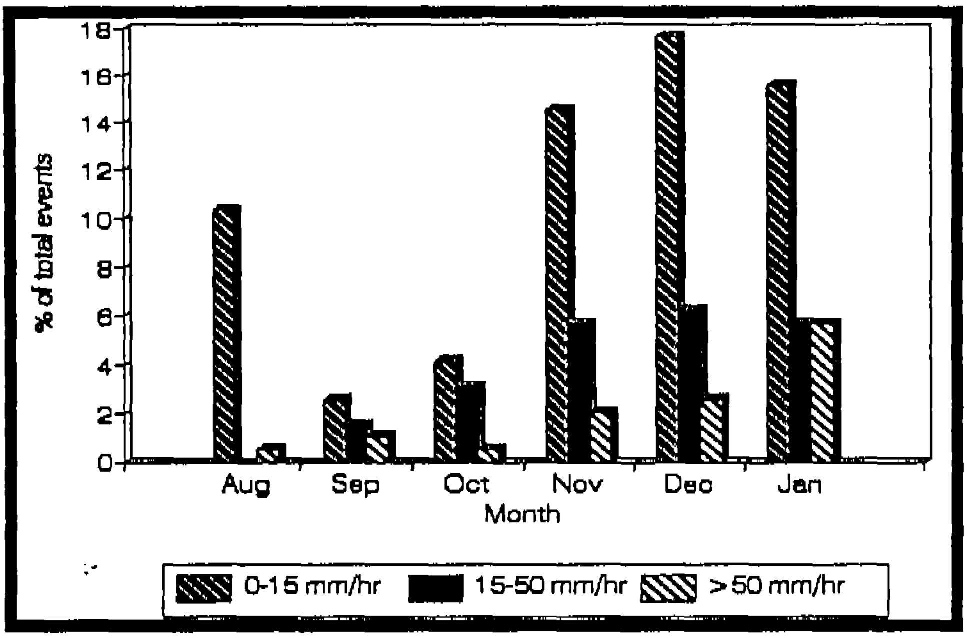


(ii) 30 minutes intensity



b) Same

(i) 5 minutes maximum intensity



(ii) 30 minutes maximum intensity

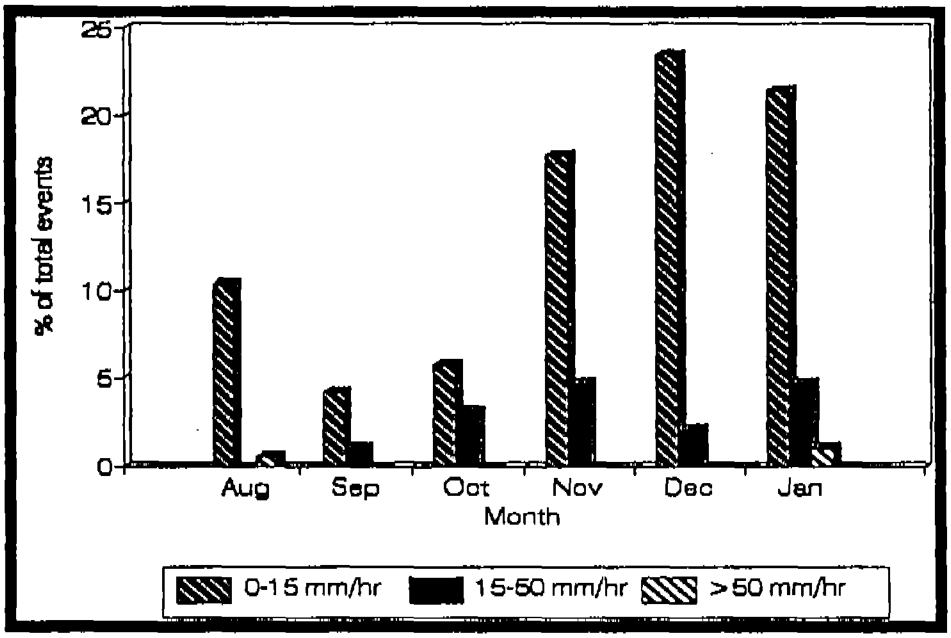
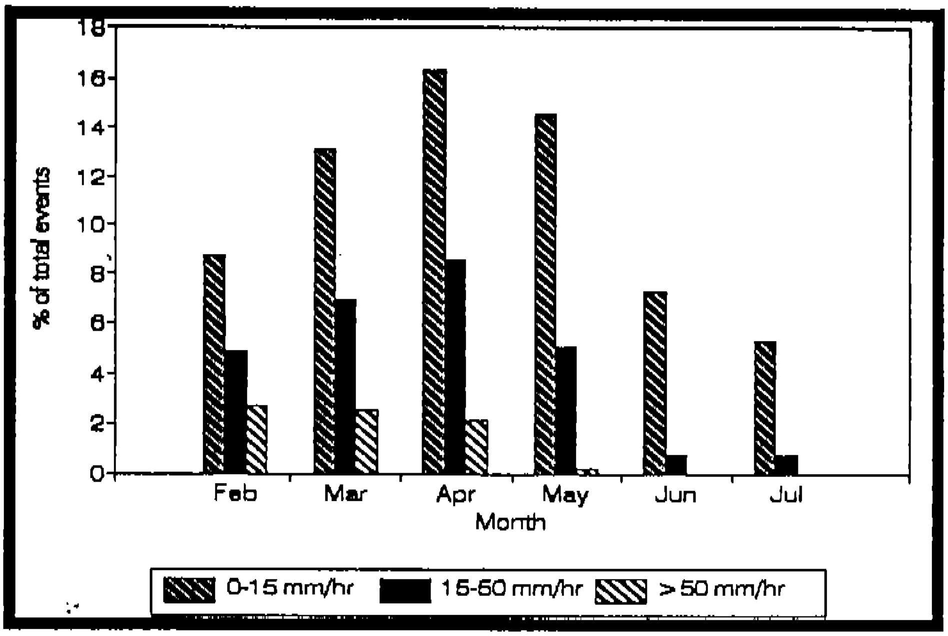


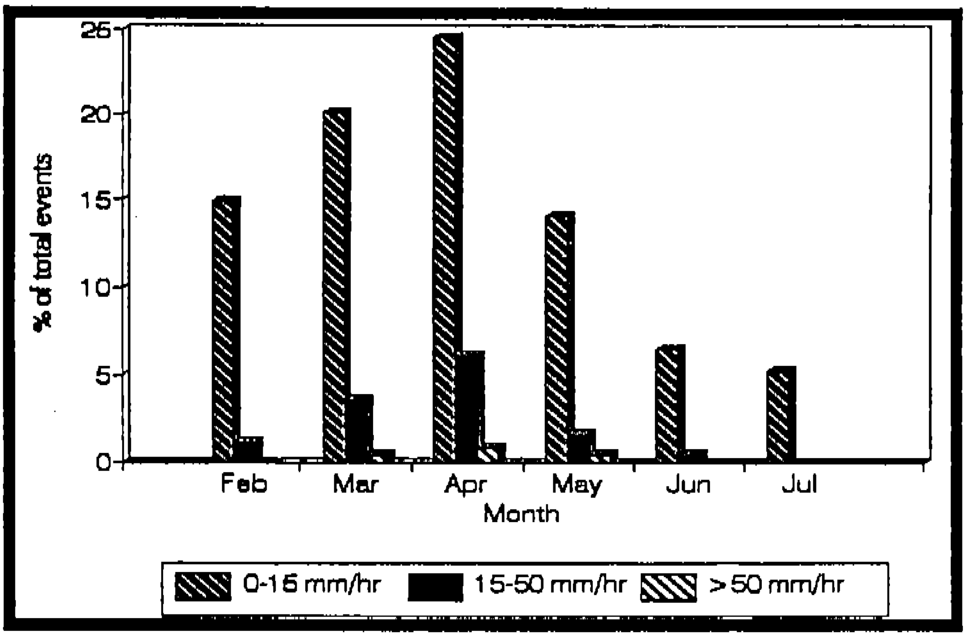
Figure 4.1 Frequency distribution of I_5 and I_{30} during Vuli, in Morogoro and Same

