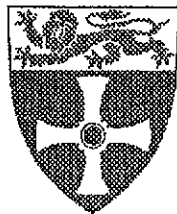


**THE EFFECT OF RAINWATER HARVESTING
ON MAIZE YIELD IN KISANGARA, SEMI-ARID
TANZANIA**

by

Bilal Acar

This Thesis is Submitted in Partial Fulfilment of the Requirements for the
Degree of Master of Science in the
Faculty of Agriculture and Biological Sciences



**Department of Agricultural and Environmental Science
The University of Newcastle upon Tyne**

September 1995

PASS LIST

UNIVERSITY OF NEWCASTLE UPON TYNE

FACULTY OF AGRICULTURE AND BIOLOGICAL SCIENCES

DEGREE OF MASTER OF SCIENCE IN IRRIGATION

The following candidates have satisfied the examiners:

Bilal ACAR

*** Alexia SMITH**

*** Distinction**

D. J. Buck

D J Buck
Senior Assistant Registrar

19th October 1995

Office of the Registrar
6 Kensington Terrace
Newcastle-upon-Tyne NE1 7RU

DJB/dw/Agric. Bio 13
(1994-95)



ABSTRACT

Rainwater harvesting is a technique for increasing the soil moisture content in the soil profile during the drought season. It is suitable for many field crops as well as tree cropping. One of the most important advantages of using this technique is that initial establishment may be improved through the concentration of early showers and crop can be helped to weather a mid-season dry spell, or at critical period the availability of rainfall for crops may be increased.

This study aimed to identify the effect of rainwater harvesting on crop yield. It was conducted at Kisangara, semi-arid Tanzania, in two different land slopes, named 3% and 8% and three catchment area to cropped field ratio, CA:CF, (4:1, 2:1 and 0:1). Reference crop evapotranspiration (ET_o) and soil moisture deficits were computed by using the Quattro Pro for Windows version 5, soil moisture contents were measured with neutron probe and calculations were carried out in the top 80 cm of the soil using data from 0-10, 10-30, 30-50 and 50-80 cm, runoff was measured with runoff collecting tanks, and a Class A Pan was used to measure the evaporation from the open water surface.

Mean daily soil moisture deficits were found 33.02, 44.53 and 49.76 mm for 8% slope and 27.64, 30.99 and 48.79 mm for 3% slope in 4:1, 2:1 and 0:1 catchment area to cropped field (CA:CF) ratio by using the water balance model. The crop yields for 8% slope were 4409.2, 3569.7 and 1720 kg/ha in 4:1, 2:1 and 0:1 ratio at Kisangara. The regression analysis were carried out between calculated mean daily soil moisture deficits and average crop yields for 8% slope. According to the results that crop yields were highly affected by the soil moisture deficits ($R^2 = 0.82$). Crop yields increased with a decrease in soil moisture deficits.

ACKNOWLEDGEMENTS

I would like to thank my supervisor, Dr. G. C. L Wyseure, for his help, advice and encouragement throughout the period of the research project and Turkish Government for their financial support and Research Associate M. D. B Young for kindly help. In addition, I am very grateful to Prof. Dr. Mehmet Kara, Assist Prof. Dr. Huseyin Simsek and Nizamettin Ciftci and all academic staff of Agricultural Faculty of Selcuk University for their sending to me to England for doing MSc and also would like to thank my friends, Hakan Erbas, Necip Camuscu, Zafer Tatli and Vedat Demir for kindly help.

CONTENTS

	<u>Page</u>
Abstract	i
Acknowledgements	ii
List of Abbreviations and Symbols	vi
List of Tables	viii
List of Figures	ix
List of Plates	xi
CHAPTER 1 INTRODUCTION	1
CHAPTER 2 LITERATURE REVIEW	4
2. 1 Rainfall Effects	4
2. 2 Rainwater Harvesting	5
2. 3 Crop Water Requirement	6
2. 4 Evaporation Process	6
2. 5 Maize Temperature Requirement	7
2. 6 Factors Affecting Maize Yield	7
2. 7 Maize Yield	9
2. 8 Soil Conservation	9
2. 9 Soil Characteristics in Semi-Arid Regions	9
2. 10 Crop Coefficient	10
2. 11 Pan Coefficient	10

CHAPTER 3 MATERIAL AND METHOD	11
3. 1 Location	11
3. 2 Reference Crop Evapotranspirations	11
3. 3 Evaporation Measurements	15
3. 4 Pan Coefficient Calculations	15
3. 5 Crop Coefficients	17
3. 6 Crop Water Requirement Calculations	17
3. 7 RWH Crop Experiment	18
3. 8 Calculation of soil Moisture Deficits	18
3. 9 Runoff Experiments	20
3. 10 Soil Moisture Measurements	21
 CHAPTER 4 RESULTS AND DISCUSSIONS	 26
4. 1 Reference Crop Evapotranspiration	26
4. 2 Pan Evaporation and Rainfall	28
4. 3 Pan Coefficients	30
4. 4 Crop Water Requirements	31
4. 5 Runoff Collecting Results	33
4. 6 Soil Moisture Contents	36
4. 7 Comparison of Observed and Calculated Soil Moisture Content	39
4. 8 Comparison of Total Water Supply with Crop Water Requirement	44
4. 9 Soil Moisture Deficit	46
4. 10 Crop Yield	48

CHAPTER 5 CONCLUSIONS

50

REFERENCES

53

APPENDIX

LIST OF ABBREVIATIONS AND SYMBOLS

%	percent
mm	millimetre
EC _e	electrical conductivity in soil extract
mmhos/cm	millimhos per centimetre
kg/ha	kilogram per hectare
N	nitrogen
P	phosphorus
K	potassium
K _c	crop coefficient
ET _a	potential crop water requirement
ET _o	reference crop water requirement
cm	centimetre
km/day	kilometre per day
mm/day	millimetre per day
In.	Inch
m	metre
RWH	rainwater harvesting
mm/month	millimetre per month
SUA	sokaine university of agriculture
ft	feet
CA	catchment area
CF	cropped field
BC	bare and compacted surface
FC	Field capacity
PWP	permanent wilting point

DAW	difficult available water
Po	soil water depletion
Obs.	observed
cal.	calculated
SMC	soil moisture content

LIST OF TABLES

	<u>Page</u>
TABLE 1 Monthly Seasonal and Annual Rainfall for Morogoro, Same and Kisangara.	13
TABLE 2 The Amount of Runoff Collected in Tanks for Bare and Compacted Soil Surface per Unit Area.	35
TABLE 3 Total Water Supply	45

LIST OF FIGURES

		<u>Page</u>
FIGURE 1	Tanzania, Classification of Agro-Ecological Zones	12
FIGURE 2	Reference Crop Evapotranspiration	27
FIGURE 3	Mean Monthly Pan Evaporation and Rainfall	29
FIGURE 4	Average Pan Coefficients in Same During the Periods 1982-1986.	31
FIGURE 5	Crop Water Requirements for Kisangara in 2 December 1993-15 March 1994.	32
FIGURE 6	Soil Moisture Content for 80 cm Rooting Depth in 8% Slope.	38
FIGURE 7	Soil Moisture Content for 80 cm Rooting Depth in 3% Slope.	39
FIGURE 8	Calculated and Observed Soil Moisture Content for 80 cm Rooting Depth in 4:1 Ratio for 8% Slope.	41
FIGURE 9	Calculated and Observed Soil Moisture Content for 80 cm Rooting Depth in 2:1 Ratio for 8% Slope.	42
FIGURE 10	Calculated and Observed Soil Moisture Content for 80 cm Rooting Depth in 0:1 Ratio for 8% Slope.	42
FIGURE 11	Calculated and Observed Soil Moisture Content for 80 cm Rooting Depth in 4:1 Ratio for 3% Slope.	43
FIGURE 12	Calculated and Observed Soil Moisture Content for 80 cm Rooting Depth in 2:1 Ratio for 3% Slope.	43
FIGURE 13	Calculated and Observed Soil Moisture Content for 80 cm Rooting Depth in 0:1 Ratio for 3% Slope.	44
FIGURE 14	Mean Daily calculated Soil Moisture Deficit for 8% Slope	47
FIGURE 15	Mean Daily Calculated Soil Moisture Deficit for 3% Slope	47



LIST OF PLATES

		<u>Page</u>
PLATE 1	Pan Evaporation Measurements	16
PLATE 2	RWH Crop Systems in Kisangara	19
PLATE 3	Maize Growing Under RWH	22
PLATE 4	Bare and Compacted Soil Surface	23
PLATE 5	Runoff Collecting Tanks	24

CHAPTER 1

INTRODUCTION

Rainwater harvesting or runoff irrigation can be widely used in arid and semi-arid regions. This is based on the rainwater harvesting principle: runoff captured in the catchment area is diverted to cropped fields and it is used to supplement the crop water requirement.

In these regions, the limited availability of water is often the most important factors affecting the crop yields because the amount of rainfall is not sufficient to obtain optimum crop yields. Therefore, there is a water stress in the rootzone during the crop growth season due to the high evapotranspiration .

The greatest problems in these regions such as most of countries in Africa have been lack of food and increase of population . People do not feed sufficiently and starvation has become major problem. Climate limits the optimum crop production so that the aim of the agricultural engineers is to get the more yield. Maize is one of the most important cereals and is consumed for many purposes . The water deficits affect the maize growth differently during the growing stages. Maize is relatively tolerant to water deficits during the vegetative and ripening periods. On the other hand, the greatest decrease in grain yields occurs during the flowering period due to mainly reduction in grain number per cob.

There are a number of ways which crop production per unit area can be increased in semi-arid areas. These are rainwater harvesting in arid and semi-arid regions, applying suitable fertilisers for crop, crop protection, improvements of saline and sodic soils etc. Irrigation and rainwater harvesting are the most important factors affecting the crop yield directly. It is impossible to produce crops without water. Therefore, storing more water in the soil profile is the major objective of irrigation engineers in these regions. Rainwater harvesting is a very good technique to increase the crop yield. This is used to improve plant performance in areas where moisture deficiency limits production. The advantages of this technique can be subdivided into particular components (Critchley et al. , 1992) : initial establishment can be improved through the concentration of early showers, the crop may be helped to weather a mid-season dry spell, or rainfall may be multiplied at critical periods when the season ends prematurely. Still, there can obviously be no control over the timing of water harvested, in contrast to most irrigation systems.

Careful timing of planting is very important to optimise the plant's use of the available moisture. Different strategies may be used according to the rainfall characteristics of the area. For example, in the Turkana Region of Kenya, crops are planted into residual moisture after a heavy runoff event (Critchley et al. , 1992).

Soil moisture storage may also be increased by applying crop residues on the soil surface in the cropped fields. Thus, water is mainly held in the rootzone and very little water evaporates from the soil surface. They result in decreasing the evaporation from the soil surface so more water is available for transpiration from the crops. As the transpiration increases crop yield will increase because of the using more water for dry matter production. In order to increase the efficiency of rainwater harvesting a bare and compacted soil surface can be used. A Bare and

compacted surface leads to decreasing infiltration and thus increasing the runoff from the catchment area to cropped fields. Therefore, more water is diverted to the cropped area and is held in the soil profile. This water can be used by crops, especially during the drought season.

In this study, the first chapter is related to introduction, the second chapter covers the literature reviews, the third chapter concerns with the material and method, the fourth chapter covers the results and discussions, and the fifth chapter is the conclusion.

The aims of the thesis are to investigate the effect of soil moisture deficit on maize yield considering the two different land slopes (3% and 8%) and three catchment area to cropped field ratio (4:1, 2:1, and 0:1) for Kisangara in Semi-arid Tanzania.

CHAPTER 2

LITERATURE REVIEW

2.1 Rainfall Effects

In arid and semi-arid regions the limited availability of water is the main constraint to rainfed agriculture in most cases. Especially in the arid regions the amount of rainfall is not enough to sustain a crop production, while in the semi-arid regions it is not so much the quantity, but the uneven distribution of rainfall in time and space that makes rainfed agriculture a risky enterprise. Even where the amount of rainfall is sufficient for crop production, part of the rainfall can be lost as surface runoff before even reaching the crop rootzone (Reij et al. , 1988).

Precipitation in all dryland areas is variable and is difficult to predict . Hatfield (1990) stressed that there is no reliable method of predicting the amount of precipitation with season. Distribution of rainfall is a major factor affecting optimum crop production. Poor distribution of rainfall resulted in lower maize crop yield in 1986 at Mtwapa, Coast Province, Kenya. It has been found that in that year, almost 91% of the rainfall fell during the two months of the vegetative growth period and only 9% of it fell during the pollination and grain-filling period. In the previous year, the same amount of rainfall was evenly distributed. In this year, almost 58% of the rainfall fell during the first two months and 42% of it fell in the second period. In 1986 the early heavy rains brought about excessive leaching of nutrients especially N and K that were then unavailable to the maize crop (Reshid et al. , 1989).

Wallace et al. (1993) concluded that one of the most important limitation for crop growth in arid and semi-arid regions is insufficient and variable rainfall. Crop performance should be determined by not only the total amount of rainfall but also its distribution during the growth period.

2.2 Rainwater Harvesting

Rainwater harvesting is an appropriate technology which can be used for sustainable agriculture and rural water supply. This technology is more appropriate for developing countries with a lack of rainfall.

Runoff irrigation or runoff agriculture is based on the rainwater harvesting principle. Runoff captured in the catchment area is diverted to the cropped fields and it is used to supplement the crop water requirement (Klemm , 1987). Water harvesting can be also defined as " a method of collecting surface runoff from a catchment area, using channels, dams or diversion systems, and storing it in a surface reservoir or in the rootzone of a cropped fields for direct use" (Reij et al. , 1988).

Reij et al. (1988) suggested that in a situation where total seasonal rainfall is not enough for crop production, the focus of the management practices will be general on increasing the amount of surface runoff towards and into the plant-soil system to get feasible crop production.

Agassi et al. (1990) found that on the consolidated surfaces, the percent of runoff increased with an increase in slope, while it decreased with an increase in slope on

the disturbed surfaces at the northern Negev of Israel near Kibbutz Bet Qama. If the slope increases runoff also increases because surface storage decreases.

2.3 Crop Water Requirement

Mohan and Arumugam, (1994) suggested that irrigation water has to be utilised in a method that matches the crop water requirement. Crop water requirements vary substantially over the growing season mainly due to variation in crop cover and climatic conditions.

2.4 Evaporation Process

Evaporation can be defined as it is the process whereby a liquid is transformed entirely into a gas (Burman and Pochop, 1994).

