

**GROWTH AND YIELD PERFORMANCE OF MAIZE GROWN UNDER  
SUPPLEMENTARY IRRIGATION FROM GULLY FLOW**

**BY**

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## ABSTRACT

A study was conducted to assess the growth and yield performance of maize grown under supplementary irrigation using gully flow from large external catchment during the 1997/98 short rainy season. Two fields each of 180m x 60m size were prepared. One of the fields was dominated by fine sandy loam soils (field F1) and the other field was dominated by silty clay loam soils (field F2). Three water application treatments were applied to each field. The treatments were flat cultivation without water conservation or supplementary irrigation (FC), flat cultivation with water conservation but without supplementary irrigation (WC) and flat cultivation with water conservation and supplementary irrigation from gully flow (WCIR).

Supplementary irrigation when applied to plots with water conservation was found to improve the depth of the effective rainfall. However when direct rainfall amount was higher than 40 mm, application of supplementary irrigation from gully flows resulted into wastage of large volumes of water through runoff and deep percolation. The effect of prolonged dry spells on soil moisture status was found to be reduced by supplementary irrigation, especially in soils having higher water holding capacity. Grain yields were 1.9 t/ha, 2.1 t/ha and 2.5 t/ha from treatments FC, WC and WCIR respectively in field F1 and 1.8 t/ha, 2.5 t/ha and 2.7t/ha from treatments FC, WC and WCIR respectively in field F2. Biomass yields were 6.7t/ha, 6.0t/ha and 5.6t/ha from treatments WCIR, WC and FC respectively in field F1 and 7.4t/ha, 6.0t/ha and 4.2t/ha from treatments WCIR, WC and FC respectively in field F2. In field F1, both biomass and grain yields from all treatments were not significantly different while for

field F2 both biomass and grain yields from treatments WCIR were significantly higher than those from treatment FC at  $p = 0.05$ .

It was concluded that whereas much runoff from marginal lands of the semi arid areas is wasted through gully flows, crop growth and yields can be improved when gully flow is used to supplement crop water needs in a field with water conservation in place. However, better results will depend on the water holding capacity of the soils. Further, care must be made to avoid excessive application of water on cropped fields during heavy rains. Finally it is recommended that this study be extended for several seasons to obtain enough data which will enable to establish a field manual to be used by farmers in their fields.

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## DECLARATION

I, Amin Masud Bakari, do hereby declare to the senate of the Sokoine University of Agriculture that this dissertation is my own original work and that it has never before been submitted for a degree in any other university.

Signature.....



Date.....

20/10/1999

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## **DEDICATION**

To my parents whose constructive and directional upbringing built a strong life foundation on which I stand and to my children by whom I see the meaning of every thing I do in my life.

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**LIST OF ABBREVIATIONS**

<b>CA</b>	<b>Catchment area</b>
<b>CB</b>	<b>Cropped basin</b>
<b>DLR</b>	<b>Data logging rain gauge</b>
<b>DNMRT</b>	<b>Duncan's Multiple Range Test</b>
<b>FC</b>	<b>Flat cultivation</b>
<b>L&amp;WMRP</b>	<b>Land And Water Management Research Project</b>
<b>LSD</b>	<b>Least significant difference</b>
<b>MALC</b>	<b>Ministry of Agriculture livestock Development and Co-operatives</b>
<b>RWH</b>	<b>Rain Water Harvesting</b>
<b>SADCC</b>	<b>Southern African Development Co-ordination Conference</b>
<b>SWMRP</b>	<b>Soil Water Management Research Project</b>
<b>TMV1</b>	<b>Tanzania maize variety 1</b>
<b>WPLL</b>	<b>Western Pare lowlands</b>
<b>WC</b>	<b>Water conservation</b>
<b>WCIR</b>	<b>Water conservation with supplementary irrigation</b>

## **CHAPTER ONE**

### **INTRODUCTION**

#### **1.1 Crop Production in Semi- Arid areas**

##### **1.1.1 Main characteristics**

Semi arid climate is generally characterised by high evaporative demand, low annual rainfall amount, high rainfall intensities and poor rainfall reliability. The atmospheric evapotranspiration demand usually exceed rainfall in 5 to 10 months in a year (SWMRG, 1993; Critchley et al., 1986) and rainfall never exceed potential evapotranspiration on long term averages (Harris et al., 1992). For example, total crop water demand for optimum production of maize in semi arid areas is between 500mm to 800mm (L&WMRP, 1989; Doorenbos and Kassam, 1981; Fried and Barrada, 1967) while the average rainfall amount during the growing period in the semi arid areas of Tanzania is 350mm (Kingamkono, 1994; Kassase, 1992). Apart from rainfall amount being lower than crop water demand in semi arid areas, a considerable amount of rain water is lost through surface runoff from cropped fields. Studies on runoff losses conducted in semi arid areas of the SADCC region reported runoff losses from cropped fields of up to 10% of the effective rainfall (Miller, 1991).