a) Morogoro

(i) 5 minutes maximum intensity

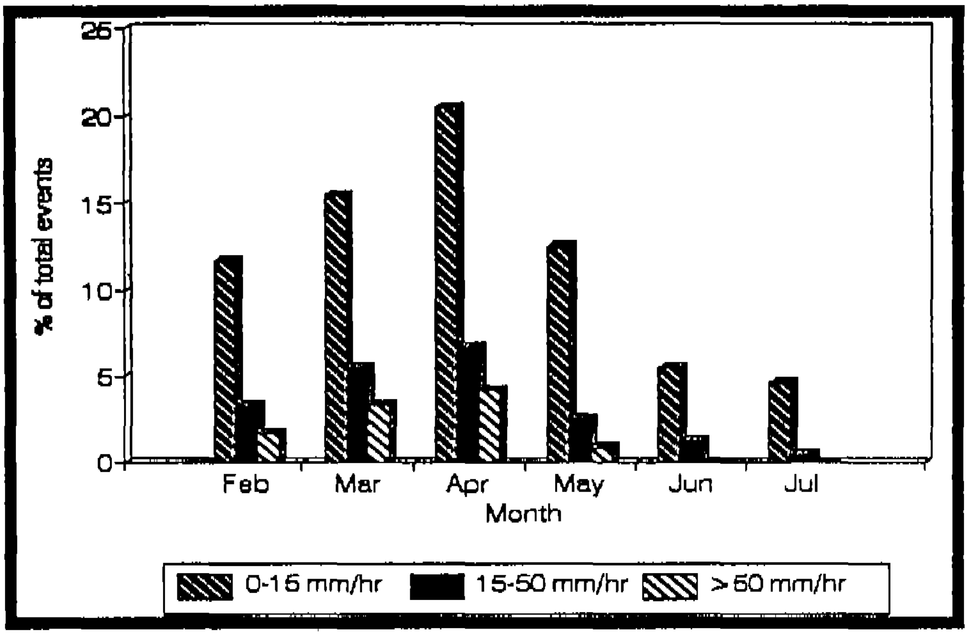


(ii) 30 minutes maximum intensity



b) Same

(i) 5 minutes maximum intensity



(ii) 30 minutes maximum intensity

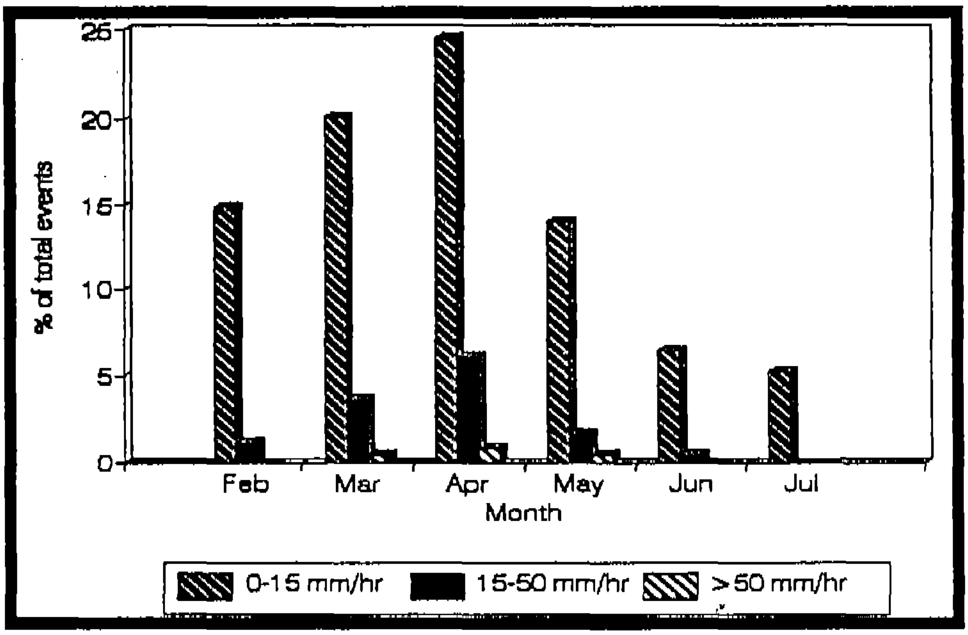
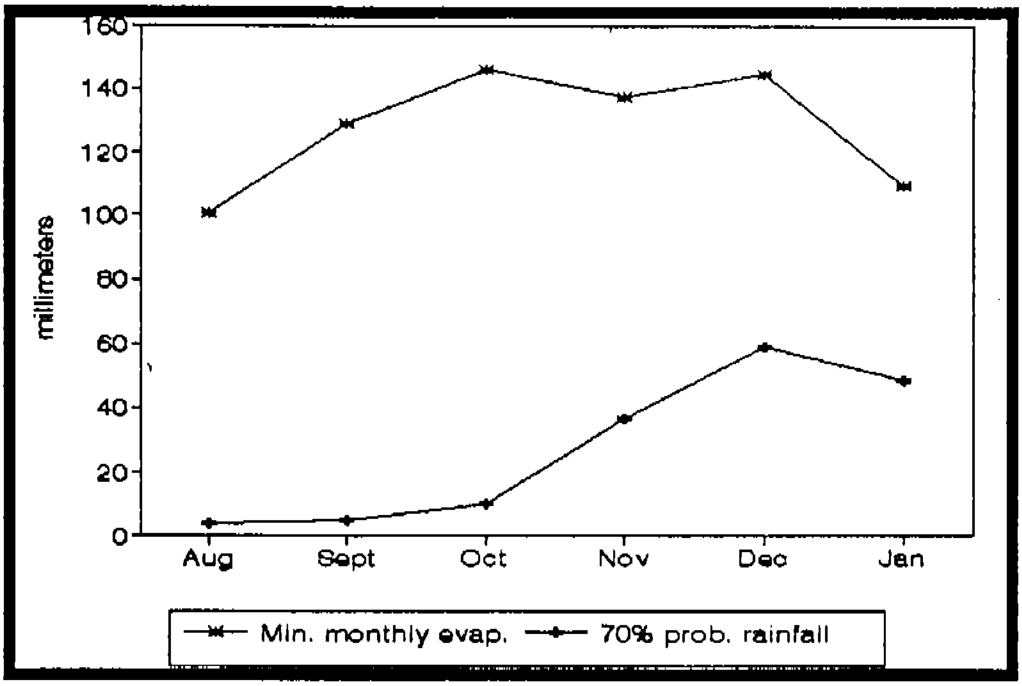


Figure 4.2: Frequency distribution of I_5 and I_{30} during Masika, in Morogoro and Same

a) Morogoro



b) Same

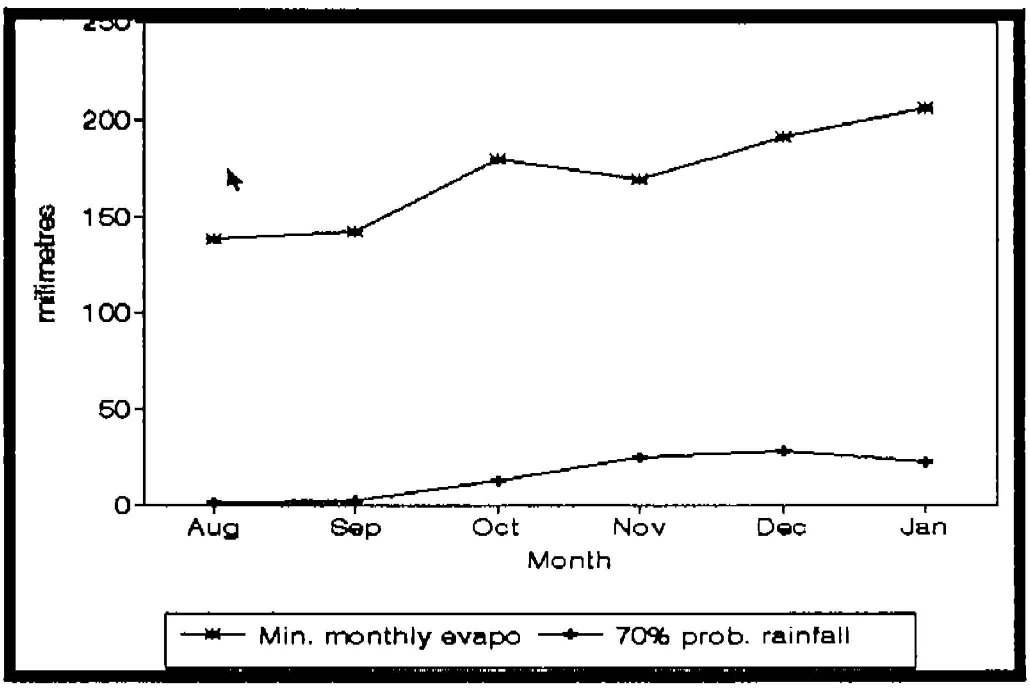
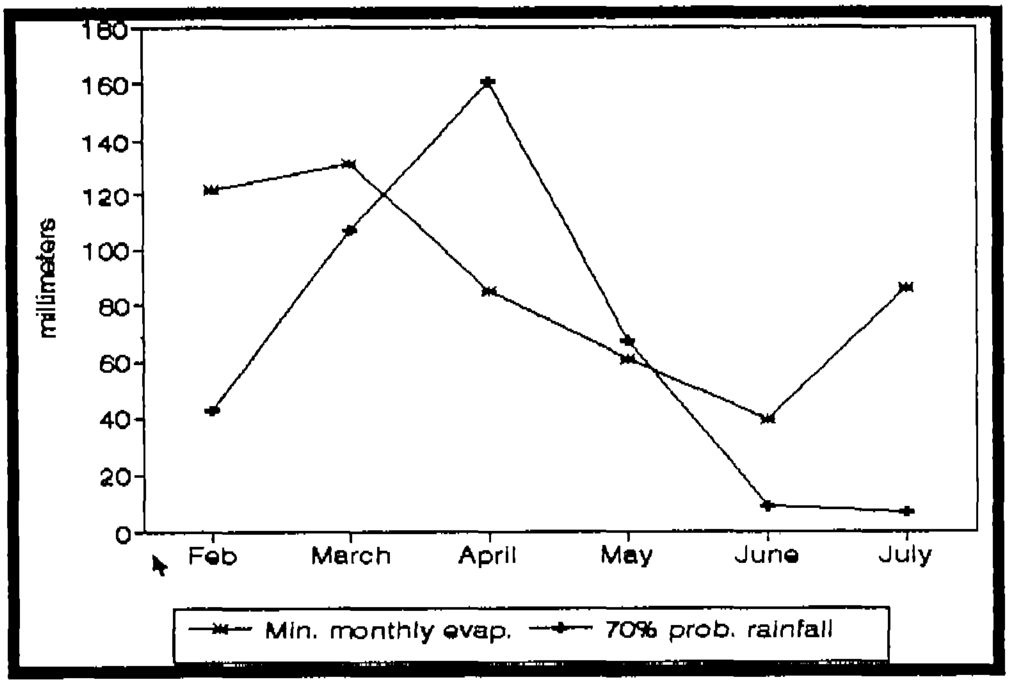