Water is lost mainly from the soil surface by means of the evaporation in drylands. It has been found that approximately 60% of the 500 mm of mean annual precipitation has been lost directly via evaporation in the U.S.A Great Plains (Unger, 1990). Water evaporates from the soil surface before it infiltrates. Evaporation can be classified into three stages (Unger, 1990; Hsiao, 1990). Firstly it takes place rapidly and steadily. It depends on the net effects of water transmission to the surface and the above ground conditions (e.g. relative humidity, temperature, wind speed etc.). Next as the soil moisture deficit increases evaporation decreases and the rate of water movement towards the surface is controlled by soil factors while above ground conditions only marginally affect the evaporation. Finally, evaporation is controlled by adsorptive forces at the solid-liquid interface and is extremely slow. The cycle is repeated when rainfall or irrigation wets the surface again.

2. 5 Maize Temperature Requirement

The temperature requirement of maize is variable. Doorenbos et al. (1986) suggested that maize can be grown in climates ranging from temperate to tropical during when daily temperatures are above 15 °C.

2. 6 Factors Affecting Maize Yield

Maize is classified as a moderately sensitive crop in terms of soil salinity level. The crop yield decreases under increasing soil salinity. It has been found that the reductions of yield as a percentage are 0% at ECe below 1.7 dS/m, 10% at 2.5, 25% at 3.8, 50% at 5.9 and 100% at ECe 10 dS/m (Doorenbos et al. , 1986).

It has been found (Weill et al. , 1990) that there are three main factors that control total maize yield in clay textured soils: plant population, soil nitrate content, and soil bulk density with in the same climate. This confirms that the higher yields obtained with inorganic fertilisers are led to by higher quantities of nitrates available to the plant. Year and plant population accounted for 69% of the variability of the total plant yield; year, plant population and nitrates for 81%; and year, plant population, nitrates and soil bulk density accounted for 87%. The fertiliser requirements of maize are very high. To obtain high crop productions as much as 200 kg/ha N, 50 to 80 kg/ha P and 60 to 100 kg/ha K should be applied (Doorenbos et al. , 1986).

Maize grain is affected mainly by the frequency and depth of irrigation and rainfall. During the vegetative and ripening periods maize appears relatively tolerant to water deficits. It has been found that during the flowering period water deficits

result in the greatest decrease in grain yields due mainly to a reduction in grain number per cob. Severe water deficits during the flowering period, especially at the time of silking and pollination, could lead to little or no grain yield due to silk drying. The reduced yield may result from water deficits during the seed formation period due to a reduction in grain size. Water deficits have little effect on grain yield during the ripening period (Doorenbos et al. , 1986).

The crop yield is influenced by the physical, chemical and micro biological conditions of the soil as well as the climatic factors such as amount and timing of precipitation during the growing season. It has been suggested that in addition to the weather, the physical condition of the soil has a major influence on crops because it controls the environment in which roots develop. Thus, the crop yields from year to year can be also affected by the changes in soil physical properties, such as water availability, density and air-filled porosity leading to compaction caused by tillage and no tillage (Negi et al. , 1990) .

Doorenbos et al. (1986) stressed that reduced maize grain yield can be caused by water logging so that it should be avoided especially during the flowering and seed formation periods. Water logging during the flowering period may reduce grain yields by 50% or more.

Maize can be grown effectively on most soils but less so on very heavy dense clay and very sandy soils. The soils desired for optimum crop yield should be well-aerated and well-drained. Commercial crops ,such as maize , can be adopted to moist conditions and do not tolerate long periods of saturation or low soil water conditions (Burman and Pochop, 1994).

Smika (1986) suggested that soil texture is the major factor affecting in soil water holding capacity. Crop yields are influenced by the soil water holding capacity. Some soils can hold too much water and require drainage before crops can be successfully grown. However, other soils may not contain enough water and need water conservation practices for increasing crop production.

2. 7 Maize Yield

It has been found that under irrigation a good commercial grain yield can be obtained between 6000 to 9000 kg /ha (Doorenbos et al. , 1986).

2. 8 Soil Conservation

In dryland farming increasing the infiltration is very important to match the crop water requirement. Papendick et al. (1990) concluded that small to moderate amount of surface residues are very effective in controlling the wind and water erosion over a wide range of climatic, slope, and soil conditions. Surface mulch slows evaporation and breaks the raindrop impact, thus decreasing runoff and surface crusting, especially on structurally weak soil during the rainy season.

2. 9 Soil Characteristics in Semi-Arid Regions

Agassi et al. (1990) reported that soils in semi-arid regions are characterised by poor structure and relatively high sodicity in the soil profile. The most important result of poor structure is the tendency of these soils to display marked sealing during rainfall, which leads to excessive runoff and soil erosion. The water holding capacity, infiltration rate, and available depth for rooting are the most important

soil characteristics that affect the irrigation or rainfall efficiencies in semi-arid regions (Hatfield, 1990).

2. 10 Crop Coefficient

Crop coefficient or K_c is the empirical ratio of the potential crop water requirement (ET_a) of a given crop under non-stressed conditions to reference crop evapotranspiration (ET_o). It represents crop specific water use and facilitates accurate prediction of irrigation water requirements. It includes soil evaporation. Mohan and Arumugam, (1994) provided crop coefficient values for most of crops grown under different climatic conditions. These values can be used commonly in places where local data are not available. On the other hand, they stressed the strong need for local calibration of crop coefficients under given climatic conditions.

2. 11 Pan Coefficient

It has been reported that the ratio of grass ET_o to Open Class A Pan evaporation at Davis, California was 0.80. Many references in the literature report similar values in the range of 0.75 to 0.85 for an Open Class A Pan coefficient (Howell et al. , 1983).

CHAPTER 3

MATERIAL AND METHOD

3. 1 Location

The study was carried out in Kisangara ($3^{\circ} 43' S$, $37^{\circ} 35' E$; 870 m altitude) near the Mwanga Township in Kilimanjaro region in semi-arid Tanzania (Figure 1). There are two rainy seasons in this region. These are called the short rainy season (*Vuli*) lasting from October to December and the long rainy season (*Masika*) covers February to May. The mean annual rainfall is 835.5 mm. The rainfall and evaporation patterns for Morogoro, Same and Kisangara Sites are represented in Table 1.

At Kisangara, the land slope is not gentle. It ranges from 2-3% on lower part, 7-10% on the upper part. The soils have reddish colour with a fairly deep subsoil (100-130 cm) which has a stony rock base. Due to a long history of sisal cultivation, a high density of sisal root network dominates the first 0-10 cm depth of the soil (S.U.A. , 1993).

3. 2 Reference Crop Evapotranspiration Calculations

There are number of available methods for estimation of reference crop evapotranspiration. The Modified Penman, Radiation, The Blaney Criddle and Pan Evaporation have been extensively used for different climatic conditions all over the world. The FAO Modified Penman method was chosen for our study. The are two main reasonschoosing this program. Firstly, data were suitable for applying

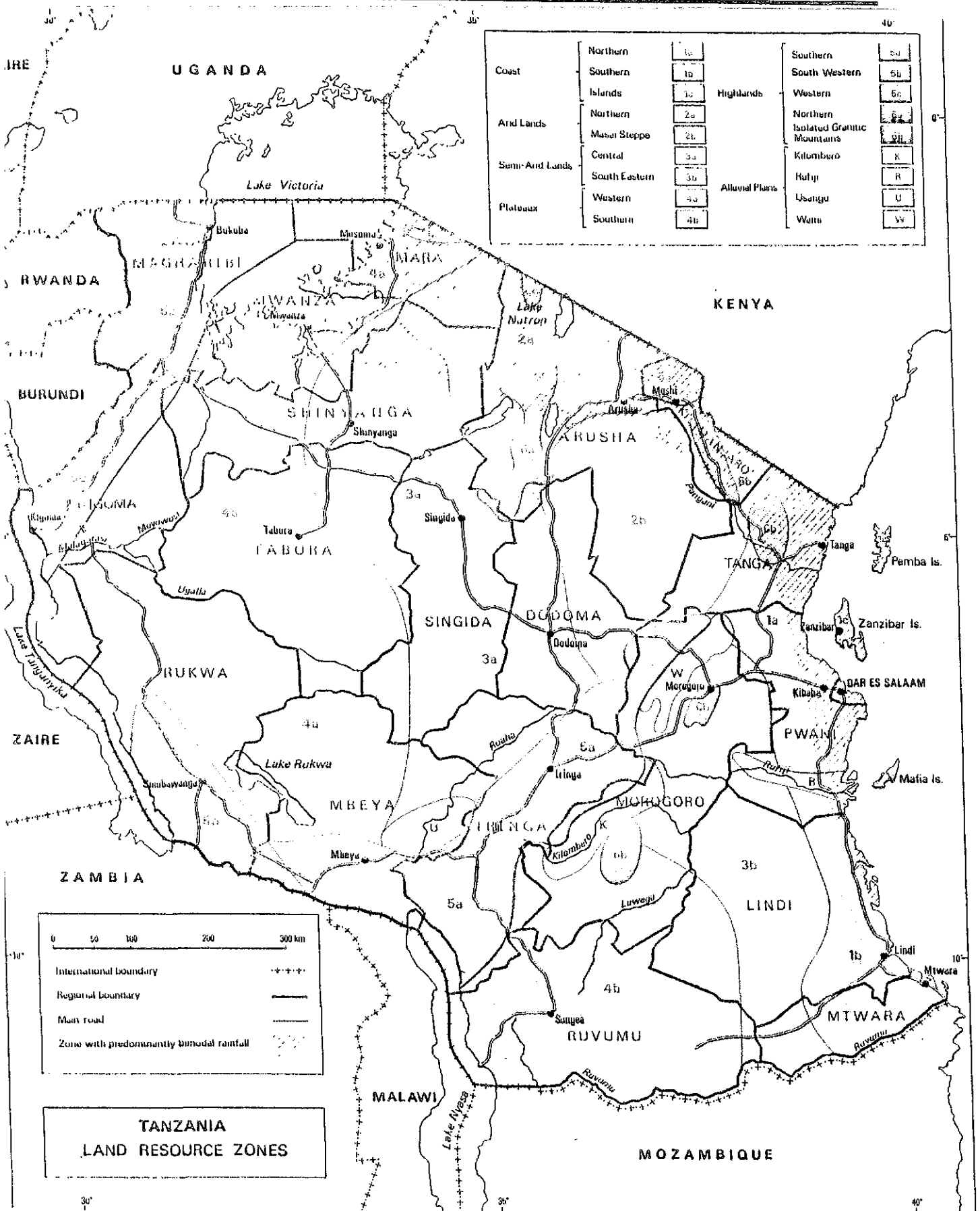


Figure 1: Tanzania, classification of agro-ecological zones

TABLE 1. Monthly seasonal and annual rainfall for Morogoro, Same & Kisangara (S.U.A. , 1993).

Season	Morogoro			Same		Kisangara
	Month	Rainfall (mm)	Pan Evaporat (mm)	Rainfall (mm)	Pan Evaporat (mm)	Rainfall (mm)
Short Rains (Vuli)	Septem.	10.3	166.1	15.8	185.8	17.7
	October	30	193.5	41.6	223.5	42.4
	Novem.	65.1	209.2	61.8	223.8	135.7
	Decem.	112.5	204.7	66.2	258.2	100.2
	Janua.	97.5	191.6	57.7	287.7	77.5
	Total	315.4	965.1	243.1	1179	373.5
Long Rains (Masika)	Febru.	75.1	188.6	45	218.3	47.5
	March	120.4	172.6	87.5	262.7	166.4
	April	177.8	117.1	120	174.5	171.4
	May	84.9	98.1	66.2	138.5	64.3
	June	17.8	93.8	11.9	147.7	12.4
	Total	476.1	670.3	330.6	941.7	462
Annual		791.5	1635.3	573.7	2120.7	835.5

this method and secondly, they were calculated easily by means of a spreadsheet macro. Thus, calculations were carried out quickly.

The Modified Penman formula is given by (Mohan and Arumugam. , 1994);

$$ET_o = C_p [wR_n + (1-w)f(u)(e_a - e_d)]$$

Where;

ET_o = reference crop evapotranspiration (mm/day);

e_a = saturation vapour pressure (millibar);

e_d = actual vapour pressure(millibar);

$$f(u) = 0.27(1 + \frac{u}{100})$$

Where;

u = wind speed (km/day);

R_n = total net radiation (mm/day);

w = temperature and altitude dependent weighting factor and;

C_p = adjustment factor for Uday / U night;

Wind speeds measured at different heights for Same station were converted to 2 m height. The data used for calculation ET_o were taken from the Same during the periods 1982-1986. A Penman Macro (Wyseure, pers. comm.) Quattro Pro for Windows version 5 was used. Julian day, maximum and minimum temperatures (oC), relative humidity (%), sunshine (hours), wind speed (km/day), evaporation (mm/day), rainfall (mm/day), and dew point (oC) data were entered into the computer. Secondly, two different files named Same and Etdewp.wb1 were opened

(It has the Penman equation program). Having opened these files, tools/ macro/ Etdewp. wb1 / Penman was chosen. The values of altitude and latitude for Same were entered. Selecting the Julian day, maximum and minimum temperature, dew point, relative humidity, daily sunshine, and wind speed columns the program was run and thereby reference crop evapotranspiration (ET_o) values were computed in mm/day for periods 1982-1986.

3. 3 Evaporation Measurements

The Class A Pan was used to measure the evaporation for Same. The measurements were carried out during the periods 2 December 1993-15 March 1994 that include maize growth period. The Class A pan is a cylindrical container, 0.24 m (10 in.) deep and 1.22 m (4 ft) inside diameter (Plate 1). In general galvanised steel (22 gauge) and rarely other non-rusting metals are used to construct the pan. It is placed on a wood pallet so the bottom of the pan is 0.10 to 0.20 m (4 to 8 in.) above the soil surface and ventilation under the pan can take place freely. The water level in the pan was maintained between 0.025 to 0.050 m (1.0 to 2.0 in.) from the top of the rim (Phene et al. , 1992). The water level in the pan was measured at the same time daily with a hook micrometer in a stilling well.