The length of the effective growing seasons in semi arid areas is usually shorter than the growing period of many crops. Kassase (1992) and Kingamkono (1994) studied the characteristics of rainfall during the growing seasons in Tanzania and showed that the average effective length of the growing period in semi arid areas was 45 days for

short rains and hardly 60 days for long rains. This is less than the growing period of many maize varieties that are mostly preferred by farmers in semi arid areas. They also found that there is a high probability of occurrence of dry spells`of longer than 10 days during the growing seasons. Hatibu et al. (1997) obtained similar results from four season rainfall characteristics study in the western Pare low lands and Morogoro.

A combination of these characteristics make soil moisture deficiency inevitable during growing periods of many crops grown in semi arid areas. For instance, Mulengera and Ngobei (1990) noted that, for the short rainy season in Morogoro, soil moisture storage can be below 50% of the water holding capacity of the maize root zone (1.2m depth).

### **1.1.2 Crop performance in semi arid areas**

In general, performance of crops in semi arid areas is very low compared to the soil production potential. It has been estimated that moisture deficiency of more than 50% of the crop water requirement during the flowering stage of maize may cause yield reduction of more than 70%. It is concluded that soil moisture deficiency account for more than 80% of crop failure in semi arid areas (L&WMRP, 1992 and Doorenbos Kassam, 1979;).

Government and other concerned institutions have been appealing to people in semi arid areas to adopt cropping systems that involve crops with low crop water requirement like sorghum, millet and cassava, to mention just a few. Although there has been some considerable success, more than 60% of the cropped land in semi arid

areas in Tanzania is still grown with maize. The crop is also still a major staple food for the majority of Tanzanians . Since available soil moisture is still a major constraint to the production of this crop in these areas, it follows that more efforts have to be directed to soil moisture conservation and supplement irrigation through rainwater harvesting.

## **1.2 Role of Rain Water Harvesting**

### **1.2.1 Definition**

Rain water harvesting (RWH) is defined as the collection, concentration and storing of various forms of runoff for various purposes (Critchley and Siegest, 1991). RWH systems for crop production are classified into two main categories. These are runoff farming and flood water farming. Runoff farming include micro catchment and external catchment systems. In micro catchment RWH system, catchments are of short slope with area of the order of 0.5ha or less and adjacent to cropped fields. In external catchment RWH system, catchments are of long slope with area of the order of 0.5ha to few square kilometers and can be adjacent or a distance away from the cropped fields (Ambira, 1986). In flood water farming, water which flow over the river banks is diverted onto adjacent cropped fields. Flood water farming is common on river banks and valleys.

Despite these differences between the two RWH systems, both comprise of a catchment area (CA) and a cropped basin (CB) (Critchley and Siegest, 1991; Duty and McBride and Shifter, 1974). The function of the CA is to generate, collect and

concentrate runoff water. The function of CB is to receive distribute and store the runoff water within the soil profile for crop production. Runoff water from CA is conveyed to CB in sheet flow or channel flow. It is common within few to hundred meters from the sides of big rivers, within big valleys and on big flat lands with heavy soils (Pritz, 1994). Channel flow is a characteristic of runoff farming which involve stream or gully diversion from a CA closer or far from CB (Critchley and Siegest, 1991).

### **1.2.2 Gully flow as a potential source of runoff**

Gully flow exist only during and a very short time after a rainfall event (Pritz, 1994, Bäckman and Isaksson, 1994). In semi arid areas due to poor vegetation cover, high rainfall amount and intensities, gully flow is very common especially in areas with land sloping at more than 8%. Runoff coefficient of up to 30% from these areas is reported to have been observed ( Harris et al., 1992; Christiansson, 1989).

A discharge rate of about  $1.1\text{m}^3/\text{s}$  per square kilometre from a rainstorm with 35mm/hr intensity was recorded in the western Pare low lands (Hatibu et al., 1995). It is common to have at least four storms of that magnitude per season in the western Pare lowlands with a duration of at least 20 minutes. This means about  $8000\text{m}^3$  of seasonal rainfall water is lost by runoff through gully flow per square kilometre in the area. If this would be fully utilised in supplementing rain water for crop production, every square kilometre would generate about 200mm additional soil moisture depth to a 4ha cropped field per season.