Figure 4.3: Comparison of average monthly evaporation and 70% probability rainfall for Vuli, in Morogoro and Same

a) Morogoro



b) Same

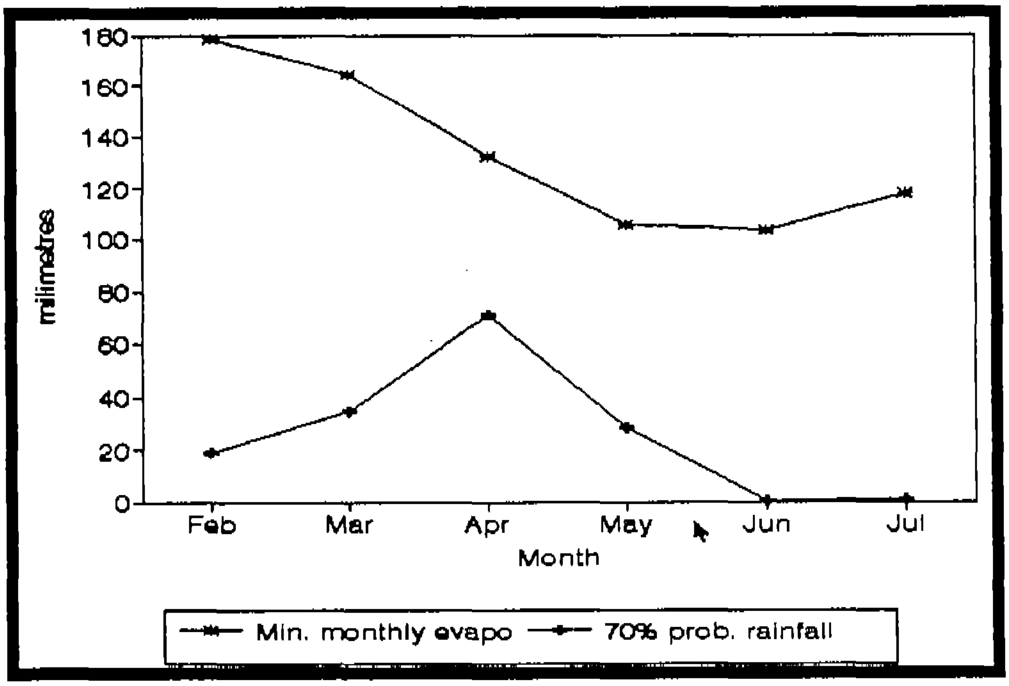
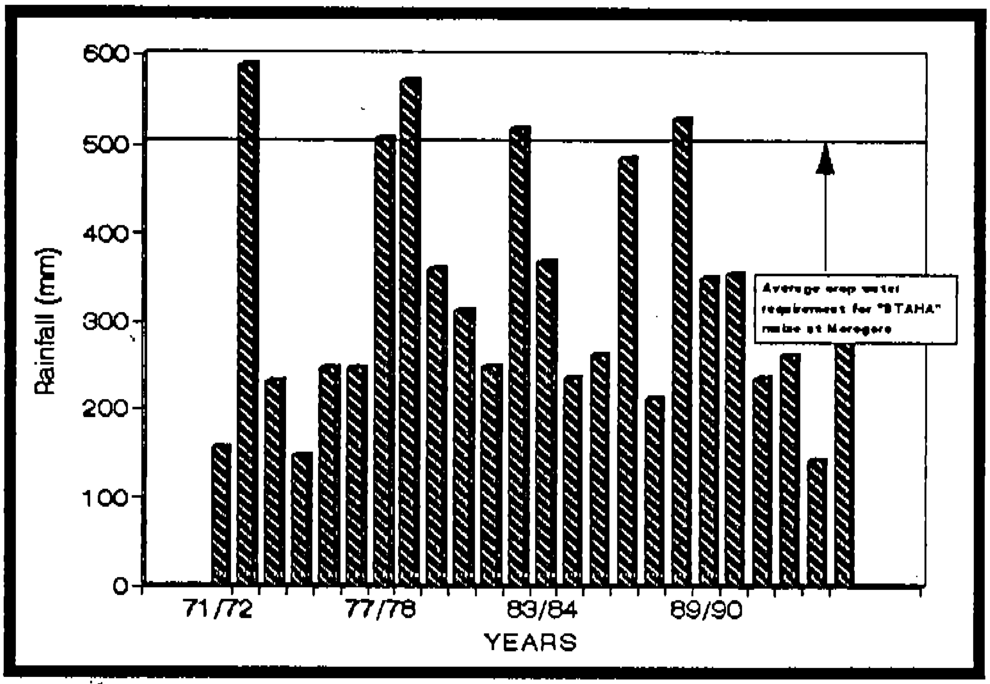


Figure 4.4 Comparison of average monthly minimum evaporation and 70% probability rainfall for Masika, on Morogoro and Same

a) Morogoro



b) Kisangara

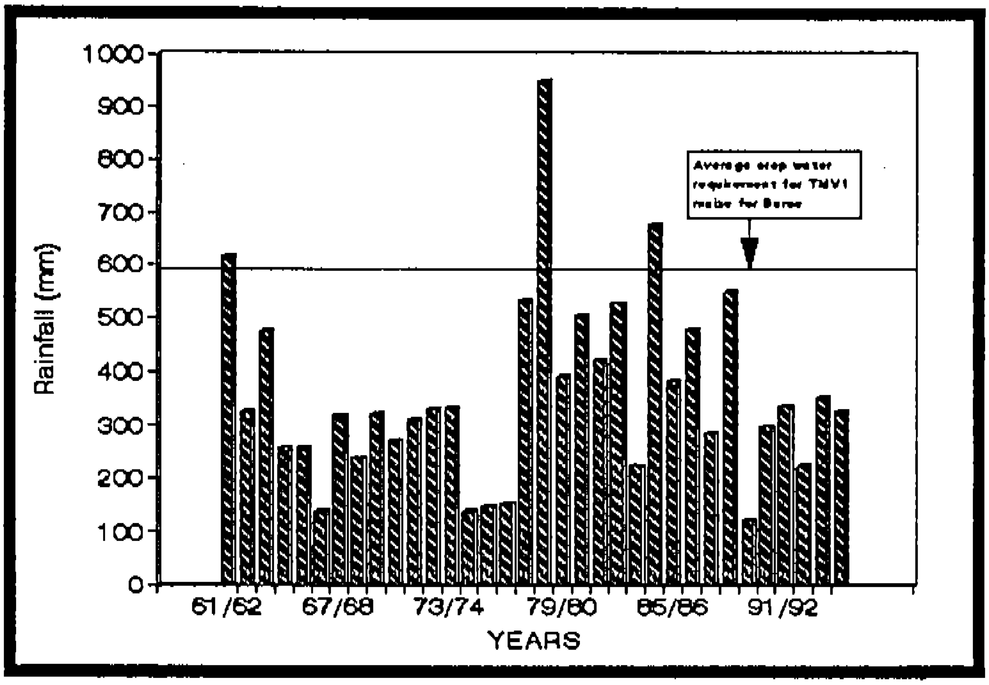
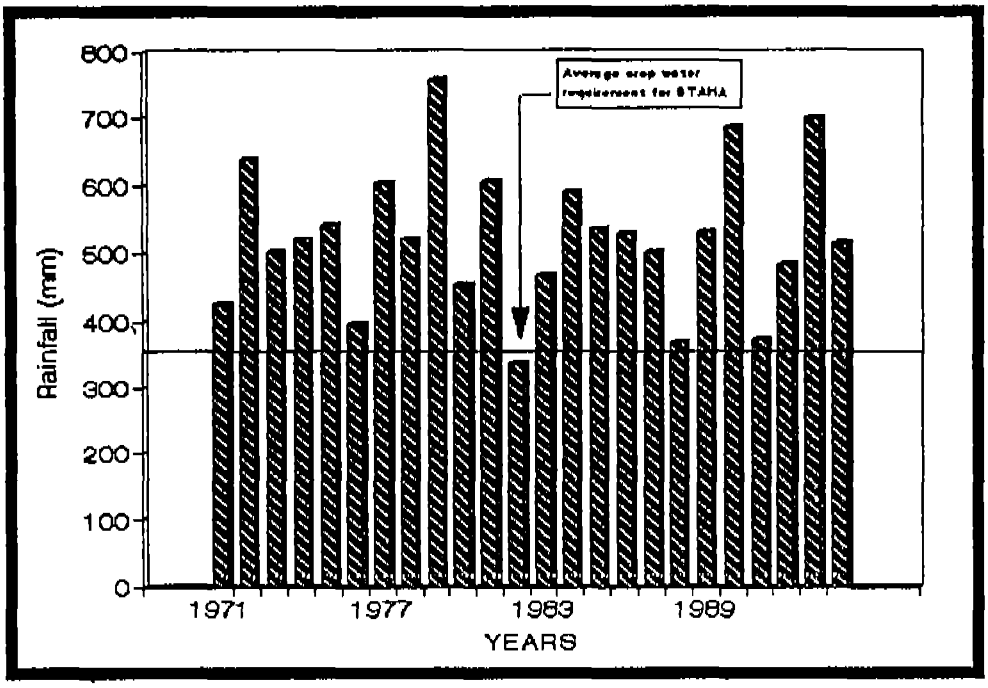