3. 4 Pan Coefficient Calculations

Pan evaporation and reference crop evapotranspiration data were used to compute the pan coefficient. The formula used to calculate pan coefficient is given by;

$$K_p = \frac{ET_o}{E_{pan}}$$

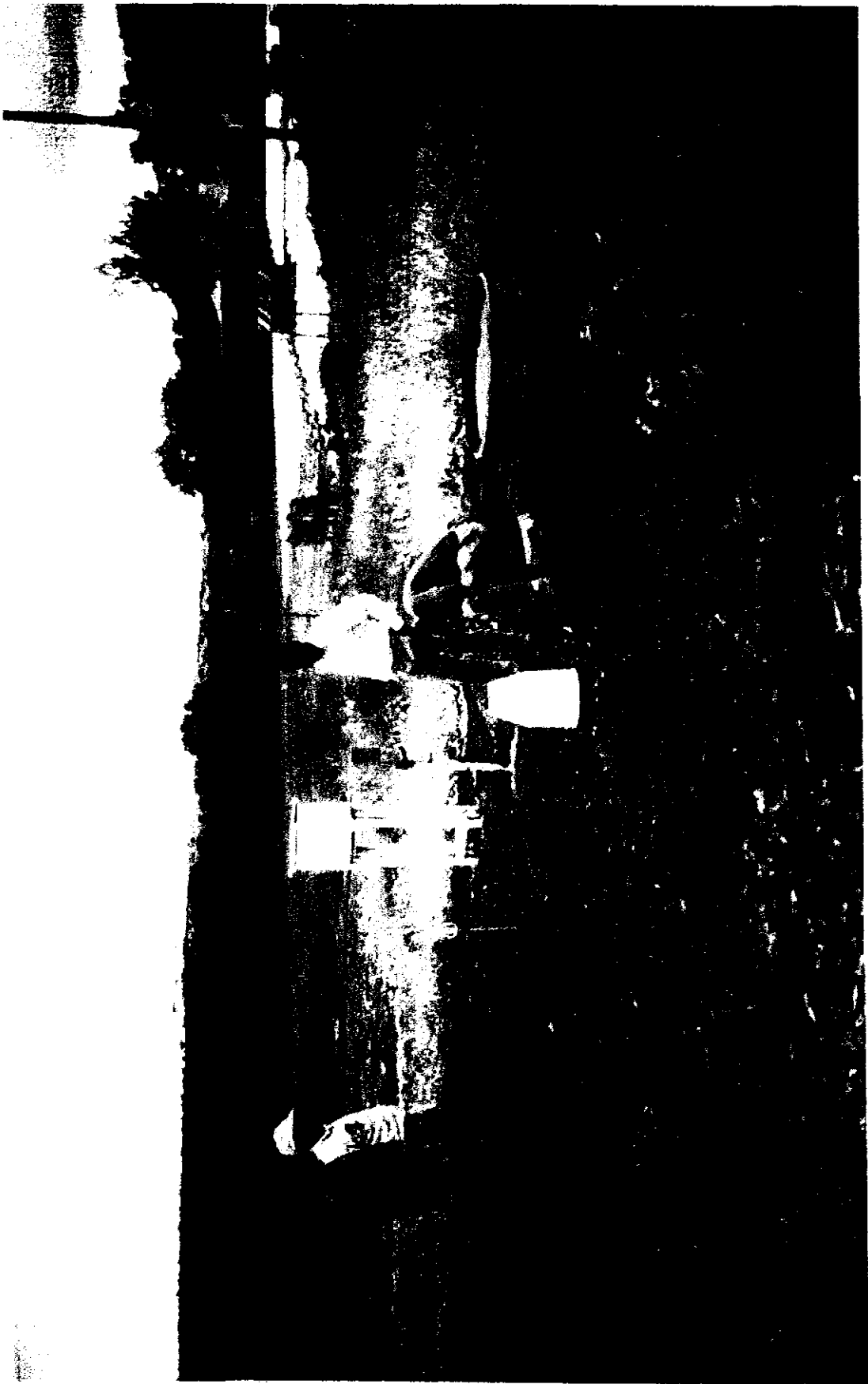


PLATE 1. Pan evaporation measurements

Where;

K_p = pan coefficient;

ET_0 = reference crop evapotranspiration (mm/day) and;

E_{pan} = Pan evaporation (mm/day).

The nature of the data was very erratic. In order to get meaningful relationship, smoothing was needed. Therefore, they were converted to the 3 days moving average values. Thus, the stable values of pan coefficients were obtained.

3. 5 Crop Coefficients

The maize growth period was 104 days; from 2 December 1993 to 14-15 march 1994. The crop coefficients (K_c) were taken from the FAO Irrigation And Drainage Paper No. 33 (Doorenbos et al. , 1986). The K_c values were 0.40 for the initial stage ; 0.78 for the development stage ; 1.13 for the mid season stage ; 0.85 for late season stage , and 0.57 for harvest time. The K_c values were interpolated between successive growth stages.

3. 6 Crop Water Requirement Calculations

The crop water requirements (ET_{crop}) were calculated by multiplying the evaporation from the pan (E_{pan}) by a average pan coefficient ($K_{pav.}$) and crop coefficients (K_c). The formula can be expressed by (Phene et al. , 1992);

$$ET_c = K_c K_{pav.} E_{pan}$$

Where;

ET_c = the crop water requirement (mm/day);

$K_{pav.}$ = three days moving average pan coefficient;

K_c = crop coefficient and;

E_{pan} = pan evaporation (mm/day).

3.7 RWH Crop Experiment

The Kisangara site is the main experiment site because one of the objectives is to promote RHW agrosystems in the semi-arid lowlands of Kilimanjaro region. A maize trial of three runoff generating area cum two tillage treatments was carried out on the 8 and 3% slope. The six treatments were arranged in a randomised block design with three replications (Plate 2). The plots were divided into a cropped field (CF) of 10 m wide by 5 m long and a bare and compacted (BC) catchment area (CA) at the same width located up slope the cropped field. The runoff generating areas were based on the three CA:CF area ratio, and these were 4:1, 2:1, and 0:1. These plots were planted with maize (*Zea mays cv TMVI*). Maize was planted 2 December 1993 and were harvested on 14-15 March 1994. Growth was monitored by measuring biomass harvested at two stages, at 6th leaf stage and at final harvest. At final harvest, plant population, number of cobs per hectare and grain yield etc. were measured.

3.8 Calculation of Soil Moisture Deficit

Experiments were conducted in Kisangara for two slopes, named; 3 and 8% in three different CA:CF ratio (4:1, 2:1 and 0:1). Soil moisture deficits were computed with water balance by using the Quattro Pro for windows version 5 computer program. This was based on the water balance model. Firstly, days, rainfall, run-on produced from the catchment area, daily crop water requirement,

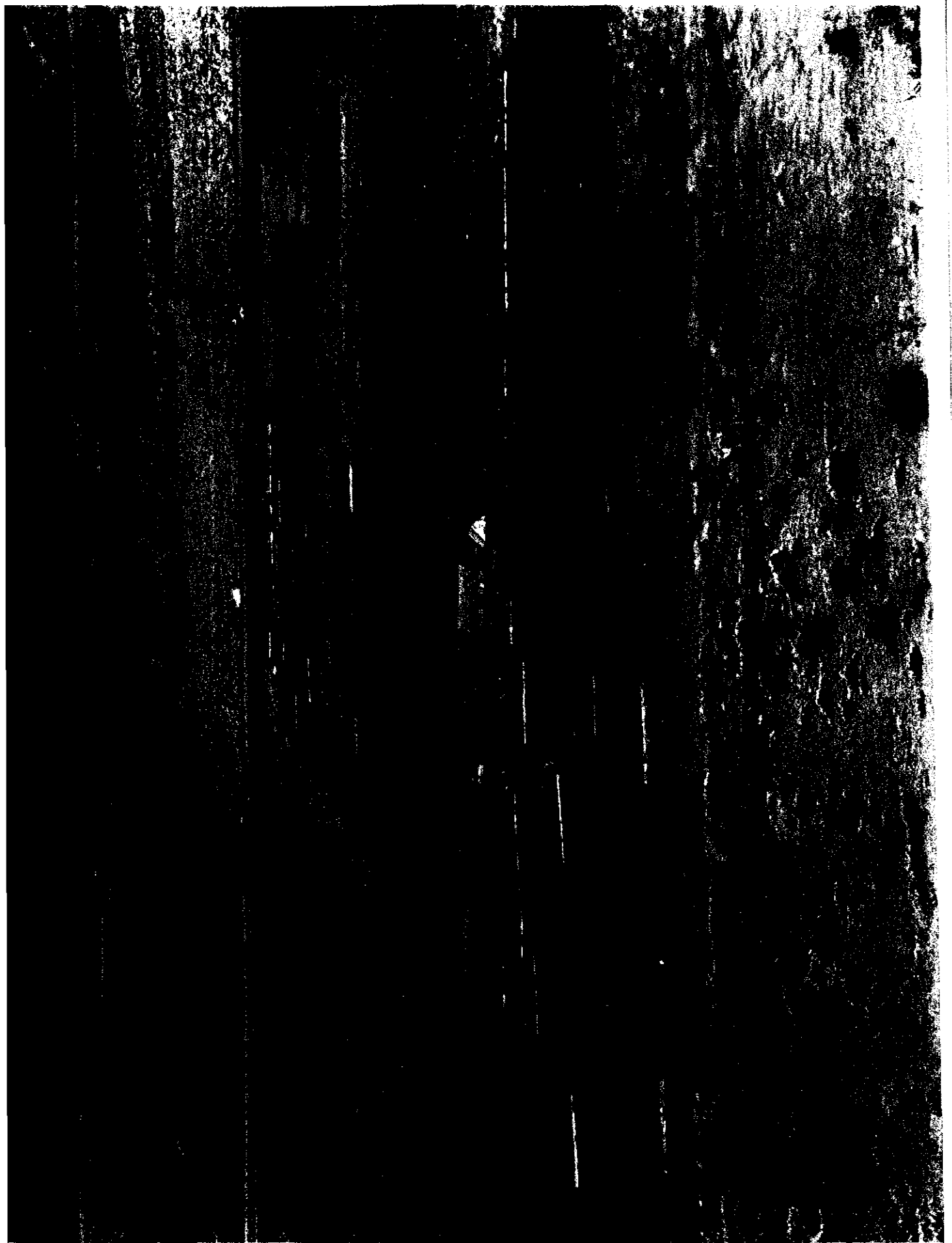


PLATE 2. RWH crop systems in Kisangara

and first day observed soil moisture content value were entered to the computer. The daily soil moisture deficit was the difference between the field capacity value in rooting depth and the calculated daily soil moisture content value. If the calculated soil moisture content value is greater than the field capacity, water drains under the rootzone otherwise, it is retained in the rootzone. Soil water depletion for maize up to about 55% of available soil water depth was used (Doorenbos et al. , 1986). Crop may take the 55% of the total available water easily ($P_s = 55\%$). Some values used for calculations of soil moisture deficit are as follows (Rawls and Brakensiek. , 1989);

Profile depth	800 mm
Saturated water content	0.45 (for sandy clay soil)
Saturated water content in profile	360 mm (800*0.45)
Field capacity(FC)	0.25
Field capacity in profile	200 mm (0.25*800)
Permanent wilting point (PWP)	0.12
Permanent wilting point in profile	96 mm (0.12*800)
Soil water depletion (P)	55 %
Difficult available water (DAW)	96 mm+(FC-PWP)*P
Difficult available water in profile	153.2 mm
Air dry soil	0.045
Air dry soil in profile	36 mm (0.045*800).

3. 9 Runoff Experiments

This experiments were conducted at Kisangara. A Bare and compacted soil surface was used to get more water from catchment area to cropped fields (Plate 3). Two different land slopes were examined; 3% and 8%. The runoff measurements were

carried out as vol/vol and then converted to the millimetric units. Runoff tanks on a level base were installed in order to obtain accurate measurements (Plate 4). A spirit level was used to make sure that the tank level in its horizontal and the level was maintained during the process of refilling and compaction of the pit. A portion of soil was put behind the tank and it was then compacted. Water was applied to compact the soils. The tank was placed 15 cm above the ground (Plate 5). No replication was done due to the large number of experiments.

3. 10 Soil Moisture Measurements

The soil water contents were measured by a neutron probe. Access tube auger, guide tube of the size of access tube, access tube hammer, puller, access tubes, jack, neutron probe and data sheet were used for this purpose. Firstly, a vertical hole of almost 2.5 m was drilled by access tube auger. The guide tube was secondly pushed through the hole by using access tube hammer. To remove the guide tube puller and jack were used. Access tube thereafter was installed vertically to depth of 180 cm. The probe was lowered into the access tube to the appropriate depth and readings were taken from 10, 30, 50, 80, and 150 cm depth. The data were recorded into the data sheet. The readings were conducted in two different land slopes; 3% and 8% and under RWH crop system with CA:CF (catchment area/cropped field) ratio of 4:1, 2:1 and 0:1 to compare the soil moisture content. Maize usually takes up water from 80 to 100 cm depth for this reason, soil moisture contents were measured in the top 80 cm of the soil using data from 0-10, 10-30, 30-50 and 50-80 cm. Having calculated the actual soil moisture contents for each layer, they were summed and thereby actual moisture contents in mm in the top 80 cm depth were obtained. They then were grouped in terms of the