Runoff flow from uncultivated and low vegetated areas is reported to carry sediment load of up to 30m<sup>3</sup>/ha per season (Hatibu et al.,1997). Several studies on soil loss through runoff done in various places in Tanzania reported soil losses from cultivated lands of up to 90m<sup>3</sup>/ha per season (Christiansson, 1989). The sediment loads are deposited on low lands with gentle slopes of less than 1% normally in valley bottoms. The high fertility level observed in valley bottoms is due to the deposition of this sediment load. Therefore, the use of gully flow as a supplement to irrigation, for crop production, can also have an added advantage of improving soil fertility on the cultivated fields. Conversely, runoff flow from cropped fields should be prevented to conserve soil fertility as well as enhancing soil moisture status.

### **1.3 Use of gully flow for crop production in Tanzania**

Studies on RWH conducted in Dodoma, Mwanza, Shinyanga and Kilimanjaro regions show that farmers prefer large catchment RWH to infield or micro catchment RWH (BACAS, 1997; SWMRG, 1993; Mwakalila, 1992). This is because many farmers are unwilling to allocate portions of their fertile land to serve as within-field micro catchments. Ryoba (1995) also noted that, activities which increase capital investment and labour demand such as those needed in the preparation and management of within-field catchment RWH systems would generally not be accepted by farmers.

Gully flow is one of the means by which runoff from large catchment is harvested and diverted into cropped fields. Some farmers in the Western Pare lowlands have been attempting to divert gully flows for supplementing water needs to their farms. But they have not been successful due to poor control over the huge volumes of water

delivered from gullies at high rates. The practice have actually caused some of the farmers to abandon their fields after being heavily damaged by runoff erosion. It shows that farmers lacked knowledge on proper management of water from diverted gully flows.

The current design criteria for RWH systems are based on micro catchment parameters (BACAS, 1997; Hatibu et al., 1995; Lameck, 1994; Boers, 1994; SWMRG, 1993; Boers et al.,1986). These criteria may not directly fit for use in external catchment RWH. This is due to several factors such as the distance between CA and CB, spatial rainfall variability with distance, time between start and end of rainfall events between CA and CB, and nature and conditions of CA. These factors may cause large variability in runoff yield characteristics between external and within-field catchments.

Therefore, design criteria for microcatchment RWH systems often do not apply for the design of external catchment RWH systems without precaution. Harris et al. (1992) recommended more research work on external catchment RWH systems to be done in order to obtain information that will help to improve existing design criteria to suit the design for external catchment RWH.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Conditions for Runoff Occurrence

A situation whereby heavy storms occur on a watershed that has poor vegetation due to dry climate, overgrazed, deforested and with high sloping landscape, is a form of a 'hot spot' condition as described by Bäckman and Isaksson (1994). This situation causes excessive loss of useful soil and rain water through runoff and the damaging of land through formation of gullies.

There are many 'hot spot' areas in Tanzania. Soil loss of up to 80m<sup>3</sup>/ha per annum and water loss through runoff of up to 30% of rainfall amount have been reported from various places in Tanzania (Mwakalila, 1994; Pritz, D., 1994 and Christiansson, 1989). Other results from a four season plot runoff study in the western Pare lowlands showed that plots under natural vegetation (NV), low managed crop (LMC), bare (B) and bare and compacted(BC) had runoff yield of up to 8.8%, 7.5%, 22.9% and 33.8% respectively (Hatibu et al., 1997; Ojesi, 1995).

#### 2.2 Availability of Runoff

The amount of rain water which is returned to the sea through rivers has increased world wide over the past 30 years (Wolf and Hubener, 1996). In Tanzania the discharge rates of big rivers has increased significantly over the last two decades. For example a hydrological study done on the Usambara catchments which are drained by

the Soni (west) and the Sigi (East) rivers showed that the rivers' discharge increased by  $0.4 \text{ m}^3/\text{s}/\text{yr}$  between 1965 and 1995 (Munishi, 1994).

Ten years (1971-1980) hydrologic data from the Pangani river basin at Nyumba ya Mungu and Korogwe stations showed that the maximum water drained through the stations were 215mm and 178mm depth, with respect to catchments, respectively. Also the annual water drained through those stations was more than 97mm and 93mm depth, with respect to catchments, respectively in more than 50% of the years analysed. The minimum annual water depth drained through Nyumba ya mungu and Korogwe stations was equivalent to 61mm and 48mm respectively. This information suggests that the potential runoff yield from the catchments which are drained by the Pangani basin can be as high as 40% and is usually not lower than 8% of the annual rainfall amount.