Figure 4.5 Comparison of historical Vuli rainfall and average maize crop water requirement, in Morogoro and Kisangara

a) Morogoro



b) Kisangara

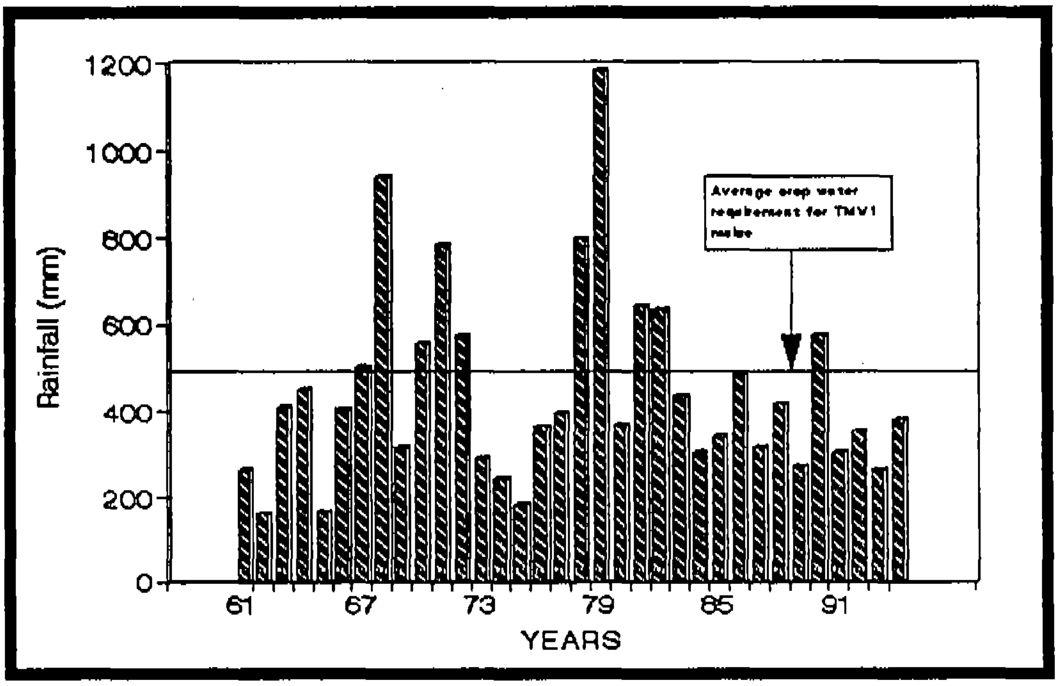


Figure 4.6: Comparison of historical Masika rainfall and average maize water requirement, in Morogoro and Kisangara

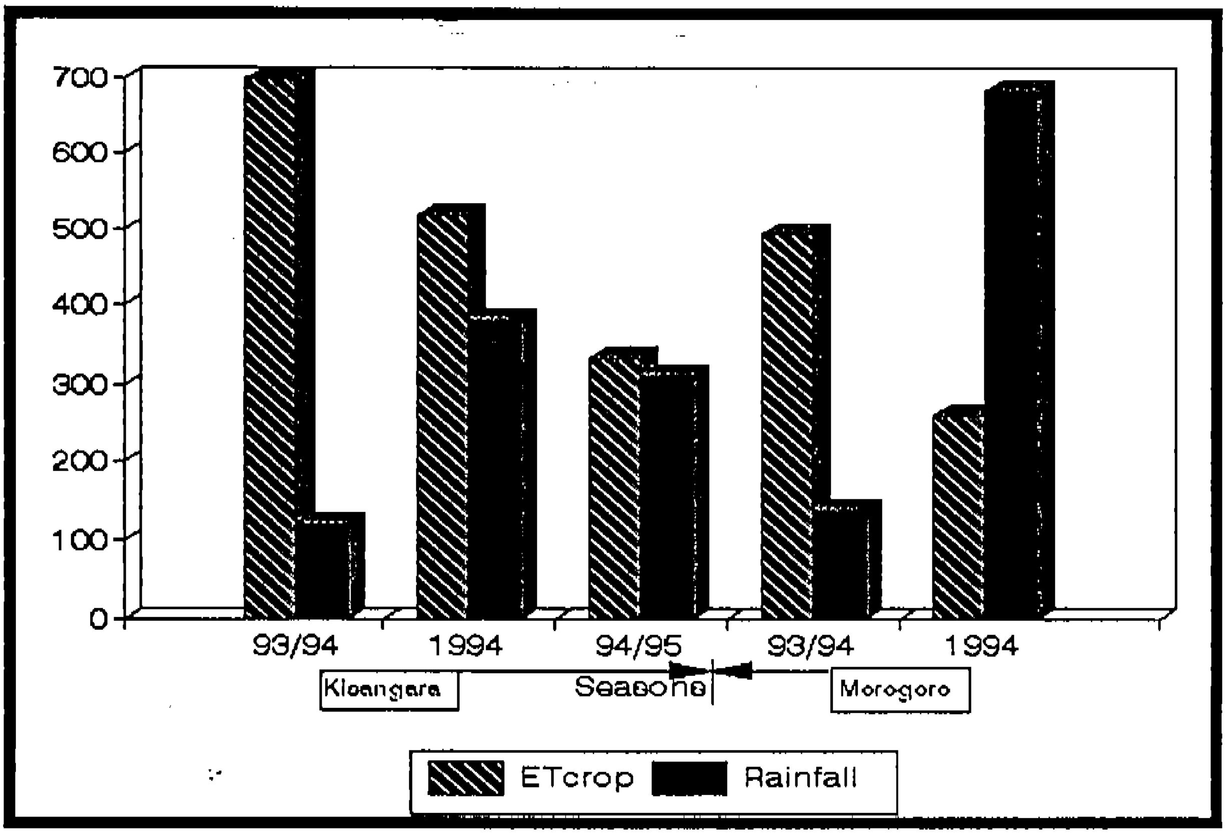


Figure 4.7: Comparison of seasonal rainfall and maize crop water requirement during the research period

Table 4.1: Summary of long term rainfall characteristics

	Parameter		VULI							MASIKA						
			Aug	Sep	Oct	Nov	Dec	Jan	Season	Feb	Mar	Apr	May	Jun	Jul	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	20	4	8	13	8	2	1	36
		5mm+	0	1	2	3	5	5	16	3	6	11	7	1	1	29
		10mm+	0	0	1	2	3	3	9	3	4	7	3	0	0	21
	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	18.0	0.0	0.0	121.3	0.0	28.0	31.7	0.0	0.0	0.0	163.7
		Mean	5.0	9.5	35.3	138.3	106.4	65.1	354.9	44.7	165.5	162.3	64.5	6.8	12.0	449.9
		70%	0.0	0.0	8.5	78.5	50.5	22.0	258.6	23.5	76.7	101.0	35.2	0.0	0.0	327.45
		Max	32.0	55.0	130.0	424.0	385.0	211.8	950.0	161.3	451.0	423.0	203.0	47.0	33.0	1185.0
	WET DAYS	3mm +	1	1	3	7	6	3	21	2	5	8	5	1	1	20
		5mm +	1	1	2	6	5	3	16	2	4	7	4	1	0	17
		10mm +	0	0	2	4	3	2	11	1	3	5	3	0	0	12
	LONGEST DRY SPELL	Min	10	14	4	5	4	9		11	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	21	33	39	

Table 4.1 (continue):

SAME	Parameter		VULI							MASIKA						
			Aug	Sep	Oct	Nov	Dec	Jan	Season	Feb	Mar	Apr	May	Jun	Jul	Season
	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	178.35	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 4.2: Summary of rainfall characteristics during the research period

Morogoro	Parameter		VULI							MASIKA						
			Aug	Sep	Oct	Nov	Dec	Jan	Season	Feb	Mar	Apr	May	Jun	Jul	Season
	RAINFALL	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	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	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							
	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							
	LONGEST DRY SPELL	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								

Table 4.3: Mean monthly evaporation, Minimum and Maximum temperatures

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	

4.2 Hydrological Analysis

4.2.1 Bulk Density

The variation of bulk density during the growing season was very small. For Morogoro site the increase in bulk density at 0-10 cm depth between tillage and harvest was 8-11%, in Kisangara site the increase was only 1-3% (Table 4.4).

4.2.2 Cumulative Infiltration

Cumulative infiltration (cm) after 150 min was on average highest for the NV treatment and lowest for the BC treatment (Table 4.5). A marked difference is also observed between the Morogoro and Kisangara site. At the Morogoro site the cumulative infiltration after 150 minutes varied between 18.45 - 149.7 cm while in Kisangara the values were 20.0 - 67.3 cm. However, generally the infiltration rates are similar in the two sites.