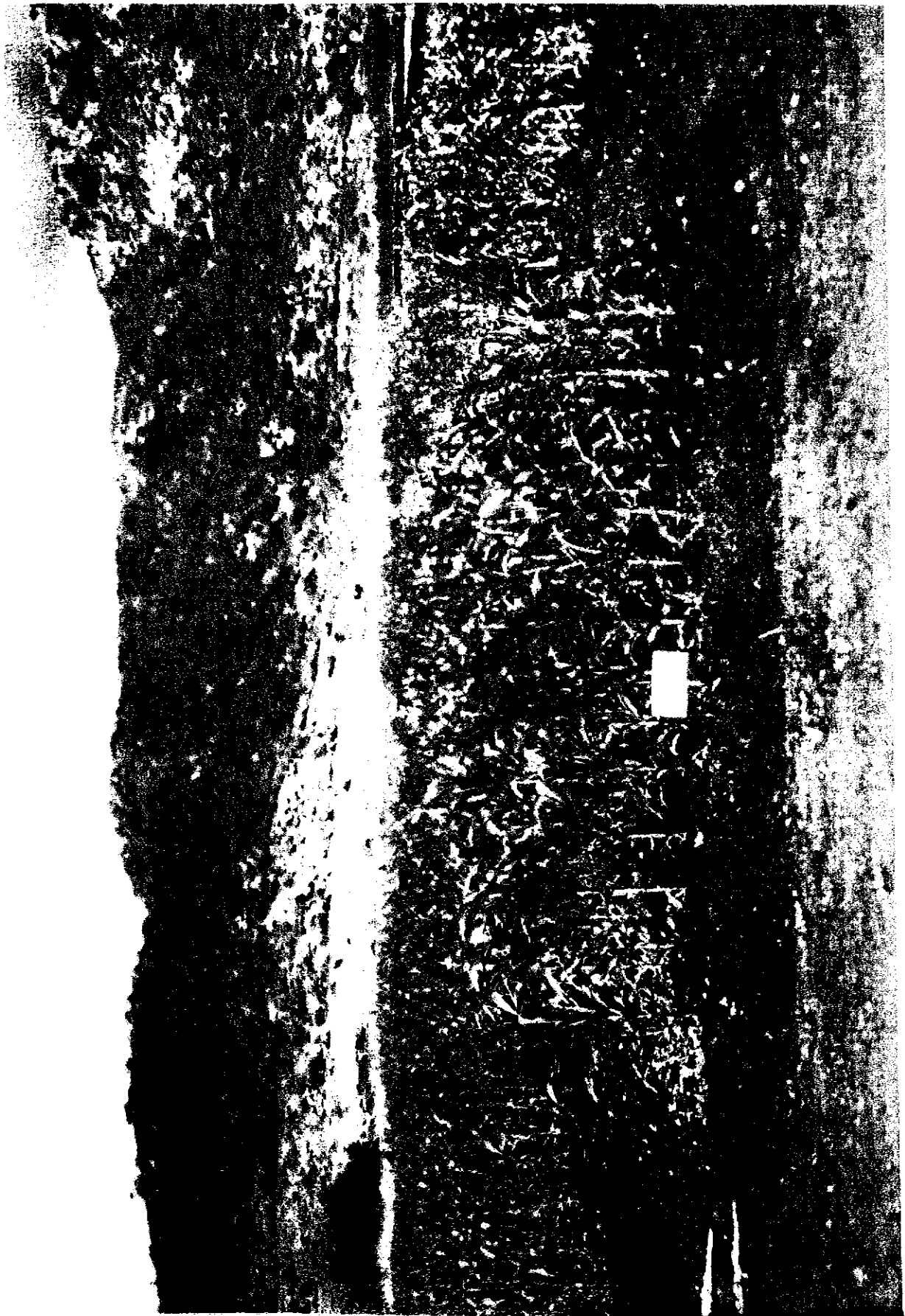


PLATE 3. Maize growing under RWH

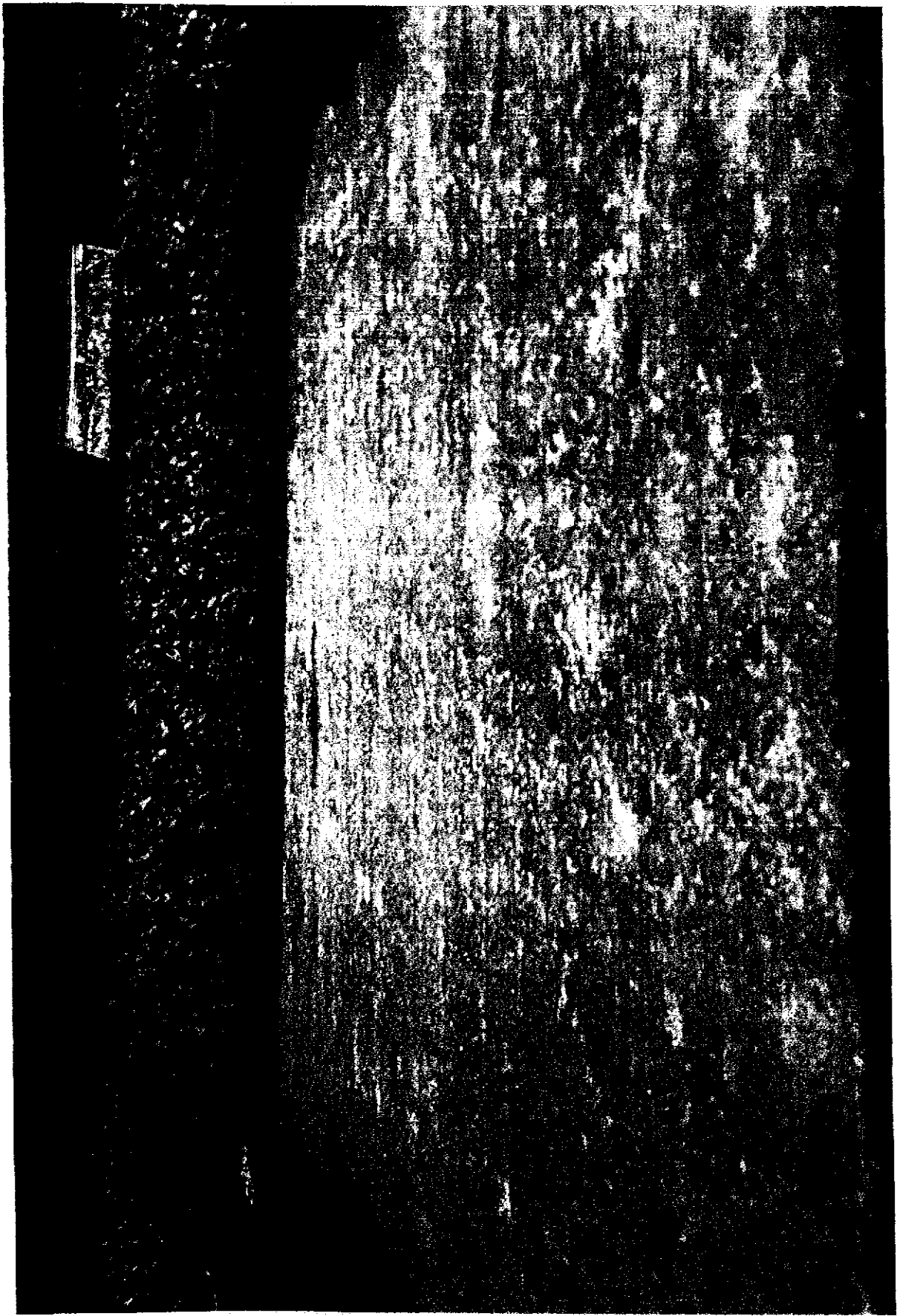


PLATE 4. Bare and compacted soil surface

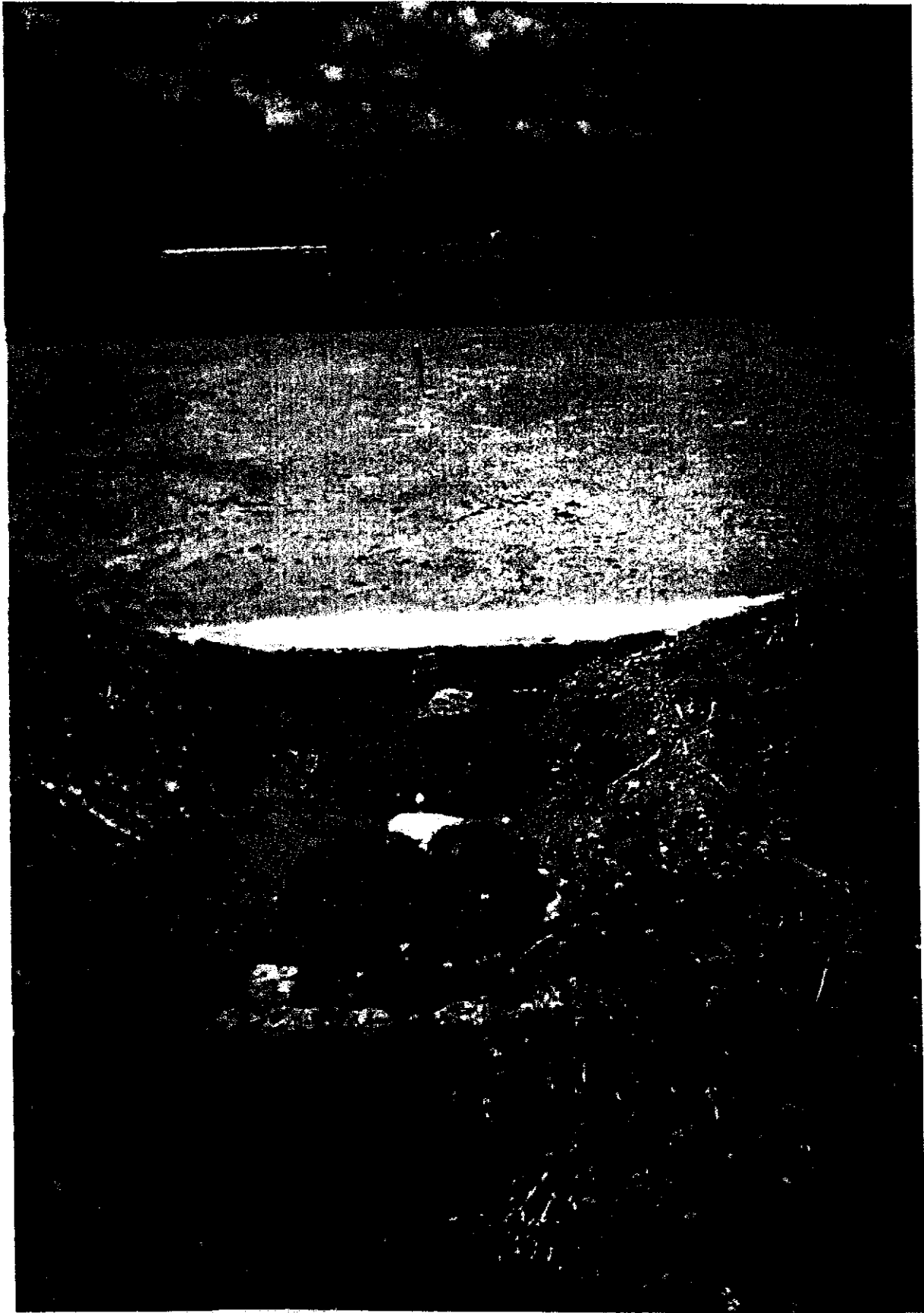


PLATE 5. Runoff collecting tanks

RWH crop system ratio (CA/CF) and then were averaged. Using these values and observation date figure was generated shown soil moisture content against time. Therefore the amount of water in soil profile during the maize growing period was determined. However, in 3 % land slope, measurements were intermittent due to lack of observation data.

CHAPTER 4

RESULTS AND DISCUSSIONS

4. 1 Reference Crop Evapotranspiration

Values of reference crop evapotranspiration (ET_0) pertaining to the different years were computed on a daily basis using the procedure outlined earlier (chapter 3. 2). The data used to compute the ET_0 were taken from Same during the periods 1982-1986 due to the only having enough data for these time periods. There were no data for Kisangara thus, data were taken from the Same station because, it is the nearest station to Kisangara. The reference crop evapotranspiration (ET_0) values show variations among seasons due to differences in climatic conditions among seasons. Figure 2 shows the values of reference crop evapotranspiration against time at Same regions in semi-arid Tanzania.

It can be seen from the figure that reference crop evapotranspiration values show firstly a rising trend in 1982 due to changes in climatic characteristics. ET_0 was found to be approximately in the range of 3.1 to 7.3; 3.5 to 6.6; 3.1 to 6.6; 3.3 to 7 ; and 3.1 to 6.5 during in 1982, 1983, 1984, 1985, 1986 respectively. There are two marked trends that can be seen from the figure very easily. The first, although in 1982, 1983, 1984, and 1986 the values of ET_0 show an increasing trend up to first 40 days, there has been falling trend in 1985 followed by an increasing trend. The other, in 1983 after approximately 340 days, there is a falling trend whereas there is a rising trend in 1982, 1984, 1985, and 1986. In general, the variation looks similar in 1982, 1983, 1984, and 1986.

Reference Crop Evapotranspiration

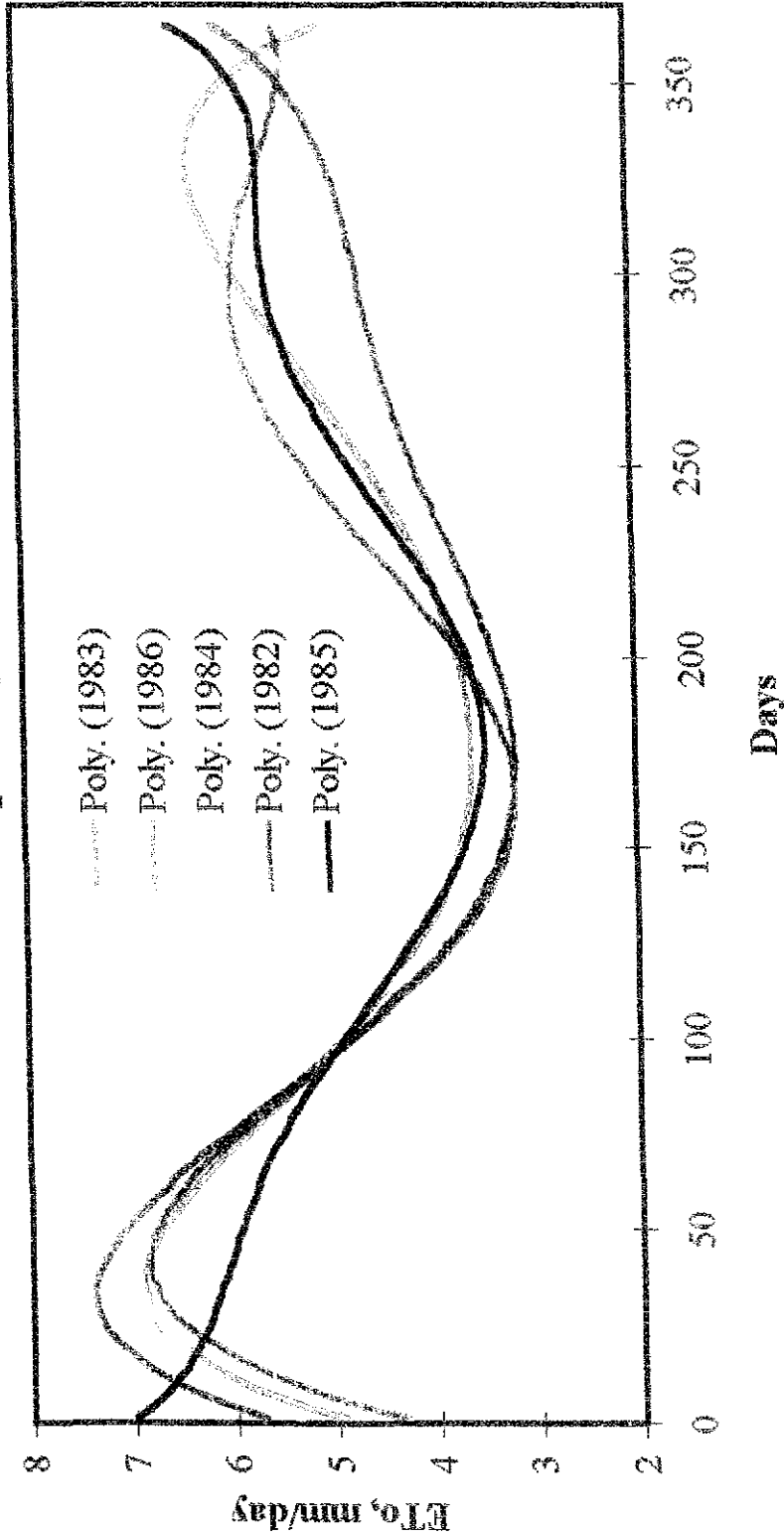


Figure 2. Reference crop evapotranspiration.