### **2.3 Factors affecting runoff yields from catchments**

There are several factors that influence runoff yields from catchments. These include soil characteristics, the catchment surface conditions, the catchment size and shape, and rainfall characteristics (Linsley et al., 1988).

#### **2.3.1 Soil characteristics**

##### **2.3.1.1 Nature of soils**

Nature of soils has a significant effect on runoff yields. For example the Centre for Arid Zone Studies in Jodpar India and the ICRISAT in Hyderabad studied the effect of soil characteristics on runoff yield of two natural soil classes, alfisols and vertisols. They both found that alfisols have greater runoff yield response than vertisols (Ryan

et. al., 1980). The low runoff yield of vertisols is due to its cracking behaviour on drying which accelerates the infiltration rate of the first rains. The swelling behaviour of vertisols on wetting also increase the water holding capacity thus decrease runoff coefficient of the soil. Alfisols have the opposite behaviour to that of vertisols mentioned above leading to an opposite runoff effect to that of vertisols (Miller, 1995). These characteristics show that vertisols are suitable for CB and alfisols are suitable for CA in a RWH system.

#### **2.3.1.2 Soil physical and chemical properties**

Soil physical and chemical properties such as texture, profile depth, structure, fertility and salinity have high influence on runoff (Critchley and Siegest, 1994). Soil structure and texture are very important in infiltration of water into soils. Heavy, fine textured and compact soils are desirable for CAs due to their high impedance to infiltration and low porosity percentage which increase the runoff potential of the soil. Conversely, light soils, moderately coarse textured and well aggregated have higher infiltration rates and higher water holding capacity. Soils of this type are desirable for CBs due to their low runoff coefficient and can store large volumes of water for plant use (Mahoo et al., 1994; Morin and Benyamin, 1977). However the deeper the soil layer the more advantageous is the soil for moisture storage.

The primary importance of soil fertility to crop production is to provide nutrient to crops. The added importance of soil fertility to RWH is on vegetation cover potential. A soil with low fertility is characterised by poor vegetation growth, therefore high runoff potential is expected from such a soil. Soils with low fertility are thus suitable

for CAs. Fertile soils can most profitably be used for CBs and not for CAs due to low runoff potential and better crop growth (Critchley and Siegest, 1991)

Saline soils are normally not desirable in crop production due to the ill effects they cause to plants. However, the tendency of sodium ions to break the soil structure (Gardner, 1989) and thus lowering soil infiltration rate and water holding capacity make sodic soils be of higher runoff potential. Therefore, non saline sodic soils are desired for CAs if only the runoff water from catchments with sodic soils contain tolerable amounts of salts for crop production.

### **2.3.2 Catchment surface conditions**

Preferable catchment surface conditions are those which decrease infiltration and enhance runoff. Surface conditions of much interest in RWH include, slope, surface cover, physical and chemical treatments.

#### **2.3.2.1 Catchment slope**

The effect of slope on runoff yield of a catchment is limited by rainfall amount. In a study reported by Hatibu et al., (1995) showed that runoff produced from catchments with 3-4% slope and that from catchments with 6-8% slope was not significantly different when rainfall amount was less than 8mm. However, runoff yield increased with increasing catchment slope for rainfall amount larger than 8mm. Other studies in India and Botswana on the same subject reported similar results (Sharma, 1993; Harris et al., 1992 and L&WMP, 1989).

Although runoff is generally expected to occur when the water application rate onto the soil is higher than the infiltration rate, the effect of catchment slope brings in the infiltration time factor. This factor depends on the net effect of the components of gravitational force acting on water drops falling on a sloping surface (Morin and Benjamin, 1977). When the surface slope increases from zero, the force component along the surface increase with increasing slope. As the force along the slope increase, the velocity of the drop along the slope also increase. The higher the velocity along the slope the shorter the time available for that drop to wait for infiltration or ponding time (Freeze, 1982).

#### **2.3.2.2 Surface cover**

Surface cover plays a very significant role on surface runoff. Significant higher runoff yields have been reported to occur from bare catchments than from vegetated catchments (Ojesi, 1995; Hatibu, et al.,1995; L&WMP, 1992). These results are in agreement with those reported by Harris et al., (1992) who concluded that vegetation cover exerted a dominant influence on runoff yields from rangelands. Moreover, vegetation cover increase the resistance to water flow and thus increase surface storage capacity of the catchment as well as increasing ponding time. As the time of ponding increase more water infiltrates into the soil although a substantial amount of it is evaporated (Kitheka, 1994).