4.2.3 Hydraulic Conductivity

Preliminary results from the Morogoro site are shown in Table 4.6. The trend is not not consistent with what would be expected. Therefore, more samples have been collected for further testing.

4.2.4 Water Release Characteristics

Preliminary results from the Morogoro site are shown in Figure 4.8. The combined results from all the plots show that available moisture is about 25% (v/v) at 5 cm and 10 cm depth. This decreases to about 20% (v/v) at 15 and 20 cm depth. Measurements of moisture release characteristics are continuing.

4.2.5 Soil Moisture changes

The analysis of soil-moisture characteristics data has not been completed.

4.2.6 Rainfall-runoff Analysis: Morogoro Site

4.2.6.1 Runoff yield from different slopes

Low rainfall amounts (ranging from 6 - 8 mm) produced significantly higher runoff (at $P=0.01$) on the 6-8% slope as compared to the 3-4% slope (Table 4.7). However, at higher rainfall amounts (more than 9 mm) the runoff yield from both slopes was not significantly different.

4.2.6.2 Runoff yield as affected by plot length

Generally, runoff yield per unit area of catchment was not significantly different from the 5 m and 10 m length plots except for the two storms on 28/2/94 and 7/4/94 whereby the 10m length plots produced significantly different runoff yield (at $P = 0.05$) (Table 4.8). However, the runoff yield (in mm) from the 5 m length plots was 10% higher than the runoff from the 10 m length plots.

4.2.6.3 Runoff yield as affected by different catchment surface cover

Runoff generated from natural vegetation (NV) and low managed crop (LMC) treatments was generally low compared to bare (B) and bare-compacted (BC) treatments (Table 4.9). However, at the onset of the rainy season, runoff generated from all catchments was not significantly different. However, as the frequency of rainfall increased, the treatment effect became distinct. The mean separation test showed that runoff yield obtained from bare and compacted plots was significantly higher as compared to runoff yield from the other treatments.

4.2.6.4 Runoff yield as affected by rainfall characteristics

Runoff generated (RO) from each plot was compared by the rainfall characteristics i.e rainfall amount (R), rainfall intensity (RI) and Rainfall duration (RD) and the resulting regression coefficients for the above regression parameters are presented in Table 4.10. The results of Table 4.10 show that rainfall characteristics explained more than 85% of the variations observed in runoff yield produced from low managed crop, bare and bare and compacted catchments. However, for natural vegetation plots rainfall characteristics explained only 33% of the observed variations, indicating that indeed natural vegetation is effective in reducing the amount of runoff yield from a catchment.

4.2.7 Rainfall-runoff Analysis: Kisangara Site

The runoff experiments at Kisangara are not replicated and therefore statistical analysis is not possible. The results show that there are more run-off generating storms (73.6%) during Vuli than during Masika (36.6%) (Table 4.11). Total runoff as a percent of seasonal rainfall is therefore higher in Vuli than Masika. For example, the runoff produced by the BC catchment was 22-23% in Vuli and only 7-10% during Masika. The least run-off is produced on the LMC catchment, where the seasonal runoff was only 1-3% of the seasonal rainfall.

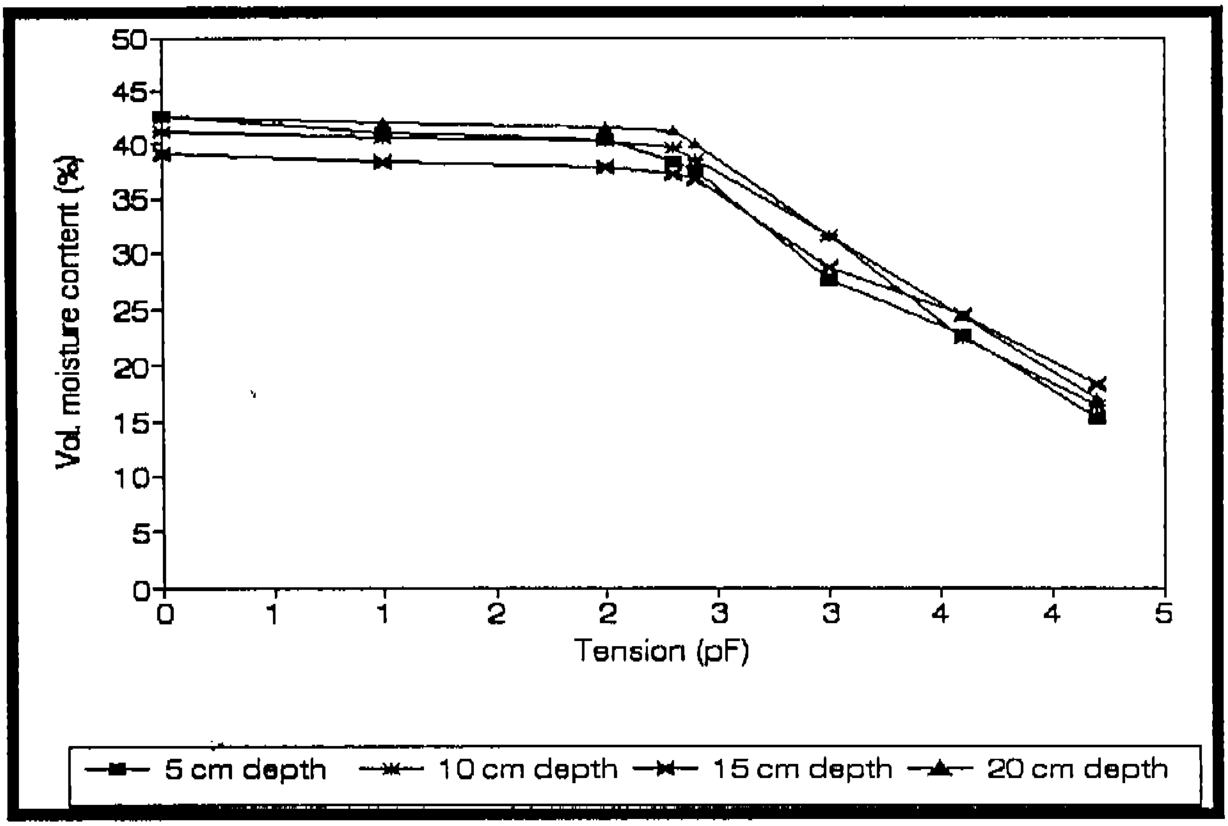


Figure 4.8 Effects of soil depth on Moisture release characteristics at Morogoro site

Table 4.4: Temporal variation of bulk density

Site	Depth	Before treatments	Immediately after tillage	At harvest
Morogoro	0-5	1.40	1.35	1.51
	5-10	1.59	1.40	1.51
	10-15	1.55	1.42	1.54
	15-20	1.48	1.53	1.62
Kisangara	0-5	1.39	1.38	1.40
	5-10	1.37	1.37	1.41
	10-15	1.50		
	15-20	1.50	1.51	1.49

Table 4.5: Effects of surface treatments on cumulative infiltration

Site	Slope	Treatment	Cumulative infiltration (cm)				
			30 min	60 min	90 min	120 min	150 min
Morogoro	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	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

Table 4.6 Saturated hydraulic conductivity for Morogoro runoff catchments

Slope	Catchment characteristics	Hydraulic conductivity (m/day)
3-4 %	NV LMC B BC	0.35 0.73 0.47 0.23
6-7 %	NV LMC B BC	0.07 0.18 0.27 0.07

Table 4.7 (a): Effects of slope on runoff produced at Morogoro during Masika 1994 season

Date	Rainfall (mm)	Runoff (mm)		
		3 - 4% slope	6 - 8% slope	statistical inference
8/1/94	38.6	2.42	5.39	ns
10/1/94	8.0	0.96	2.71	**
14/2/94	13.0	1.67	1.56	ns
19/2/94	21.0	7.38	5.53	ns
20/2/94	6.0	0.52	1.40	**
26/2/94	38.1	11.47	11.73	ns
28/2/94	10.0	0.53	0.47	ns
4/3/94	17.9	0.53	0.56	ns
17/3/94	6.0	0.06	0.38	**
18/3/94	7.0	0.05	0.45	**
22/3/94	6.0	3.81	4.33	**
27/3/94	12.0	0.06	0.38	ns
6/4/94	25.0	7.45	5.24	ns
7/4/94	47.0	10.70	8.09	ns
11/4/94	6.0	0.02	0.03	**
23/4/94	7.0	0.13	0.34	ns
24/4/94	9.0	0.91	1.25	*
25/4/94	15.0	0.91	1.84	*
4/5/94	14.0	4.50	4.44	ns
14/5/94	8.0	1.04	1.35	ns
16/5/94	10.0	1.35	1.35	ns
5/7/94	17.0	0.40	0.51	ns
6/7/94	4.0	0.17	0.07	ns
7/7/94	18.5	0.56	0.64	ns

Table 4.7 (b): Effects of slope on runoff produced at Morogoro during Vuli 1994/95 season