In general, calculation of mean daily reference crop evapotranspiration should be made for periods no shorter than one month. Since for a given location climatic conditions and consequently reference crop evapotranspiration could vary widely from year to year, ETo should be calculated for each calendar month for each year of record rather than by using mean temperatures based on several years' records.

4. 2 Pan Evaporation and Rainfall

In order to determine the evaporation a Class A Pan was used in Same Meteorological Station during the periods December 1993-March 1994 . The results are shown in Figure 3. The greatest evaporation values occurred in January 1994. The total measured pan evaporation values were 370.6, 398.7, 278.2, and 279.4 mm in December 93, January, February and March 1994 respectively. In these periods, total monthly evaporation is significantly greater than monthly rainfall . The total rainfall recorded were 9.1, 15.7, 48.6 and 80.2 in December 93, January, February, and March 1994 respectively. The highest rain was recorded in January 1994.

Evaporation from a soil can be treated as a two-step phenomenon, namely, conversion of liquid water to vapour and its escape into the atmosphere. There are three requisites for evaporation to proceed. First, the source of energy is needed to meet the latent heat of vaporisation of water. Second, It should be a vapour pressure gradient between the evaporating surface and the surrounding atmosphere. Finally, it should be supply of water to the evaporating surface. The sun is the major source of energy for meeting the latent heat of vaporisation of water. The first two conditions, namely, supply of energy and removal of vapour, are the external to the evaporating surface. These are mainly influenced by meteorological factors such as air temperature, wind speed, relative humidity.

According to the results, evaporation measured by means of the Class A Pan was considerably greater than rainfall during the maize growth period. This would be in keeping with the argument that evaporation needs three requisites; namely, source of energy, supply of water, and vapour pressure gradient between the evaporating surface and the surrounding atmosphere. In arid and semi-arid regions these three requisites are generally exist (Unger, 1990). As the evaporation increases transpiration decreases for this reason, less amount of water is taken up by crops. Therefore, crop can not use enough water for grain production. To increase the transpiration, evaporation from the soil surface should be decreased

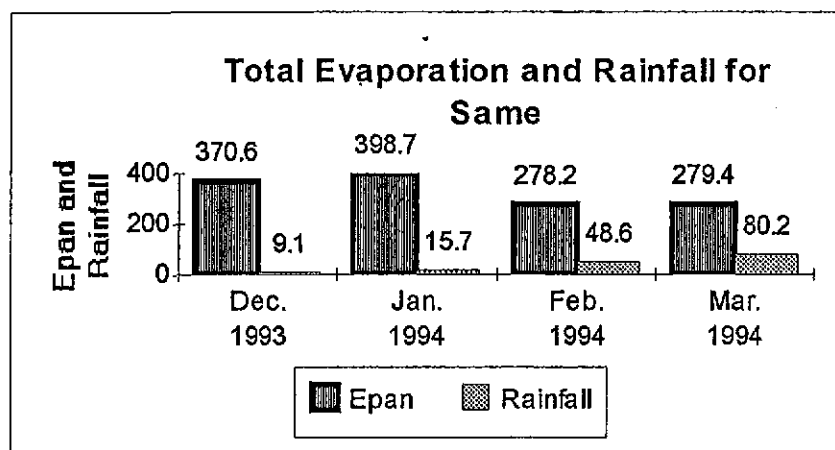


FIGURE 3. Mean Monthly Pan Evaporation and Rainfall.

thereby, soil moisture deficit falls. Crop residues are very practical way to increase the infiltration and decrease the surface runoff. Therefore, water is held in the soil profile and used for crop production. It is very essential for farmers to apply crop residues on the soil surface in arid and semi-arid regions to get more yield.

4.3 Pan Coefficients

Pan coefficients for Same were computed by dividing the reference crop evapotranspiration values by pan evaporation values for during the periods 1982-1986 due to only having meteorological data to calculate pan coefficients in these time periods. The calculation were not carried out for Kisangara because meteorological data were not exist. Figure 4 shows the average pan coefficient values against time. In general, the pan coefficient value varied in the range of 0.50 to 0.82 but it was between 0.60 to 0.75 in most of the year. It increased from 0.70 to 0.80 between 1 and 28 days and decreased from 0.80 to 0.58 during the periods 28-30 days. On the other hand, there was a gradual rising trend between 30 and 110 days. It decreased then during the periods 110-121 days and followed a gradual rising trend between 121 and 180 days. It was almost stable value between 180 and 365 days. In these periods, the pan coefficient value was approximately 0.65.

The observation that pan coefficient is consistent with the results of Howell et al. (1983).

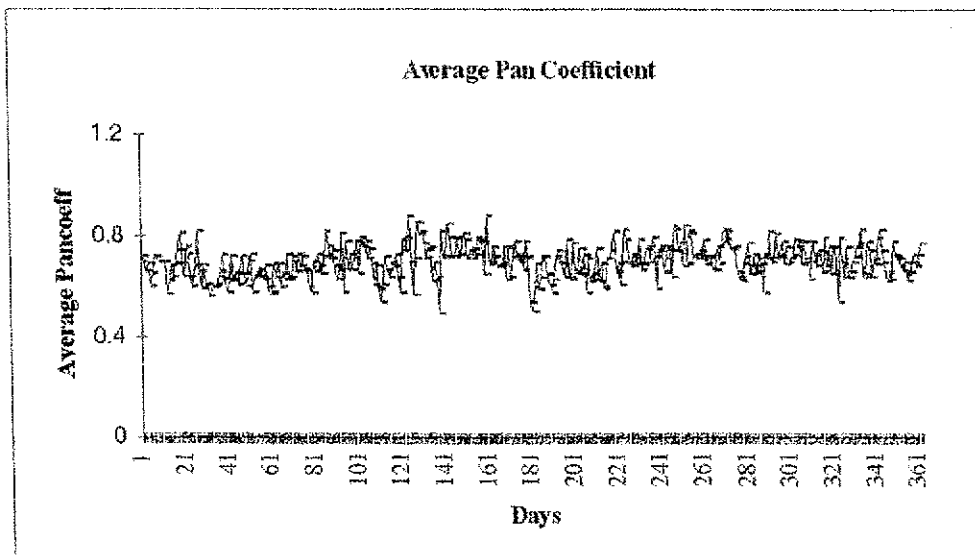


FIGURE 4. Average Pan Coefficients in Same during the periods 1982-1986.

4. 4 Crop water Requirements

Values of crop water requirement (ET_{crop}) pertaining to the short rainy season (2 December 1993-15 March 1994) were computed on daily basis using the procedure outlined earlier (chapter 3. 6). They were not computed for Kisangara due to the lack of meteorological data although the experiments were conducted in Kisangara. Same was chosen as the nearest station to the Kisangara.

As is apparent from the figure 5 that, crop water requirements varied widely during the growing season. The total crop water requirements were 593 mm for whole maize growth season. ET_{crop} increased gradually from 3 to 8.3 mm in first 52 days and decreased dramatically then from 8.3 to 4 mm between 52 and 76 days. There was a rapid increase from 4 to 6.10 mm between 76 and 79 days and

followed a falling trend during the periods 79-104 days. In these periods, they decreased from 6.10 to 2.6 mm. The calculations are given in Appendix I.

The average daily crop water requirement was 5.7 mm and it was high. The possible reason may be that pan evaporation values were high. As a result of this, high crop water requirements were resulted from the high pan evaporation values.

According to results, crop water requirements of maize depended upon its growth stages. It increased gradually from initial to at the end of the developing stage. This

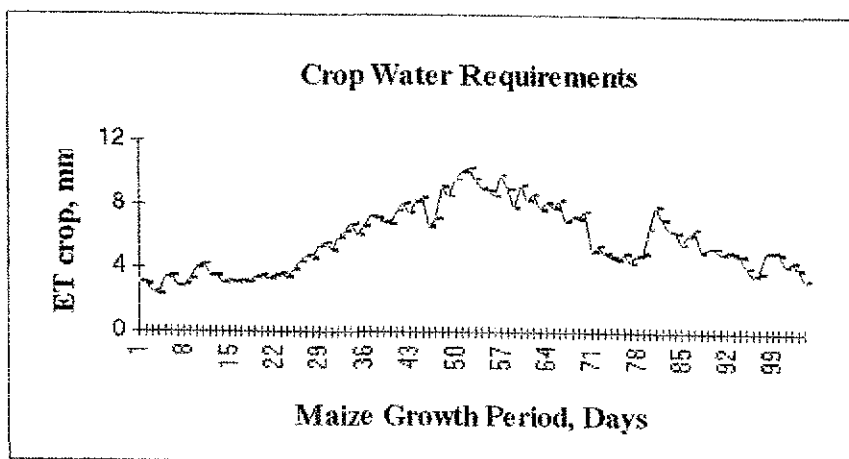


FIGURE 5. Crop water requirements for Kisangara in 2 December 1993-15 March 1994.

may be due to the fact that crops were small during the germination period for this reason, they transpired very little amount of water. Crops may use less water due to the having small root system. When the crop growth increases water requirement also increases and especially during the flowering phase, more water was consumed by crops.

During the periods late season-harvest stage, crop water requirements decrease and crop yields are not highly affected by water deficits during between these two stages.

In order to calculate the crop water requirement, mean climatic data are often used more. However, crop water requirement varies from year to year because of the weather changes. In selecting ET_{crop} for project planning and design, knowledge should be obtained on level and frequency at which high demands for water can be expected, especially in month of peak water use.

Meteorological data used are often collected prior to irrigation development in stations located in rainfed or cultivated areas. In irrigated area micro climate is different and crop water requirement may not be equal to estimated values based on these meteorological data.

Crop water requirement can also vary in a given climatic zone. The possible reason may be that crop water requirements could be affected by changes in temperature and humidity.

4. 5 Runoff Collecting Results

There was a considerable difference in the amount of runoff for two land slopes in bare and compacted soil surface conditions. The calculations were carried out per unit area. The total runoff values were 33.28 mm for 8% and 52.18 mm for 3% land slope. The total collected runoff value was equal to 12.58% of the total rainfall (258.58 mm) for 8% slope whereas it was equal to 20.18% of the total rainfall for 3% land slope. The results are given in Table 2. The maximum runoff

was observed in the 12 th. of February 1994 for both 3 and 8% land slope. In this date, the runoff values were 17.43 mm for 3% and 6.92 mm for 8% slope.

According to the results, the total runoff value was much more greater in 3% than 8% land slope. Although the runoff increases with an increase in land slope due to decreasing surface storage it was observed more in 3% than 8% land slope. These results are against to some previous study of Agassi et al. (1990). The possible reason may be that there was a difference in the infiltration rate between 3% and 8% slope or soil surface was more compacted in 3% slope than 8% slope. This can bring about decrease the infiltration rate in 3% land slope. If the soil infiltration decreases runoff will increase. Thus, more water will come trough the cropped field from the catchment area.

One of the most important factor affecting the amount of runoff is rainfall intensity and amount. Rainwater infiltrates into the soil profile if its precipitation rate is lower than the soil infiltration rate. Soil infiltration rate is higher for initial and then decreases because some of the pores in the soil profile fill with water. This causes decreasing volume of air-filled pores. As the soil moisture content increases runoff will also increase due to the decreasing soil infiltration rate.

Soil texture also has a major role to play in the infiltration process. Water infiltrates faster in sandy-textured soils than clay-textured soils. Although infiltration rate is lower in clay soils they absorbs more water because, total percentage of pores is greater.

TABLE 2. The amount of runoff collected in tanks for bare and compacted soil surface per unit area.

Date	Runoff, mm (3% Slope)	Runoff, mm (8% Slope)
1-December-1993	5.75	5.46
3-December-1993	0.57	1.54
4-December-1993	2.10	3.27
10-December-1993	0.33	0.12
13-December-1993	0.10	0.35
14-December-1993	8.30	0.83
15-December-1993	0.75	1.61
16-December-1993	2.07	1.32
18-December-1993	2.36	3.61
17-January-1994	2.80	5.0
12-February-1994	17.43	6.92
13-February-1994	1.19	0.37
16-February-1994	0.10	0.08
18-February-1994	0.61	0.38
24-February-1994	1.22	1.62
28-February-1994	0.04	0.03
5-March-1994	1.10	0.25
7-March-1994	5.36	0.52
TOTAL	52.18	33.28

Why is the runoff important? In arid and semi-arid regions, crop water requirement can be supplemented by two ways: rainfall and runoff agriculture or runoff irrigation. It is almost impossible to increase the amount of rainfall but the effectiveness of the rainfall can be increased by different water management practices. Rainwater harvesting is one of the important management practices increasing the availability of water for crops. Rainwater is diverted from catchment area to cropped field so that water stress in the rootzone during the drought period is reduced. Therefore, crops take up more water and crop production increases.

4. 6 Soil Moisture Content

Soil moisture contents in the rootzone (measured with a neutron probe) from 1 December 1993 to 15 March 1994 at Kisangara site were observed in the top 80 cm rooting depth. It can be seen from the figure 6 that in the 8 % slope, the soil moisture was the greatest under RWH with CA:CF (ratio of catchment area to cropped area) of 4:1 and the lowest with a ratio of 2:1 . The soil moisture contents in ratio of 4:1 increased suddenly from almost 115 to 190 mm during the periods 1 December-18 December 1993 and decreased gradually from 190 to 137 mm between 18 December 1993 and 15 January 1994. There was a marked increase in the soil moisture content from 137 to 181 mm during the periods 15 January-17 January and again declined gradually from 181 to 116 mm between 17 January and 7 February 1994. It was almost 158 mm at the end of growing season (15 March 1994). The lowest soil moisture content values were observed in the ratio of 2:1. They varied from 111.7 to 161 mm in 0:1 ratio. Although catchment area was twice greater in 2:1 ratio than in 0:1 ratio, values of soil moisture content were considerably low. The possible reason may be that crops did not transpire enough so that more water contents were resulted from this situation in 0:1 ratio.