#### **2.3.2.3 Physical and chemical treatments**

The most widely used physical treatment on RWH catchment surfaces is mechanical compaction. Bare compacted surfaces are reported to generate more runoff than non

compacted surfaces (Mahoo et al., 1994; Ojesi, 1995; Hatibu et al., 1995). Mechanical cover like polished surfaces and plastic sheets have also been used in Australia, India and North America to increase runoff from catchments (Meckelson, 1974).

There are many reports on the use of chemicals such as oil, bitumen, silcones, stearic and dimer acids, for treating catchments to enhance runoff (Laing and Prout, 1974; Plueddeman, 1974; de Jong and Wallace, 1974). The main functions of chemicals used for treating catchments, are to provide a water seal on the soil surface and to inhibit vegetation growth. These artificial methods may not be of interest to a small scale farmer due to high costs involved in the purchase of the needed materials. However, catchments with surfaces which are chemically or physically treated can be used if the crop production economics allow.

### **2.3.3 Catchment size and shape**

The volume of runoff generated per unit area of a catchment decrease with increasing size of catchment (Hatibu et al., 1995; Ojesi, 1995). This is because of increased time of concentration as the size of the catchment increased. Linsley et al. (1988) reported on increased runoff yield as the length to width ratio increased. Contrary, Hatibu et al. (1995) and Ojesi, (1995) reported that there were no significant difference in runoff yields between micro catchments with different length to width ratios. This contradiction is explained by the fact that, factors such as soil properties, surface interception and storage have significant effect in large natural catchments than in

micro catchments( Miller and Veenendaal 1990). Therefore when dealing with natural catchments the shape of the catchment must be taken into consideration.

#### **2.3.4 Rainfall characteristics**

Rainfall characteristics such as amount and intensity have significant influence on runoff occurrence (Ojesi, 1995; Hatibu et al., 1995; Kitheka, 1994; Harris et al., 1992). Runoff experiments conducted in the Pare semi arid areas by SWMRP and reported by Hatibu et al. (1995) indicated that the rainfall characteristics accounted for more than 85% of runoff generation variations observed in bare and bare compacted catchments. However, rainfall characteristics accounted for hardly 35% of runoff generation variation observed in natural vegetated catchments.

Experiments conducted in Botswana by L&WMRP on catchment rainfall-runoff relationships and reported by Harris et al., (1992), revealed that rainfall amount and intensity had dominant effect on runoff generation from managed catchments than any of the other factors that had shown measurable effects on infiltration. However for complex natural situations rainfall amount was the main controlling factor for runoff occurrence.

Miller and Veenendaal (1990), performed regression analysis on rainfall-runoff data obtained from experimental results in south western Botswana. A strong relationship ( $r^2 = 0.89$ ) between rainfall amount and runoff causing rainfall events was observed. Also, a strong relationship ( $r^2 = 0.76$ ) was observed between runoff volume and rainfall amount and was improved ( $r^2 = 0.8$ ) when rainfall intensity was included in the

regression. Kithaka, (1994) obtained similar results in Nguu Tatu catchments in Kenya.

## 2.4 Catchment Area and Cropped Area Relationships

Catchment area and cropped field area relationship usually presented as CA:CB ratio, is the most widely used criteria in RWH system designs. There are many methods by which this ratio is determined ranging from empirical methods to theoretical methods as discussed in the following sections.

### 2.4.1 CA:CB ratio basing on root area size

A study on *in situ* rain water harvesting conducted in Mexico in 1977/78 season provided a relationship between the micro basin size and root area size, runoff coefficient, crop consumptive use and precipitation during the vegetative cycle (Cluff, 1980). The relationship is presented as shown in equation 1.

$$D = D_r + \frac{(C - p) D_r}{kp} \quad (1)$$

Where:-

$D$  = Micro basin area ( $\text{cm}^2$ ).

$D_r$  = Diameter of the rooting area (cm).

$C$  = Consumptive use for a reference period (mm).

$k$  = Soil runoff coefficient.

$p$  = Precipitation during the reference period (mm).

This method is useful for tree crops. The use of this method for row seasonal crops may be limited to the economics involved in the production costs per unit area. This is because, adoption of this method would dictate the inter row and plant spacing in order to provide an allowance for the needed basin area. The spacing for tree crops is always abundant.