Date	Rainfall (mm)	Runoff in mm		
		3-4% slope	6 % slope	Statistical inference
14/10/94	5.0	0.13	0.24	ns
2/11/94	23.2	2.15	2.74	ns
4/11/94	2.4	0.09	0.07	ns
7/11/94	18.5	0.08	0.39	**
11/11/94	4.8	0.01	0.24	**
15/11/94	4.5	0.40	0.51	**
8/12/94	6.6	0.00	0.01	*
10/12/94	4.0	0.02	0.16	**
17/12/94	8.3	0.02	0.01	ns
19/12/94	4.0	0.13	0.05	**
27/12/94	8.0	0.72	1.27	**
2/1/95	32.0	12.67	9.95	ns
3/1/95	15.0	7.22	7.77	ns
5/1/95	6.0	1.33	1.47	ns
14/1/95	19.0	2.72	3.86	ns
22/1/95	65.3	14.80	4.17	ns

* Significant at 5%
** Significant at 1%
ns not significant

Table 4.8 (a): Effects of length of catchment on run-off yield from Morogoro site during Masika 1994

Date	Rainfall (mm)	Runoff yield (mm)		
		5	10	Statistical Inference
8/1/94	38.6	3.59	4.22	ns
10/1/94	8.0	1.89	1.78	ns
14/2/94	13.0	2.03	1.20	ns
19/2/94	21.0	7.38	5.57	ns
20/2/94	6.0	0.98	0.93	ns
26/2/94	38.1	13.28	9.92	ns
28/2/94	10.0	0.38	0.63	**
4/3/94	17.9	0.55	0.54	ns
17/3/94	6.0	0.24	0.20	ns
18/3/94	7.0	0.21	0.29	ns
22/3/94	6.0	0.23	0.21	ns
26/3/94	12.0	4.23	3.90	ns
27/3/94	6.0	0.03	0.01	ns
6/4/94	25.0	6.84	5.85	ns
7/4/94	47.0	9.11	9.68	*
11/4/94	6.0	0.24	0.22	ns
23/4/94	7.0	0.69	1.01	ns
24/4/94	9.0	1.03	1.25	ns
25/4/94	15.0	1.22	1.53	ns
4/5/94	14.0	4.18	4.76	ns
14/5/94	8.0	1.11	1.28	ns
16/5/94	10.0	1.08	1.62	*
5/7/94	17.0	0.49	0.42	ns
6/7/94	4.0	0.16	0.08	*
7/7/94	18.5	0.61	0.59	ns

* Significant at 5%
** Significant at 1%
ns not significant

Table 4.8 (b): Effects of length of catchment on run-off yield from Morogoro site during Vuli 1994/95

Date	Rainfall (mm)	Runoff yield (mm)		
		5 m plot length	10 m plot length	Statistical inference
14/10/94	5.0	0.19	0.18	ns
2/11/94	23.3	2.38	2.50	ns
4/11/94	2.4	0.11	0.05	ns
7/11/94	18.5	0.26	0.21	ns
11/11/94	4.8	0.11	0.13	ns
15/11/94	4.5	0.42	0.49	ns
8/12/94	6.6	0.00	0.00	ns
10/12/94	4.0	0.11	0.07	ns
17/12/94	8.3	0.01	0.01	ns
19/12/94	4.0	0.14	0.03	**
27/12/94	8.0	1.10	0.90	ns
2/1/95	32.0	12.06	10.58	ns
3/1/95	15.0	8.41	6.58	*
5/1/95	6.0	1.54	1.27	*
14/1/95	19.0	3.68	2.91	ns
22/1/95	65.3	13.65	5.32	ns

* Significant at 5%
** Significant at 1%
ns not significant

Table 4.9 (a): Effects of different catchment characteristics on runoff yields from Morogoro site during Masika 1994

Date	Rainfall				Runoff yield (mm)				
	amount (mm)	intensity (mm/hr)		Duration (hrs)	NV 1	LMC	B	BC	Statistical inference
		I5	I30						
8/1/94	38.6	65.0	37.9	5.25	1.54	2.79	5.60	5.69	ns
10/1/94	8.0	22.5	16.3	1.12	1.76	1.52	1.96	2.11	ns
14/2/94	13.0	41.0	14.0	2.32	0.47b	0.78b	2.06ab	3.14a	*
19/2/94	21.0	56.1	24.6	3.27	0.07b	7.06a	9.69a	9.00a	**
20/2/94	6.0	12.1	7.4	1.55	0.04c	0.99b	1.21b	1.69a	**
26/2/94	38.1	61.7	53.6	1.40	0.38b	10.73a	17.08a	18.20a	ns
28/2/94	10.0	44.0	16.2	1.34	0.00d	0.31c	0.60b	1.09a	**
4/3/94	17.9	14.8	5.6	4.96	0.26c	0.33b	0.24b	1.36a	*
17/3/94	6.0	21.7	11.6	1.72	0.05c	0.11bc	0.19b	0.53a	**
18/3/94	7.0	13.6	7.6	1.13	0.01	0.05bc	0.21b	0.74a	**
22/3/94	6.0	9.8	4.3	0.30	0.23b	0.06b	0.11b	0.70a	**
26/3/94	12.0	39.5	22.6	0.39	0.01b	2.31b	6.99a	6.73a	ns
27/3/94	6.0	3.3	3.0	3.17	0.01b	0.02b	0.02b	0.05a	*
6/4/94	25.0	86.0	34.0	2.77	0.41c	4.76b	13.19a	7.02a	**
7/4/94	47.0	15.7	7.4	1.94	0.23b	11.43a	13.41a	12.51a	*
11/4/94	6.0	16.0	9.3	1.67	0.00c	0.01b	0.36a	0.56a	**
23/4/94	7.0	34.5	16.7	0.93	0.03c	0.14c	1.11b	2.14a	**
24/4/94	9.0	2.3	0.8	0.80	0.02c	0.05c	1.46b	2.79a	**
25/4/94	15.0	14.1	8.0	3.25	0.01c	0.04c	1.38b	3.88a	**
4/5/94	14.0	39.4	21.9	8.71	0.04b	0.21b	8.55a	9.09a	**
14/5/94	8.0	11.2	8.1	2.19	0.0c	0.03c	1.63b	3.11a	**
16/5/94	10.0	19.0	5.8	3.04	0.0c	0.04b	2.79a	2.58a	**
5/7/94	17.0	15.7	12.7	10.82	0.0c	0.04bc	0.67b	1.12a	**
6/7/94	4.0	2.5	1.6	0.32	0.0b	0.02b	0.16a	0.28a	**
7/7/94	18.5	24.4	9.6	3.35	0.0c	0.15b	0.81b	1.45a	**

* Significant at 5%, ** Significant at 1%, ns not significant

Means followed by the same letter or none are not significantly different at 5% probability by Dancans new multiple range test

Table 4.9 (b) Effects of different catchment characteristics on runoff yields from Morogoro site during Masika 1994

Date	Rainfall				Runoff yield in mm				
	amount (mm)	Intensity (mm/hr)		Duration (hrs)	NV	LMC	B	BC	Statistical inference
		I5	I30						
14/10/94	5	19.8	8.3	2.69	0	0.02	0.33	0.39	**
02/11/94	23.2	20.9	12.9	1.80	0	0.05	3.85	5.88	**
04/11/94	2.4	12.6	2.2	1.07	0	0.02	0.1	0.12	ns
07/11/94	18.5	13.1	7.4	2.50	0	0	0.33	0.61	**
11/11/94	4.8	8.5	6.3	0.76	0	0.01	0.3	0.19	**
15/11/94	4.5	40.1	8.1	0.56	0	0.02	0.95	0.82	**
08/12/94	6.6	11.8	2.0	3.30	0	0	0.01	0.01	ns
10/12/94	4	5.3	4.4	0.60	0	0	0.17	0.18	**
17/12/94	8.3	8.1	8.1	1.70	0	0	0.02	0.02	ns
17/12/94	4	14.8	7.0	0.50	0	0.1	0.13	0.10	*
27/12/94	8	19.3	13.8	4.67	0	0.05	1.95	2.00	**
02/01/95	32	74.9	36.87	8.12	0.1	6.81	18.41	19.97	**
03/01/95	15	25.35	25.35	1.09	0.2	7.95	10.72	11.09	**
05/01/95	6	31.44	9.7	1.72	0	0.63	2.46	2.50	**
14/01/95	19	32.72	24.7	4.00	0	0.92	5.92	6.33	**
22/01/95	65.3	105.17	71.35	15.80	7.78	7.86	11.68	10.63	ns

* Significant at 5%, ** Significant at 1%, ns not significant

Table 4.10 Runoff yield as affected by rainfall characteristics

Treatment	R coefficient	RI coefficient	RD coefficient	R^2
NV	1.1444×10^{-2}	2.6162×10^{-3}	2.4415×10^{-4}	0.33^{ns}
LMC	2.0632×10^{-1}	1.051×10^{-1}	-1.556×10^{-3}	0.88^{**}
B	2.699×10^{-1}	2.115×10^{-1}	-2.935×10^{-3}	0.85^{**}
BC	2.2385×10^{-1}	2.1297×10^{-1}	1.697×10^{-3}	0.85^{**}
overall R/O from all plots	1.775×10^{-1}	1.339×10^{-1}	-4.592×10^{-4}	0.89^{**}