According to the figure 6 that there are several peaks that were resulted from rainfall events. Rainfall was not uniformly distributed during the growing season. This is the major characteristic of arid and semi-arid regions that affects the crop yield widely.

Values of soil moisture content in the 3 % land slope varied widely in terms of the RWH crop system ratio. Figure 7 shows the observed soil moisture content against time. Soil moisture contents were greater in the 2:1 ratio than in 4:1 and 0:1 ratio. The lowest values were displayed by the 0:1 ratio. The soil moisture contents were in the range of 135.5 to 216; 158.1 to 203.9 and 107.5 to 187 mm in the 2:1, 4:1 and 0:1 ratio respectively. There may be two possible reasons caused this high variation in the observed soil moisture contents. Firstly, soil moisture contents were greater in the 2:1 ratio than 4:1 due to the lack of transpiration by crops and secondly, samples taken from these plots were not enough to identify the actual soil moisture contents properly. Therefore, it was necessary to take more samples in order to get more reliable results. Run-on was the major factor affecting the soil moisture content in the soil profile and after the each rainfall event there was an increase in the amount of soil moisture. The soil moisture contents may increase not only rainfall but also capillarity rises. If the soil texture is clay, water goes up by means of the capillary force.

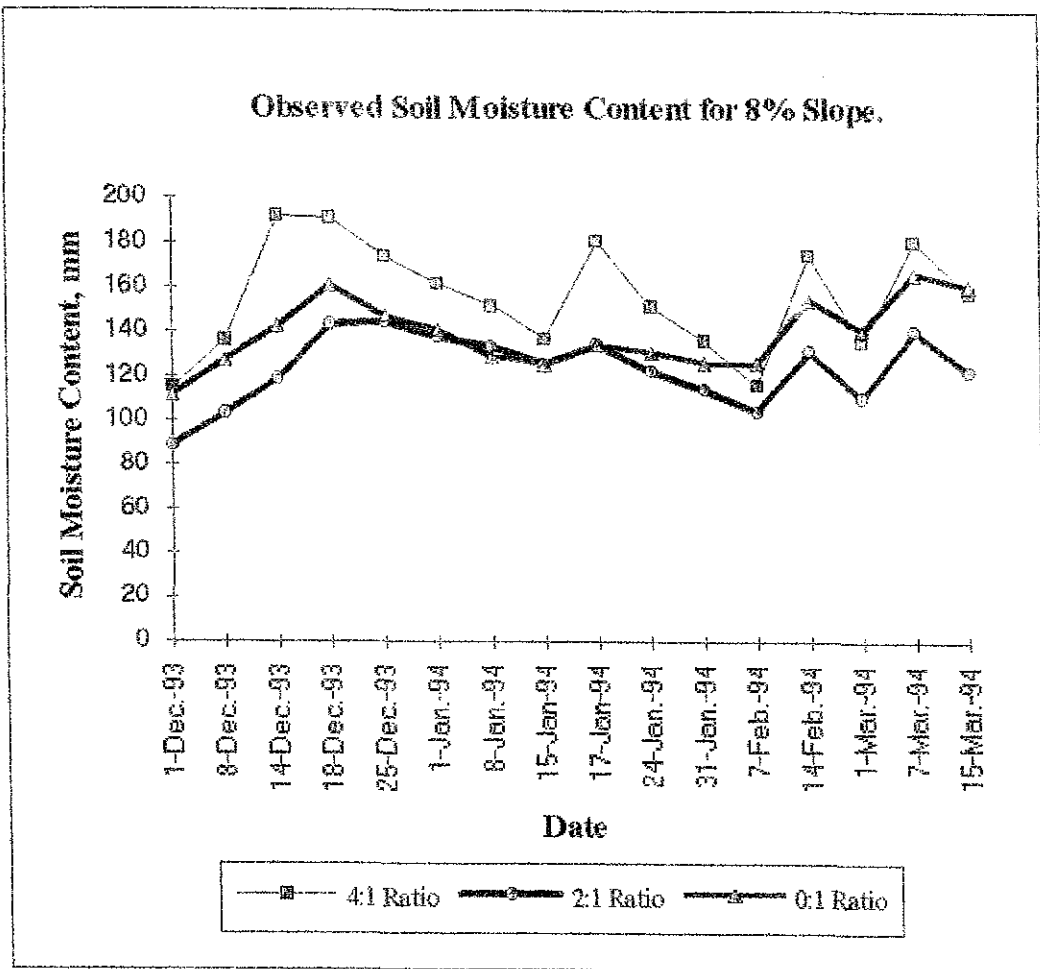


FIGURE 6. Soil Moisture Content for 80 cm Rooting Depth in 8% Slope.

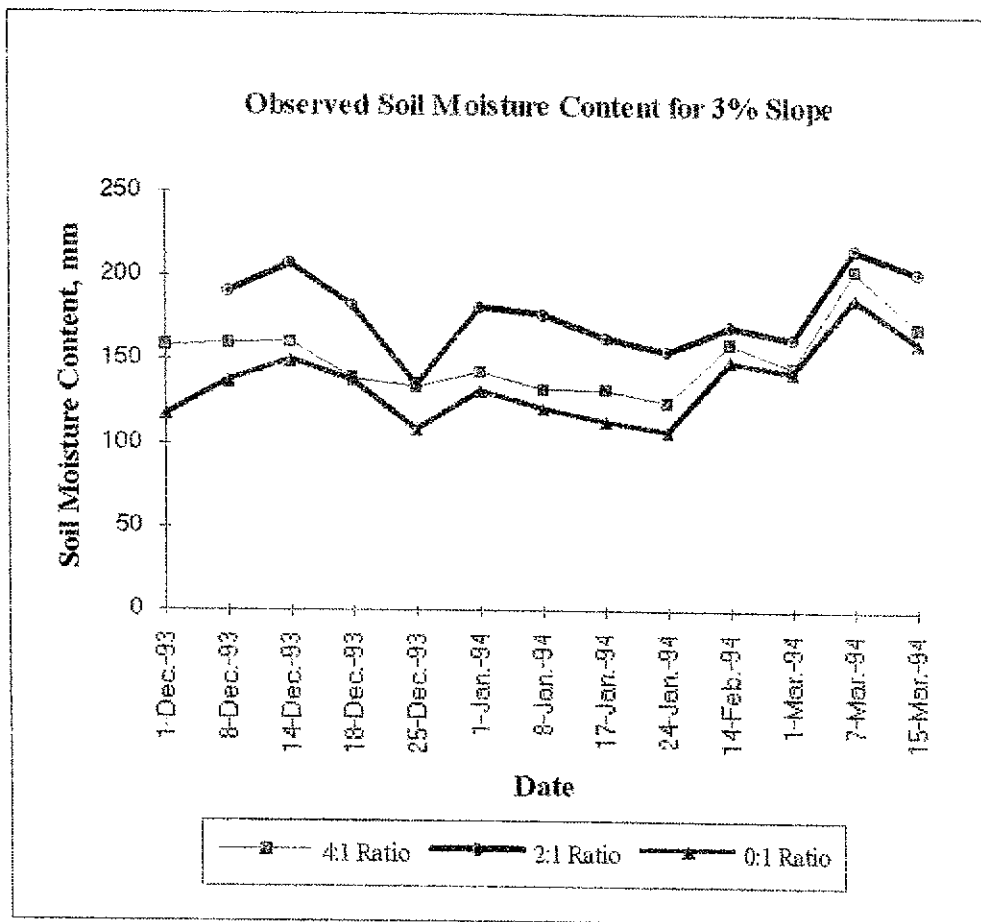


FIGURE 7. Soil Moisture Content for 80 cm Rooting Depth in 3% Slope.

4. 7 Comparison of Observed and Calculated Soil Moisture Content

Water balance model was used by using the Quattro Pro for Windows computer program for two different land slopes, named 3 and 8% and three catchment area to cropped field ratio in order to calculate soil moisture content. Having computed the calculated soil moisture content values they were compared with the observed soil moisture contents . The results are shown in figure 8, 9 10, 11, 12 and 13. In most cases, there was a notable relationship between calculated and observed soil moisture content values.

It can be seen from the figure 8, the soil moisture content values varied during the maize growth stages. The observed soil moisture content values were almost similar with the calculated values. In the first 20 days, there was a rising trend followed by a falling trend during the periods 20-45 days. They then increased suddenly from 120 to 170 mm between 45 and 50 days and after that decreased from 170 to 100 mm during the periods 50-75 days. There was a rapid increase between 75 and 77 days and followed by a gradual decrease during the period 77-104 days. There was a little change between observed and calculated moisture contents almost at the end of growth season.

As shown as in figure 9, there was a slightly difference between observed and calculated moisture content values. In general, calculated soil moisture content values were greater than observed values. The calculated soil moisture content values were in the range of 85 to 200 mm whereas observed values were in the range of 85 to 150 mm.

According to figure 10 that the observed values were almost same with calculated values. The calculated soil moisture content values varied from 105 to 200 mm. The observed values were lower than calculated values between 25 and 40 days.

It can be seen from the figure 11 that the calculated soil moisture content values were greater than the observed values. They varied from 155 to 200 mm while observed soil moisture content values varied from 130 to 170 mm.

According to the figure 12, the calculated soil moisture content values were almost seen same with the observed values.

As is apparent from the figure 13 that calculated soil moisture content values were greater than observed values.

According to final results that calculated soil moisture content values were found mostly greater than observed values. The possible reason may be that physical conditions in field are different because soil is not homogeneous material. Therefore, calculated soil moisture content values may not be exactly same with the observed values. The soil moisture content could be affected mainly by the soil texture.

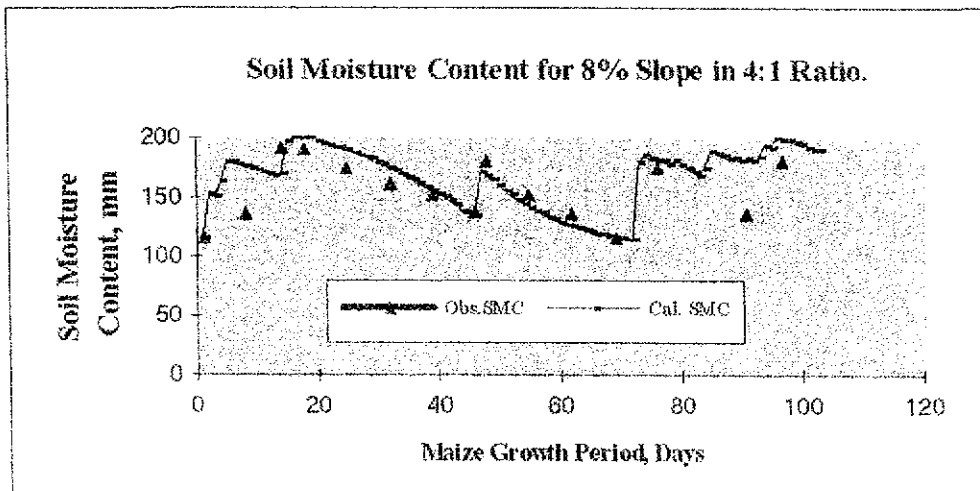


FIGURE 8. Calculated and Observed Soil Moisture Content for 80 cm Rooting Depth in 4:1 Ratio for 8% Slope.

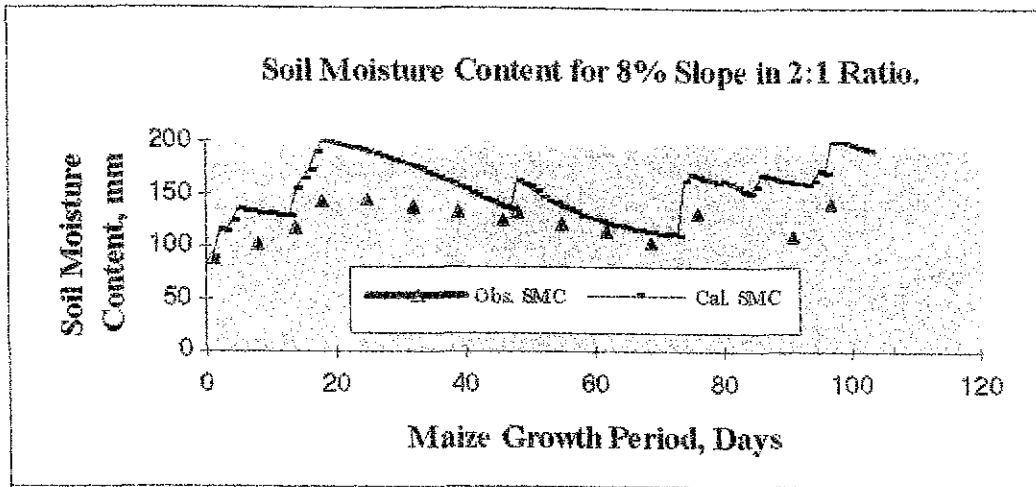


FIGURE 9. Calculated and Observed Soil Moisture Content for 80 cm Rooting Depth in 2:1 Ratio for 8% Slope.

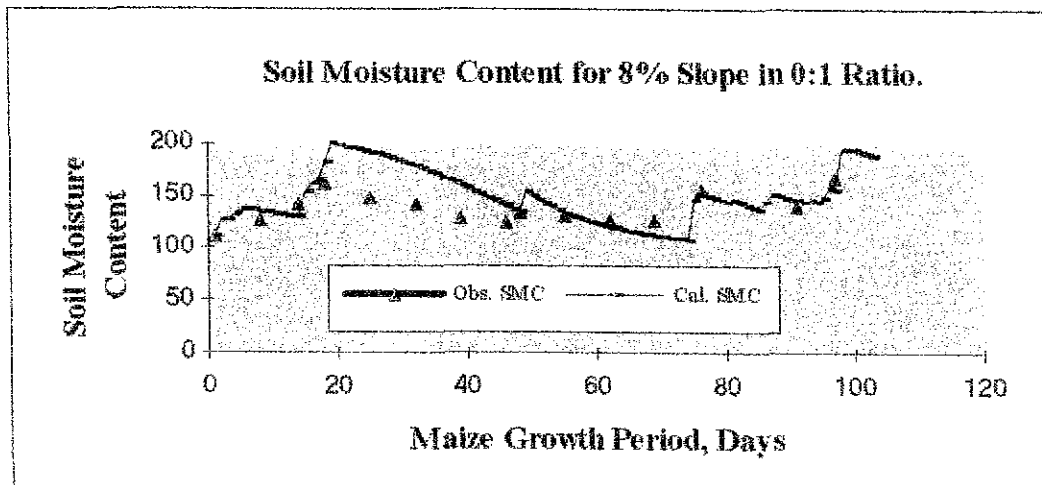


FIGURE 10. Calculated and Observed Soil Moisture Content for 80 cm Rooting Depth in 0:1 Ratio for 8% Slope.