#### **2.4.2 CA:CB ratio basing on optimum crop production**

Results from several experiments conducted in the semi arid areas on microcatchment RWH systems, indicated that there is an optimum ratio of CA:CB by which the system would give maximum crop production. Both Hatibu et al. (1995), Mahoo et al. (1993) and Lameck (1994), reported that crop production level was not statistically different when the CA:CB ratio was larger than 2:1.

Similar results were by reported by Boers et al., (1986) who obtained in Sede Boger in the northern Nagev desert in Israel for arid conditions with annual rainfall of about 500mm. A cultivated area of 40m<sup>2</sup> required runoff from a catchment area of between 40m<sup>2</sup> and 80m<sup>2</sup>. They also noted that extremely arid conditions, as is for 'true desert', are too dry for micro catchment water harvesting systems.

The diminishing crop production return observed when the CA:CB ratio is increased beyond the ratio 2:1 is due to the limited soil water storage capacity. That means the water holding capacity of the soils would not store all the harvested runoff water from catchments that were larger than twice the cropped fields. Excess water is lost either through deep percolation or runoff from the CB. The reduced maize yield in a 4:1

system as compared to the yield from a 2:1 system as observed by Lameck (1994), was due to over application of water in the 4:1 system. This was justified by the reverse performance in maize yield observed between the two systems when intermediate storage was used. Actually, Lameck (1994) noted that when intermediate storage for runoff was used, a significant increase in crop yields with increased ratio of CA:CB was observed. These results suggest that, the better use of runoff in RWH systems with larger CA:CB ratios would necessarily require intermediate storage for runoff water. Similar suggestions were given by Evenari et al. (1971).

#### **2.4.3 CA:CB ratio basing on crop water requirement, design rainfall and runoff coefficient**

According to Finkel (1986), the ratio of the catchment area to the cropped field area (CA/CF) can be estimated using equation (2) below.

$$\frac{CA}{CF} = \frac{ET_c - R_D}{R_D * \eta_s * \eta_o} \quad (2)$$

Where:-

ET<sub>c</sub> = Crop water requirement (mm)

R<sub>D</sub> = Design rainfall (mm)

η<sub>o</sub> = Runoff coefficient

η<sub>s</sub> = Runoff efficiency

There are empirical constants for runoff coefficients for catchments depending on the surface conditions, soil type and slope of the catchment area (Mahoo et. al., 1994;

SWMRG, 1996). The design rainfall  $R_D$  is the value of the dependable rainfall for a given probability  $P(\%)$  of being equalled or exceeded. This value is obtained using the Hazen-William probability equation (3) according to Doorenbos and Prutt (1977).

$$P = \frac{r - 0.44}{n + 1} \quad (3)$$

Where:-

$r$  = rank number of a given amount of annual rainfall in a list of annual rainfall amounts of at least 20 years arranged in descending order.

$n$  = Total number of observations (years).

The main component of the crop water requirement is the crop evapotranspiration  $ET_c$  (mm/day) which is normally calculated for each crop growth stage and summed for the total growing period to get the total crop water requirement. Doorenbos and Prutt (1977) expressed the crop water requirement mathematically as shown in equation (4).

$$ET_c = K_c * ET_o \quad (4)$$

Where:-

$K_c$  = Crop coefficient which depend on the stage of crop growth.

$ET_o$  = potential evapotranspiration of a reference crop

Doorenbos and Prutt (1977) and later FAO (1986) recommended a modified Penman equation for calculating ETo which is a function of temperature, radiation, wind speed and air pressure or humidity. It is expressed mathematically as shown in equation (5).

$$E T_o = C \left[ (W R_n) + (1 - W) f(u) (e_a - e_d) \right] \quad (5)$$

Where:-

ETo = Reference crop evapotranspiration (mm/day).

W = Temperature related weighing factor.

Rn = Net radiation equivalent to evapotranspiration (mm/day).

f(u) = Wind related function (km/day).

e<sub>a</sub> = Saturated vapour pressure at mean air temperature (mbar).

e<sub>d</sub> = The actual vapour pressure at mean air temperature (mbar).

C = Adjustment factor to compensate for the day and night weather conditions.

Since it is possible to determine the runoff coefficient and runoff efficiency for larger natural catchments, equation (3) can be useful in determining the CA:CB ratio for external catchment RWH systems.

## **2.5 Supplementary irrigation systems and factors affecting their performance**

The performance of supplementary irrigation systems depend mainly on the efficiency by which water is applied and distributed over the cropped field. Surface irrigation systems are classified depending on the way water is distributed in a field. The most

common surface irrigation systems are the basin, furrow and border systems (James, 1988).