** Significant at 1% probability
ns not significant

Table 4.11 (a) Runoff collected from Kisangara 8% Runoff plots

Season	Date	Total rain mm	Rainfall intensity (mm/hr)		Duration Hrs	Runoff yield from catchments (mm)			
			I 5	I 30		NV	LMC	B	BC
Masika 1994	13/2/94	15.0	na			2.67	0.66	2.51	6.26
	5/3/94	19.5	na			4.16	0.31	3.00	6.51
	7/3/94	49.0	na			7.17	2.72	12.2	16.47
	24/3/94	4.0	0.8	0.8	18.28	0.13	0.04	0.13	0.26
	24/04/94	5.5	17.61	11.84	2.13	0.23	0.14	0.6	0.62
	26/04/94	9.0	6.5	6.5	4.85	0.24	0.01	0.83	0.87
	01/05/94	10.0	4.17	4.17	8.05	0.15	0.2	0.52	0.86
	12/05/94	15.5	24.76	14.03	1.71	1.49	0.48	2.72	5.93
	15/05/94	12.0	1.66	1.66	10.39	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	22.85	14.17	2.64	0.05	0.06	1.41	1.49
	31/10/94	9.0	10.37	8.71	1.25	0.59	0.33	2.33	2.8
	11/11/94	15.0	12.75	11.04	15.53	1.36	2.02	3.78	4.42
	16/11/94	16.0	19.95	11.26	2.88	1.46	0.32	1.86	4.27
	01/12/94	52.0	na[1]	-	-	1.87	0.24	2.96	5.22
	5/12/94	7.0	na	-	-	0.51	0.69	2.43	2.83
	6/12/94	17.0	na	-	-	2.1	0.45	1.93	8.67
	9/12/94	43.0	na	-	-	11.88	0	24.78	20.41
	14/12/94	21.0	na	-	-	1.33	1.16	11	6.44
	16/12/94	19.0	na	-	-	6.53	0.88	3.36	3.37
	17/12/94	24.0	40.98	0.98	0.93	9.21	4.25	15.77	11.38
	23/12/94	10.0	21.17	14.18	1.97	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)

Table 4.11 (b) Runoff collected from Kisangara 3% slope Runoff plots

Season	Date	Total rain (mm)	Rainfall intensity		Duration Hrs	Runoff yield from catchments (mm)			
			I5	I30		NV	LMC	B	BC
	13/2/94	15.0	na			2.23	0.9	1.72	3.92
	5/3/94	19.5	na			7.19	0.2	3.44	4.79
	7/3/94	49.0	na			14.36	0.5	7.57	10.53
	24/03/94	4.0	0.8	0.8	18.28	0.0	0.0	0.0	0.00
	24/04/94	5.0	17.61	11.84	2.13	0.76	0.34	1.9	2.21
	26/04/94	9.0	6.5	6.5	4.85	0.11	0.0	0.53	1.76
	01/05/94	10.0	4.17	4.17	8.05	0.11	0.07	1.37	0.75
	12/05/93	15.5	24.76	14.03	1.71	1.47	0.46	2.11	3.75
	15/05/94	12.0	1.66	1.66	10.39	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	22.85	14.17	2.64	0.2	0.18	1.09	3.52
	31/10/94	9.0	10.37	8.71	1.25	0.0	0.0	1.19	2.62
	11/11/94	15.0	12.75	11.04	15.53	2.62	0.35	2.2	4.98
	16/11/94	16.0	19.95	11.26	2.88	1.77	0.17	2.81	7.56
	01/12/94	52.0	na[1]	-	-	5.87	0.19	13.87	11.9
	05/12/94	7.0	na	-	-	2.42	0.41	2.21	2.85
	6/12/94	17.0	na	-	-	2.56	0.17	5.59	4.91
	9/12/94	43.0	na	-	-	1.89	0.38	2.76	6.75
	14/12/94	21.0	na	-	-	2.45	0.02	6.57	9.68
	16/12/94	19.0	na	-	-	4.24	1.38	10.23	9.75
	17/12/94	24.0	40.98	40.98	0.93	4.38	0.75	8.56	7.35
	23/12/94	10.0	21.17	14.18	1.97	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)

4.3. Runoff Farming Experiment

4.3.1 Treatment and Seasonal Effects on Yield

Out of the four cropping seasons, grain were harvested in only 3 seasons in Kisangara and 2 seasons in Morogoro, as follows:

- Kisangara: Masika 1993; Masika 1994 and Vuli 1994/95
- Morogoro: Masika 1993; and Masika 1994

4.3.1.1 Masika 1993

Morogoro: During this season highest biomass yield (11950 kg/ha) was obtained from 4:1 flat cultivation at 6%. There was no significant difference between treatments and slope.

The highest grain yields (4,529.9 kg/ha) were obtained on the 3% 0:1 SR treatment. However, no significant differences were obtained between the treatments and slopes.

Kisangara: This was the first season and cropping was done only on the 8% slope and the 1:1 treatment was not yet introduced. The highest biomass harvest was obtained on the 0:1 treatment and the lowest from the zero tillage with no rain water harvesting input. There was no significant difference between the runoff farming treatments. The average harvest from the run-off farming was 5034.8 kg/ha while that of tillage treatments was only 2,932.8 kg/ha, indicating a significant difference between run-off farming and control.

During this season the highest grain yields (2,137 kg\ha) were obtained under run-off cropping system with CBAR of 2:1 with flat cultivation and the lowest yields (187 kg\ha) were obtained under the "Kitang'ang'a" treatment. Further, significant differences were observed between flat cultivation and ridging on the cultivated basin for both 0:1 and 2:1 treatments the yields under flat cultivation were significantly higher than those from ridge cultivation. The weight of 100 seeds was also highest for the 2:1 with flat cultivation, although not significantly different from the other run-off cropping treatments.

4.3.1.2 Vuli 1993/94

Morogoro: Only biomass was harvested during this season. This was done only about 65 days after emergence due to drought damage. Thus, this biomass harvest is not comparable to that obtained from other seasons. The highest biomass harvest (2,329.3 kg/ha) was obtained from the 6% slope 2:1 FC treatment. This was significantly higher than all the other treatments and the lowest yield was obtained from the 6% 0:1 FC treatment. There was no significant difference between the biomass harvest from 4:1 treatment and 0:1 treatment. On average the difference between 3% and 6% yields was not significant, although it was higher for the 6%.

Kisangara: Also only biomass was harvested about 102 days after emergence. The highest biomass harvest (4,093 kg/ha) was obtained from the 8% 4:1 FC treatment. The lowest yield (228.6 kg/ha) was obtain from the 8% LB treatment. There was a significant difference in yield between 8% and 3% slopes. The average biomass harvest on the 8% slope was 2,834.8 kg/ha while that from the

3% slope was only 533.3 kg/ha. The harvest from the no-RWH treatments was only 277.7 kg/ha.

4.3.1.3 Masika 1994

Morogoro: The highest biomass harvest (12,599.2 kg/ha) during this season was obtained from the 3% 2:1 SR treatment. On average the 2:1 treatment produced highest yields and the 4:1 treatment the lowest. The average yield from the 3% slope was higher at 8,226.9 kg/ha than the average yield of the 6% slope, which was only 6,995.2 kg/ha.

In terms of grain, the highest yield (5,654.8 kg/ha) was obtained on the 3% 1:1 SR treatment. However, there was no significant difference between the treatments. Similarly, the difference in average yields for each slope was not significant.

Kisangara: On average the biomass yield from the 8% 4:1 treatment was highest at 9,748.0 kg/ha. However, there was no significant difference in yields between the different runoff cropping treatments. There was a significant difference between the average yield of the run-off treatments and the average yield of the tillage only treätment.

The highest grain yields (4, 226 kg/ha) was obtained under 4:1 SR treatment on the 8% slope. The lowest yields (1,286.6 kg/ha) was obtained under the "Kitang'ang'a" treatment. The mean yields of the treatments were 8% (3,211 kg/ha); 3% (2,759 kg/ha) and without run-off (2,266.6 kg/ha), and are not significantly different.

4.3.1.4 Vuli 1994/95

Morogoro: Due to prolonged drought, only biomass was harvested at 96 days after emergence. The highest yield (837.4 kg/ha) was obtained on the 3% 2:1 FC treatment and the lowest was obtained on the 3% 4:1 SR. However, there was no significance difference in yields, between treatments and slopes.

Kisangara: Biomass harvest was highest (4,540 kg/ha) for the 8% 2:1 FC treatment and lowest (1,950 kg/ha) was from 8% LB treatment. The average yield was significantly higher (4,098.3 kg/ha) at the 8% slope.

In terms of grain the highest yield (1, 246.7 kg/ha) was obtained on the 8% 2:1 FC treatment. The lowest yield (405 kg/ha) was obtained from the 8% SB treatment. However, there was no significant difference between the mean yields of the 8% slopes.

.4.3.2 Seasonal Effects on Yields

4.3.2.1 Morogoro

There is a very big and significant difference between Vuli and Masika seasons. No grain has been harvested during both the Vuli seasons when the trial was conducted. At the same time the biomass harvested in Vuli is only 5% of the harvest during Masika. The overall mean biomass yield for Masika was higher in 1993 compared to 1994. In terms of grain higher grain yield was harvested in Masika 1994. There was no grain yield harvested during vuli seasons.