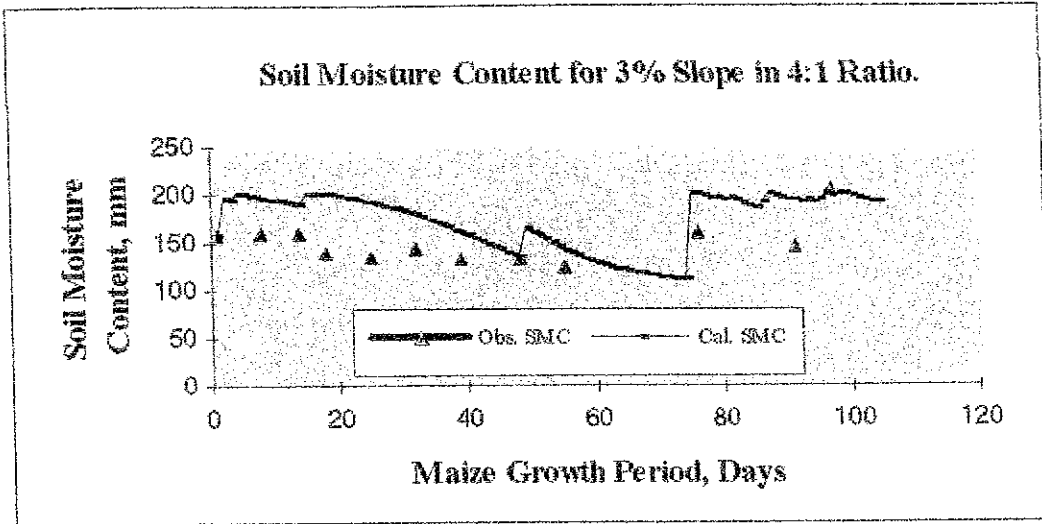


FIGURE 11. Calculated and Observed Soil Moisture Content for 80 cm Rooting Depth in 4:1 Ratio for 3% Slope.

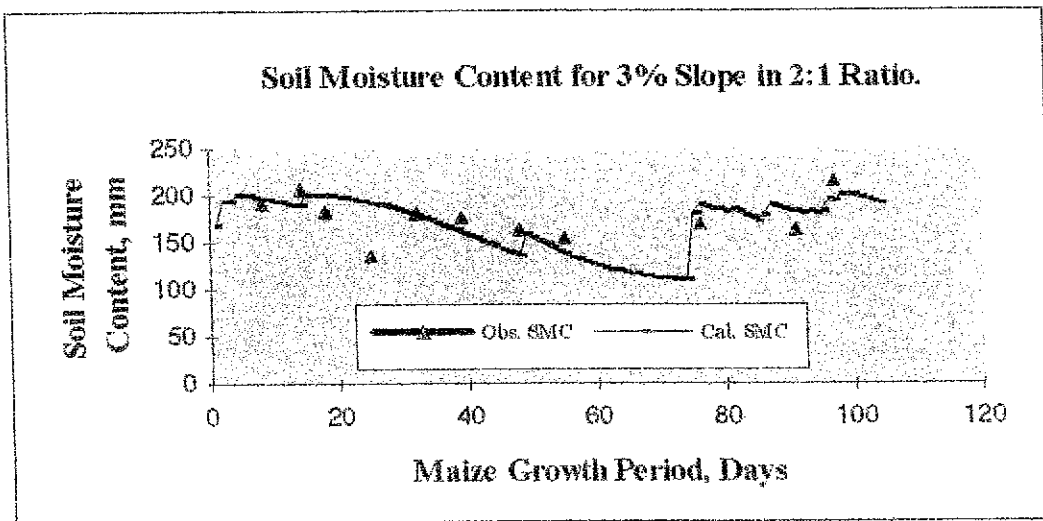


FIGURE 12. Calculated and Observed Soil Moisture Content for 80 cm Rooting Depth in 2:1 Ratio for 3% Slope.

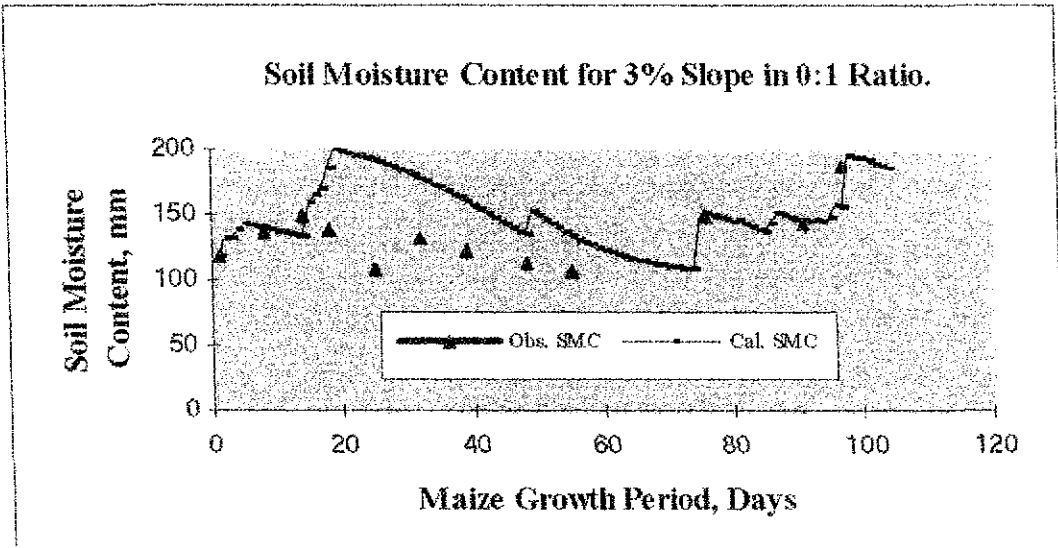


FIGURE 13. Calculated and Observed soil moisture content for 80 cm Rooting Depth in 0:1 Ratio for 3% Slope.

4. 8 Comparison of Total Water Supply with Crop Water Requirement.

High amount of water was resulted from mainly rainfall and rainwater harvesting technique. The ratio of total water supply to total crop water requirement was 0.733 (734.72/593), 0.605 and 0.519 for 8% slope; 0.817, 0.675 and 0.510 for 3% land slope in 4:1, 2:1 and 0:1 plots respectively.

As is apparent from the Table 3 that 4:1 ratio in 3% slope has the greatest water supply and it means that approximately 82% of the crop water requirement was supplemented efficiently from this plot. This may be due to the fact that total run-on value was greatest in this plot so that more water was used by crops.

TABLE 3. Total water supply

Total Run-on (mm)	8% Slope	4:1 Ratio	133.12
		2:1 Ratio	66.56
		0:1 Ratio	0.00
	3% Slope	4:1 Ratio	208.72
		2:1 Ratio	104.36
		0:1 Ratio	0.00
Total Soil Moisture Storage (mm/ 80 cm)	8% Slope	4:1 Ratio	42.8
		2:1 Ratio	33.6
		0:1 Ratio	49.3
	3% Slope	4:1 Ratio	17
		2:1 Ratio	37
		0:1 Ratio	44
Total Supply (mm)	8% Slope	4:1 Ratio	434.50
		2:1 Ratio	358.74
		0:1 Ratio	307.88
	3% Slope	4:1 Ratio	484.3
		2:1 Ratio	399.94
		0:1 Ratio	302.58

Some data considered in Table 3 are as follows;

The total rainfall = 258.58 mm (1 December 1993 -15 March 1994);

The total run-on per unit area = 33.28 mm (1 December 1993-15 March 1994) for 8% Slope;

The total run-on per unit area = 52.18 mm (1 December 1993-15 March 1994) for 3% Slope;

4. 9 Soil Moisture Deficit

The mean daily soil moisture deficits were computed by using the Spreadsheet program. The program was based on the water balance model. The mean daily soil moisture deficits were 27.64, 30.99 and 48.79 mm for 3% slope; 33.02, 44.53 and 49.76 mm for 8% slope in 4:1, 2:1 and 0:1 ratio respectively. The results are shown in figure 14 and 15.

According to the results, the mean daily soil moisture deficits were less in 3% than 8% slope and the lowest soil moisture deficits were in 4:1 plots for both 3% and 8% land slope. The possible reason may be that the amount of run-on was two times higher in 4:1 ratio than 2:1 ratio for this reason, more water came through the 4:1 plots due to having large catchment size. On the other hand, crop water requirement was supplemented by only rainfall in 0:1 plots. Therefore, greatest soil moisture deficits in 0:1 plots were resulted from the less amount of water in the soil profile.

What is the importance of water deficit for crop yield? All living things including crops can not live without water. Therefore, water is a crucial component for living things. However, crops are not affected same from the soil moisture deficits during the growth stages. For instance, crop water requirement is lower in initial stage and is the greatest during the flowering stage. This may be due to the fact that crops have small root system in initial stage and little amount of water could be enough for their growing.

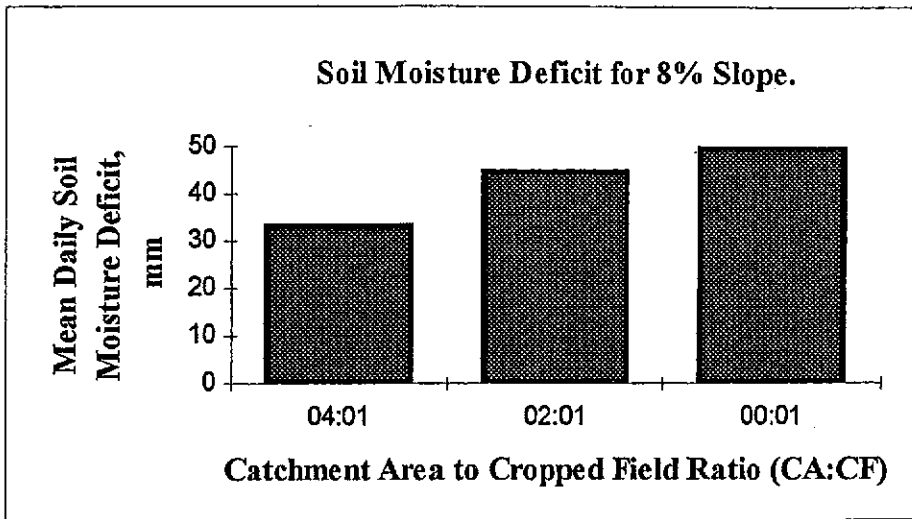


FIGURE 14 Mean Daily Calculated Soil Moisture Deficit for 8% Slope.

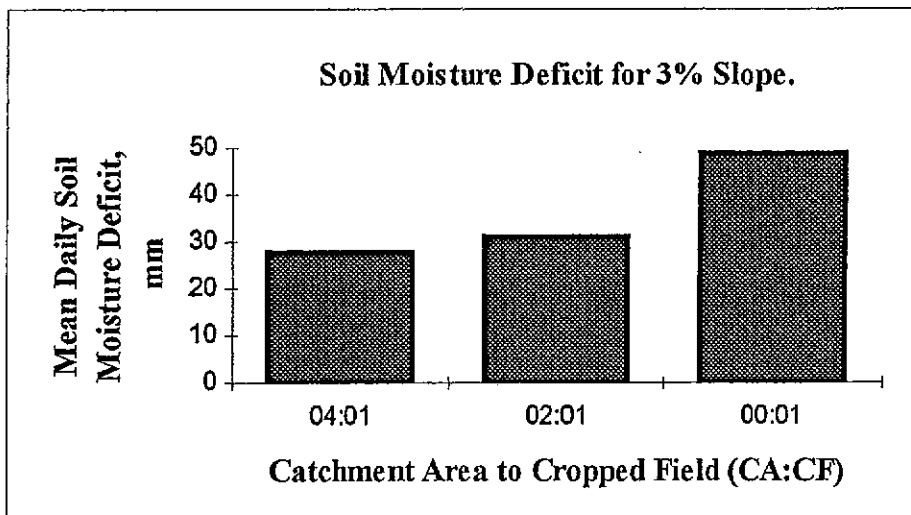


FIGURE 15. Mean Daily Calculated Soil Moisture Deficit for 3% Slope.

4. 10 Crop Yield

Experiments conducted in Kisangara with different RWH crop systems have indicated that crop yields were notably affected by soil moisture deficits in the soil profile. There are three replications of each of 8 plots. The grain yields varied from 3446 to 6320 in 4:1, 2890 to 4794 in 2:1 and 1308 to 2142 kg/ha in 0:1 plots. The results are shown in figure 16. The average crop yields were calculated 4409.2, 3569.7 and 1720 kg/ha for 4:1, 2:1 and 0:1 plots respectively.

The greatest yield was obtained from the 4:1 whereas the lowest yield was obtained from the 0:1 plots. The possible reason may be that more water came into the 4:1 plots because the run-on produced from the catchment area was greater in 4:1 plots than both in 2:1 and 0:1.

Although crop yield was increased by means of the rainwater harvesting technique, it is still lower than the crop yield where the maize is grown under good irrigation. The lower yield may be resulted from the amount and uneven distribution of rainfall during the crop growth stages. Therefore, crops took up less water and there was a water stress in soil profile especially during the flowering period. These results support the view of Hatfield (1990). In general, It may be said that crop yield is mainly based on the rainfall in these regions. If we look at the crop yield data, they are lower than the average values of 6000-9000 kg/ha (for irrigated area) reported by Doorenbos et al. (1986).