### **2.5.1 The basin irrigation system**

The basin irrigation system is the most widely used system in the production of rice, cereals, maize and cotton (Melvyn, 1993; Withers and Vipond, 1974). The system is not laborious, because it is not very sensitive to the size of the water stream and its flow duration (Melvyn, 1993). However, basin sizes must be designed and constructed properly according to slope, soil texture and crop water demand (Walker, 1989). If this is not properly done the system may lead to water logging which may be detrimental to upland crops as well as wasting water through deep percolation.

### **2.5.2 The furrow irrigation system**

This system is applied mainly for upland crops especially row crops. The most serious problems associated with this method is the high labour involved in directing the flow of water within the cropped field at the required flow rate and required time of application. This is because the system is very sensitive to the applied stream size as well as to the cut off flow times. For example according to (Melvyn, 1993; Withers and Vipond, 1974) the stream size and cut off times affect the application efficiency as follows:

- over application is caused by too small stream size and too late cut off flow time, and
- under application is caused by too large stream size and too early cut off time.

### **2.5.3 The border irrigation system**

A border is just like a basin. But a border is narrower and slopes gently along the length (Melvyn, 1993; Withers and Vipond, 1974). Water in borders is applied just like in furrows, and the design considerations and operational shortcomings are the same as those in the furrow system (Melvyn, 1993; Saffaf, 1980; Withers and Vipond, 1974).

### **2.5.4 Suitability of supplementary irrigation systems for RWH**

Water application in RWH systems, especially that with no intermediate storage, depend on rainfall events. Therefore water application activity can not be planned ahead in RWH systems because rainfall can occur at any time of the day when labour may not be available. The labour demand that is required in the basin system is lower than that needed in the systems discussed above. Therefore the basin system is the most appropriate for RWH.

## **2.6 Over view on the study area**

In semi arid areas with a 'hot spot' condition, like that in the study area, a huge runoff volume is expected to be normally generated. Culverts located at short intervals (less than 500m) across the highway that pass across the study area indicate that the area is an example of areas with a high density of gully net work. As suggested by Bäckman and Isaksson (1994), farmers in the area can adopt RWH system thereby taking advantage of wasted water through gully flow for crop production and at the same time limiting the gullies to advance in their fields.

The distinct pattern of landscape in the study area satisfies the requirements for external RWH systems. The landscape range from very steep (over 50%) slope with rocky, low vegetated and shallow soils, to a gentle (less than 4%) slope fairly vegetated with good fertile soils. The upland is highly overgrazed. Patches of bare soil surfaces are scattered all over the upland. Crop production, usually maize, is done in the lowlands. Yields are very low especially during the short rainy season which range from 0 - 0.5t/ha in bad years and 1 - 2t/ha in good years (MALC-Mwanga, 1998).

The upland rocky, overgrazed and poorly vegetated areas serve as good external catchment area that generate runoff for enhancing crop production in the low lands. However, these natural catchments have complex surface conditions which can not be readily related to conditions of the catchments which were used in microcatchment studies (Boers et. al., 1986). Also rainfall variability in such vast areas is also larger than that in small areas in which studies on micro catchments were conducted. Therefore more investigations have to be made on the potential of the natural external catchments as sources of runoff water to cropped fields to obtain information that will help to improve the criteria for RWH systems which were developed under microcatchment conditions.

## **2.7 Synthesis of literature review**

The literature survey has shown that there is a large portion of rain water that is potentially available for crop production which is still being wasted through runoff in the semi arid areas. Crops in semi arid areas often times experience soil moisture stress during the growing season although large volumes of rainwater is wasted

through runoff with consequences of land and soil degradation. Studies have suggested that RWH using external catchments could be a viable solution for soil moisture and land conservation.

A lot of work has already been done in semi arid areas on the induction and use of runoff water in various RWH studies. However, these studies have concentrated much on microcatchment or in-field RWH systems. Although there is considerable evidence that shows the existence of indigenous RWH using external catchments, the literature has very little on scientific evaluation and models on external RWH systems.

## CHAPTER THREE

### MATERIALS AND METHODS

#### 3.1 Location and climate

##### 3.1.1 Location

The study was conducted at Kifaru village in Mwanga district, Kilimanjaro region. The village is located 12km north of Mwanga town and 45km south of Moshi municipality along the Moshi- Dar es salaam highway. Mwanga district is located between 3°S and 4°S latitudes and between 37°E and 38°E longitudes (Fig. 3.1). The village is within the western Pare lowlands and extends from the western feet of the northern Pare mountains to the banks of the Pangani river..