4.3.2.2 Kisangara

The difference between Vuli and Masika is also very significant. For example the average biomass yield of the two Vuli seasons was 2,203.4 kg/ha while the average for Masika is 5,168.3 kg/ha. In terms of grain the overall average yield of the two Vuli seasons is only 329.9 kg/ha while the Masika yield average 1,916. kg/ha.

4.3.3 Site Effect on Yield

The two sites different significantly different during the Vuli seasons. Morogoro site have very poor Vuli seasons compared to Kisangara. During Masika, the performance of the Morogoro site was slightly better than that of Kisangara.

Table 4.12 Effects of runoff farming and soil conservation tillage on yield of maize for Kisangara site

Experiment and slope	Treatment		Total biomass at Harvest				Grain yield (kg/ha)			100 seed weight (g)		
	CA:BA ratio	BA Surface	Masika 1993	Vuli 1993/94[1]	Masika 1994	Vuli 1994/95	Masika 1993	Masika 1994	Vuli 1994/95	Masika 1993	Masika 1994	Vuli 1994/95
8% Runoff farming	0:1	FC	3593.0	1650.0	7303.6	3920.0	1761.0	2783.7	506.7	26.06	22.63	
		SR	6000.0	1790.0	6242.1	1436.0	1047.0	2674.6	596.7	24.52	24.03	
	1:1	FC	-	1926.0	7718.3	3975.0	-	3517.9	613.3	-	23.41	
		SR	-	2461.3	7285.7	3850.0	-	3029.8	683.3	-	27.70	
	2:1	FC	7457.0	3885.3	6649.6	4540.0	2173.0	2416.7	1246.7	26.06	27.93	
		SR	5665.0	3254.0	6958.3	3900.0	1359.0	3220.2	570.7	23.38	25.23	
	4:1	FC	5135.0	4093.0	9158.7	4050.0	1599.0	3819.5	963.3	24.90	30.26	
		SR	5059.0	3618.7	9748.0	4191.0	1323.0	4226.2	1103.3	24.85	31.73	
	Average		5034.8	2834.8	7633.0	4098.3	1543.7	3211.1	786.6	24.96	26.62	
3% runoff farming	0:1	FC	-	388.2	6798.2	3480.0	-	2822.0	666.7	-	26.53	18.18
		SR		252.8	5532.1	2780.0	-	2188.7	553.3	-	28.32	19.44
	2:1	FC	-	715.3	5988.1	3153.0	-	2919.6	961.7	-	19.36	18.00
		SR		260.4	6222.0	2920.0	-	2204.2	423.3	-	25.62	18.65
	4:1	FC	-	1121.5	8254.8	2893.0	-	3518.5	846.7	-	32.97	17.66
		SR		461.8	6958.3	2600.0	-	2900.6	780.0	-	30.95	20.39
	Average			533.3	6625.6	2971.0	-	2758.9	688.6	-	27.29	18.72
8% conservation tillage		ZT	1401.0	300.0	3979.6	2093.0	187.0	1286.6	683.3	20.12	19.80	
		FC	3332.0	270.6	4180.0	3063.5	559.3	1760.0	430.0	20.56	24.90	
		CR	3296.0	330.6	5953.4	2688.5	712.3	3113.4	560.0	22.78	24.80	
		SB	3429.0	258.6	5336.6	2723.0	649.7	2796.6	405.0	21.78	24.80	
		LB	3206.0	228.6	4550.0	1950.0	679.3	2376.6	448.0	21.32	23.30	
	Average		2932.8	277.7	4799.9	2503.6	557.5	2378.1	505.3	21.31	23.52	

[1] B total biomass harvested 102 days after planting due to drought

Table 4.13 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 [2] 1994/95	Masika 1993	Vuli 1993/94	Masika 1993	Masika 1994
3%	0:1	FC	10324.2	224.7	7777.8	239.5	4529.9	5634.9	38.93	38.00
		SR	9752.6	571.1	6746.0	315.4	3958.3	4831.3	36.50	34.17
	1:1	FC	-	273.9	8313.5	339.3	-	5476.2	-	36.33
		SR	-	561.7	8571.4	342.0	-	5654.8	-	35.00
	2:1	FC	9416.3	879.6	9027.8	837.4	3915.0	5039.7	35.30	31.67
		SR	9329.4	936.7	12599.2	413.5	3893.2	5218.3	32.90	35.33
	4:1	FC	11785.6	369.1	7025.8	131.3	4136.1	4543.7	36.00	31.17
		SR	8504.6	162.2	5754.0	62.1	3459.0	3415.0	31.00	24.00
	Mean		9852.2	439.6	8226.9	341.8	3981.9	4976.7	35.10	33.20
6%	0:1	FC	10803.1	142.7	6150.8	354.9	4129.9	4285.7	36.40	32.67
		SR	9835.2	377.9	6904.8	348.0	4236.3	3888.9	35.80	30.57
	1:1	FC	-	324.4	6329.4	377.5	-	4484.1	-	34.17
		SR	-	583.8	8839.3	386.4	-	5138.9	-	35.67
	2:1	FC	9758.7	2329.3	8115.1	373.7	3736.6	5357.1	34.67	32.33
		SR	9159.5	856.8	6467.1	381.3	4341.8	5138.9	36.13	31.50
	4:1	FC	11950.8	167.3	7440.5	263.3	4366.2	5079.4	34.77	35.83
		SR	10536.2	146.6	5714.3	148.7	3993.2	3708.3	35.30	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.

5. DISCUSSION

5.1 Rainfall Pattern

The most important elements of Vuli rainfall affecting crop growth in both Morogoro and Kisangara is seasonal amount and distribution. The same elements are also important in Kisangara also during Masika. In 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 growth months of March, April and May, not exceeding three weeks. The mean of the these dry spells is less than two weeks. Therefore, it can be said that Masika is a favourable season for maize growth in Morogoro.

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 rainfall 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, with interventions.

5.2 Runoff Generation

The rain-water harvesting intervention (run-off farming) depends on the availability of runoff. Run-off generation (85%) in the study area is controlled by rainfall characteristics. Rains of the study area have low run-off coefficients because of:

- low intensities of rainfall storms, and
- storms are interspaced by long dry spells.

A combination of a low intensity storm falling when the soil is dry leads to low run-off generation. This explains why most of the generated run-off does not exceed 12% of the rainfall.

However, the Vuli rains were found to be better in generating run-off. This is a positive aspect since RWH intervention is required more during the Vuli season. The surface characteristic of the catchment was also found to be important factor affecting run-off generation. Catchment clearing and compaction increased generated run-off nearly 10 times.

5.3 Performance of Run-off Farming

5.3.1 Vuli

During the two Vuli seasons, RWH intervention (run-off farming) was not adequate to produce grains in Morogoro. This may in part be explained by the general characteristic of the Morogoro Vuli rains, which tend to fall towards the end of the season. Run-off farming works better when there is run-off generating rainfall at the beginning of the rainy season. The same reason explains why a crop was harvested in Kisangara during the 1994/95 Vuli season and failed in 1993/94 season.

The results show that the optimum CA:BA ratio is 2:1, as very little crop yield (biomass or grain) increase is achieved by increasing this ratio to 4:1 In many instances there is 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).

In Vuli 1994/95 grain yield at Kisangara site showed that on 8% slope 2:1 and 4:1 yields were significantly (P=0.01) different from the 0:1 and 1:1 grain yields. On average the increase of grain yield resulting from run-off farming in comparison to 0:1 treatment was 420 kg/ha. On the 3% slope the difference was significant (P=0.05) and about 118 kg/ha.

Further, at 8% the RWH intervention produced significant (P=0.01) yields above the conservation tillage practice. On average the difference is about 465.7 Kg/ha.

5.3.2 Masika

In Morogoro run-off farming treatments did not show any significance difference in yields in the two Masika seasons. This is explained by the observation made earlier that the Masika rainfall in Morogoro is adequate both in terms of amount and distribution. Further, the adequacy of rainfall caused the 4:1 treatment to produce lower yields than any of the other treatments, including the 0:1 treatment. In 1993 the average yield from the RWH treatments was 3,980 kg/ha compared to 4,215.4 kg/ha. A similar trend was observed in 1994.

In Kisangara run-off farming treatments produced significantly (P=0.05) higher yields than the without RWH treatments. In 1993 the average difference with 0:1 treatment was 184.5 kg/ha and for 1994 the difference was 642.4 kg/ha. The benefit of RWH is much bigger in 1994 because there was high rainfall (189.6cm) in March followed by relatively drier April and May. This also explains the higher performance of the 4:1 treatment in 1994 season.

5.4 Conclusions

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

   - low seasonal rainfall amount which for vuli seasons is less than seasonal maize crop-water requirement;
   - low intensity storms which are interspaced with long dry spells which deplete the soil-moisture the cropped basin;
   - 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, due to low run-off yielding capacity of the rainfall run-off yield optimization require some treatment of the catchment.

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

   i) During Vuli, run-off farming significantly (P=0.01) increased grain yield by 420 kg/ha on the 8% slope. The increase on the 3% slope was 118kg/ha and significant at p = 0.05.

   ii) During Masika, run-off farming significantly (P=0.05) increased grain yield by between 185-642 kg/ha.

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

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APPENDICES

A: Monthly seasonal rainfall for Morogoro and Kisangara

Table 1 (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

Table 1 (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	56.4	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

Table 2 (a) 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

Table 2 (b): 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