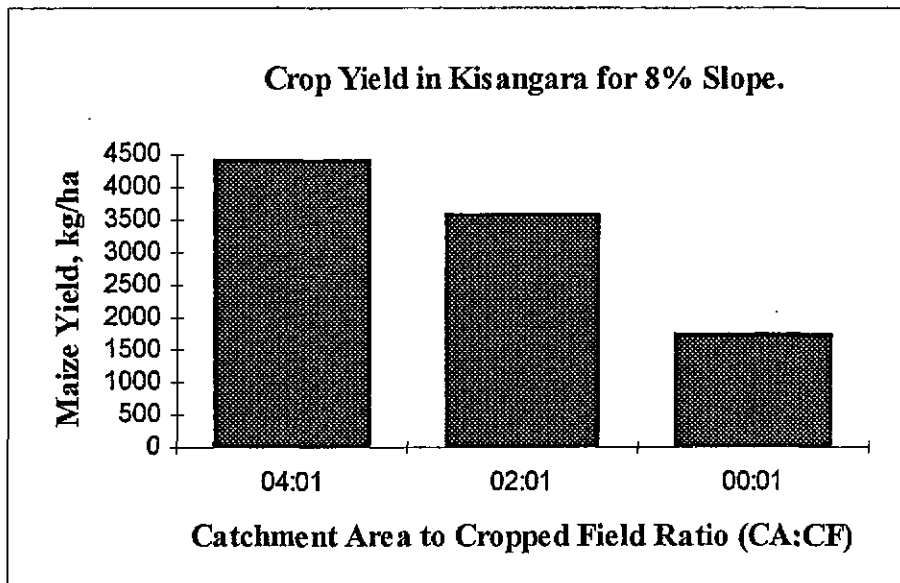


FIGURE 16. Crop yield for 8% slope in Kisangara.

CHAPTER 5

CONCLUSIONS

This thesis has tried to identify the effect of rainwater harvesting (RWH) on soil moisture deficits and maize yield in Kisangara, semi-arid Tanzania.

In the time available, some of the analysis would not have been possible due to the limited time and lack of enough data and all the parameters could not be examined properly.

Rainwater harvesting or runoff irrigation has very good effect in order to decrease the soil water stress. In water balance model, water deficits were considerably lower in the 4:1 plots than in 2:1 and 0:1 plots in both 3 and 8% slopes. The mean daily soil moisture deficits were less in 3% land slope than in 8% land slope. The average crop yield for 8% land slope was the greatest in 4:1 ratio due to the low amount of water deficits during the growing season. On the other hand, soil moisture content values were lower than the field capacity for whole growth season for this reason, drainage water depths were computed as zero. According to the soil moisture deficits values, there has been a significant relationship between crop yield and soil moisture deficits. As the soil moisture content increases in the soil profile, crop yield also increases.

Although soil moisture content was increased by means of the rainwater harvesting technique, it should be increased more to avoid the water stress and improve the crop yield. During the flowering period, soil moisture deficits were greatest and may be this situation led to low crop yield. Soil moisture content may be increased by two ways. First, the ratio of catchment area to cropped field should be

increased. If this ratio increases, more water could be diverted from catchment area to cropped fields thereby soil moisture contents will increase. As a result of this, crop yield from the unit area will also increase. The other important management practices caused increased soil moisture content are building terraces (more appropriate in steep slopes), contour ploughing , tight ridges etc. Terraces are more practical way to increase the infiltration and have been used very widely. Thus, soil moisture content will increase due to storing more water in the rootzone and it could be used by crops. Contour ploughing is also one of the important technique affecting the soil moisture content. In this method, almost zero slope is required and is suitable for mainly tree planting. Tight ridges should be also used to hold more water in soil profile. The disadvantage of this, it requires more land preparation before planting.

As a consequence, crop yields have been affected highly from the soil moisture deficits in the rootzone. The relationship between calculated soil moisture deficits and average crop yields for 8% slope was almost 82% ($R^2 = 0.82$). Crop yields were highly affected by soil moisture deficits.

Although average crop yield was greater in 4:1 ratio than in 2:1 ratio, the increment did not look like very much (the increment = $4409.2 - 3569.7 = 839.5$ kg/ha) compering with the catchment size. However, crop yield in 2:1 ratio was much more greater than in 0:1 ratio (the increment = $3569.7 - 1720 = 1849.7$ kg/ha). The increment of crop yield in 2:1 ratio (1849.7 kg/ha) was significantly higher than in 4:1 ratio (839.5 kg/ha). Therefore, 2:1 ratio should be recommended in order to obtain high crop yield from the unit area.

The effects of RWH technique should also be studied in some details to increase crop production. It would be worth investigating the effects of crop residues,

applying suitable fertiliser, building up terraces (if slope is steep), tight ridges, contour ploughing etc. on crop yield.

REFERENCES

AGASSI, M. , SHAINBERG, I and MARIN, J. , 1990. Slope, Aspect and Phosphogypsum Effects on Runoff and Erosion. *Soil Science Society of America Journal*. Vol. 54: 4, 1102-1106 pp.

BURMAN, R and POCHOP, L. O. , 1994. Evaporation, Evapotranspiration and Climatic Data. Developments in Atmospheric Science B. V. Sara Burgerhartstraat 25 P.O. Box 211, 1000 AE Amsterdam, The Netherlands.

CRITCHLEY, W. , REIJ, C and SEZNEC, A. , 1992. Water Harvesting for Plant Production. Volume II: Case Studies and Conclusions for Sub-Saharan Africa. World Bank Technical Paper Number 157 Africa Technical Department Series. The World Bank Washington, D. C.

DOORENBOS, J. , KASSAM, A.H, BENTVELSEN, C.L.M. , BRANSCHIED, V. , PLUSJE, J.M.G.A. , SMITH, M. , UITTENBOGAARD, G.O and VAN DER WAL, H.K. , 1986. Yield Response to Water. FAO Irrigation and Drainage Paper No. 33. Rome, Italy.

HATFIELD, J. L. , 1990. Agroclimatology of Semi-arid Lands. Dryland Agriculture: Strategies for Sustainability (Edited by Singh, R. P. ; Parr, J. F. ; Stewart, B. A. , in *Advances in Soil Science*, Vol. 13). 9-26; New York, U. S. A; Springer Verlag.

HOWELL, T. A. , PHENE, C. J and MEEK, D. W , 1983. Evaporation from Screened Class A Pans in a Semi-arid Climate. *Agricultural Meteorology*. Vol. 29, 111-124 pp.

HSIAO, T. C. , 1990. Plant-Atmosphere Interactions, Evapotranspiration and Irrigation Scheduling. *Acta Horticulturae*. No. 278, 55-66 pp; .Symposium on Scheduling of Irrigation for Vegetable Crops Under Field Conditions, Maratea-Potenza, Italy, 5-9 June 1989.

KLEMM, W. , 1987. Design of Runoff Irrigation Systems in Small Catchment Areas of Semi-Arid Regions. *Water for the Future* (Edited by Wunderlich, W. O; Prins, J. E). Water Resources Developments in Perspective. International Symposium on Water for the Future , Rome , 6-11 April.

MOHAN, S and ARUMUGAM, N. , 1994. Crop Coefficients of Major Crops in South India. *Agricultural Water Management*, Vol. 26: 1/2, 67-80 pp. Elsevier Science B. V. All rights Reserved SSDI.

NEGI, S. C. , RAGHAVAN, G. S. V. , MCKYES, E and TAYLOR, F. , 1990. The Effect of Compaction and Minimum Tillage on Corn Yields and Soil Properties. *Transactions of the ASAE*. Vol. 33: 3, 744-748 pp.

PAPENDICK, R. I. , PARR, J. F and MEYER, R. E. , 1990. Managing Crop Residues to Optimise Crop / Livestock Production Systems for Dryland Agriculture. *Dryland Agriculture: Strategies for Sustainability* (Edited by Singh, R. P. ; Parr, J. F. ; Stewart, B. A. , in *Advances in Soil Science*, Vol. 13). 253-272 pp; . New York, U. S. A; Springer-Verlag.

PHENE, C. J. , DE TAR, W. R and CLARK, D. A. , 1992. Real-Time Irrigation Scheduling of Cotton With an Automated Pan Evaporation System. USDA Agricultural Research Service WMRL, Fresno, CA, U.S.A. *Applied Engineering in Agriculture.* , 8: 6, 787-793 pp. Presented as ASAE Paper No. 91-2642.

RAWLS, W. J and BRAKENSIEK, D. L. , 1989. Estimation of soil water Retention and Hydraulic Properties. NATO Advanced Research Workshop. Unsaturated Flow in Hydraulic Modelling-Theory and Practice, 275-300 pp.

REIJ, C. , MULDER, P and BEGEMANN, L. , 1988. Water Harvesting for Plant Production. World Bank Technical Paper No. 91. The International Bank for Reconstruction and Development. The World Bank 1818 H Street, N. W. Washington, D. C. 20433, U.S.A.

RESHID, K. , GETAHUN, A and JAMA, B. , 1989. The Influence of Rainfall Distribution on the Yield of Maize Under *Leucaena Leucocephala* Alley Cropping at Mtwapa, Coast Province, Kenya. Meteorology and Agroforestry. Proceedings of an International Workshop on the Application of Meteorology to Agroforestry Systems Planning and Management, Nairobi 9-13 February 1987 (Edited by Reifsnnyder, W. S. ; Darnhofer, T. O.). , 383-389; Nairobi, Kenya; *International Council for Research in Agroforestry (ICRAF).*

SMIKA, D. E and UNGER, P. W. , 1986. Effect of Surface Residues on Soil Water Storage (Edited by Stewart, B. A. in *Advances in Soil Science*, Vol. 5). 111-138 pp. New York, U. S. A; Springer-Verlag.

S .U. A. , 1993. Evaluation and Promotion of Rainwater harvesting in Semi-Arid Areas of Tanzania Research Project. 1 st Interium Annual Technical Report.

UNGER, P. W. , 1990. Conservation Tillage Systems. Dryland Agriculture: Strategies for Sustainability (Edited by Singh, R. P. ; Parr, J. F. ; Stewart, B. A. , in *Advances in Soil Science*, Vol. 13). 27-68 pp; New York, U. S. A; Springer-Verlag.

WALLACE, J. S. , LLOYD, C. R and SIVAKUMAR, M. V. K. , 1993. Measurements of Soil, Plant and Total Evaporation from Millet in Niger. Institute of Hydrology, Wallingford, OX10 8BB, U.K. *Agricultural and Forest Meteorology*, Vol. 63: 3-4, 149-169 pp. Elsevier Science Publishers B. V. , Amsterdam.

WEILL, A. N. , MEHUYS, G. R and MCKYES, E. ,1990. Effect of Tillage Reduction and Fertiliser Type on Soil Properties During Corn (*Zea May L.*) Production. *Soil and Tillage Research.* , Vol. 17: 1-2, 63-76 pp. Elsevier Science Publishers B. V. Amsterdam.

APPENDIX

APPENDIX I

Calculation of crop water requirements

Panco.3da moving Average	Crop coefficient Kc	Evaporati mm/day	ETcrop mm/day
0.77	0.40	10	3.07
0.83	0.40	9	2.99
0.64	0.40	9.5	2.42
0.65	0.40	9	2.33
0.78	0.40	11	3.42
0.74	0.40	12	3.57
0.64	0.40	10.8	2.76
0.71	0.40	10.5	2.97
0.69	0.40	12	3.33
0.80	0.40	12.5	4.02
0.83	0.40	13	4.29
0.74	0.40	12	3.56
0.70	0.40	12.5	3.49
0.62	0.40	12.5	3.10
0.66	0.40	12	3.17
0.63	0.40	12	3.05
0.78	0.40	10	3.14
0.73	0.40	10.5	3.07
0.71	0.40	12	3.41
0.71	0.40	12.3	3.51
0.67	0.40	12.5	3.33
0.70	0.42	12	3.53
0.65	0.45	12.5	3.64
0.62	0.47	11.5	3.36
0.66	0.49	12	3.90
0.70	0.52	12	4.32
0.73	0.54	12	4.73
0.68	0.56	12	4.56
0.73	0.58	12.5	5.35
0.77	0.61	12	5.58
0.70	0.63	11.5	5.04
0.72	0.65	12.5	5.89
0.66	0.68	14	6.27
0.69	0.70	14	6.79
0.60	0.72	14	6.02
0.65	0.75	13.5	6.57
0.72	0.77	13	7.20
0.72	0.79	12.5	7.08
0.70	0.81	12	6.82
0.70	0.84	11.5	6.73
0.70	0.86	12.5	7.56

0.70	0.88	13	8.05
0.57	0.91	14.5	7.43
0.62	0.93	14	8.11
0.68	0.95	13	8.41
0.64	0.98	10.5	6.59
0.69	1.00	10.2	7.04
0.74	1.02	12	9.12
0.81	1.04	10	8.47
0.69	1.07	13	9.61
0.64	1.09	14.5	10.11
0.76	1.09	12.5	10.30
0.73	1.09	12	9.58
0.64	1.09	13	9.03
0.60	1.09	13.5	8.85
0.68	1.09	11.5	8.53
0.82	1.09	11	9.86
0.66	1.09	12.5	8.98
0.59	1.09	12	7.78
0.68	1.09	12.5	9.23
0.61	1.09	12.5	8.25
0.61	1.09	13	8.65
0.56	1.09	12.5	7.68
0.60	1.09	12.5	8.18
0.60	1.09	12	7.82
0.61	1.09	12.5	8.27
0.64	1.09	10	6.93
0.66	1.09	10	7.22
0.73	1.09	9	7.12
0.63	1.09	11	7.58
0.58	1.09	8	5.06
0.62	1.09	8	5.38
0.72	1.09	6.3	4.91
0.62	1.09	7	4.76
0.65	1.09	6.5	4.59
0.61	1.09	7.4	4.91
0.65	1.09	6.2	4.41
0.72	1.09	6.2	4.87
0.65	1.09	7	4.93
0.60	1.09	10	6.55
0.70	1.09	10.5	7.98
0.73	1.07	9	7.05
0.58	1.05	10.5	6.41
0.64	1.02	9.6	6.28
0.65	1.00	8.6	5.59
0.67	0.98	9.3	6.11
0.64	0.96	10.5	6.45
0.63	0.93	11	5.06
0.68	0.91	8.6	5.33
0.60	0.89	10	5.36
0.57	0.87	10	4.97
0.58	0.84	10.5	5.11
0.69	0.82	8.9	5.00
0.64	0.80	9.5	4.86

0.69	0.78	7.6	4.07
0.60	0.75	8	3.59
0.65	0.73	8	3.80
0.63	0.71	11.5	5.13
0.73	0.69	10	5.03
0.63	0.66	12	5.00
0.64	0.64	10.5	4.29
0.72	0.62	10	4.45
0.66	0.60	10.2	4.00
0.73	0.57	8	3.35

Total ETcrop
mm 596.37