The altitude ranges from 600m a.s.l. to 2424m a.s.l. The district is characterised by two agroecological zones. The highlands, 1200m-2000m a.s.l and the lowlands, 600m-1200m a.s.l. The highlands divide the lowlands into two parts namely the eastern lowlands and the western lowlands (Fig. 3.1).

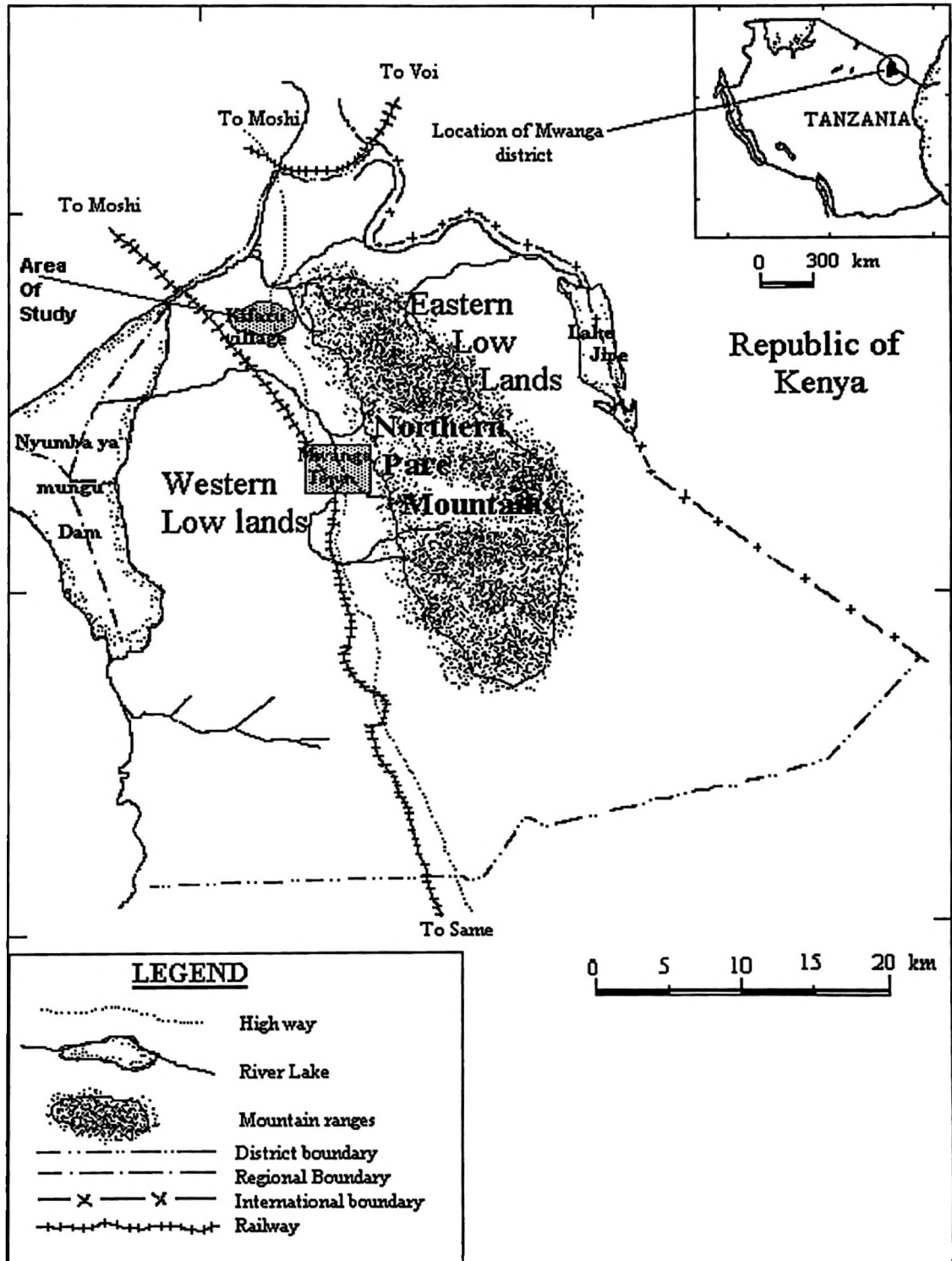


Figure 3.1 Mwanga district map (Source: SWMR, 1993)

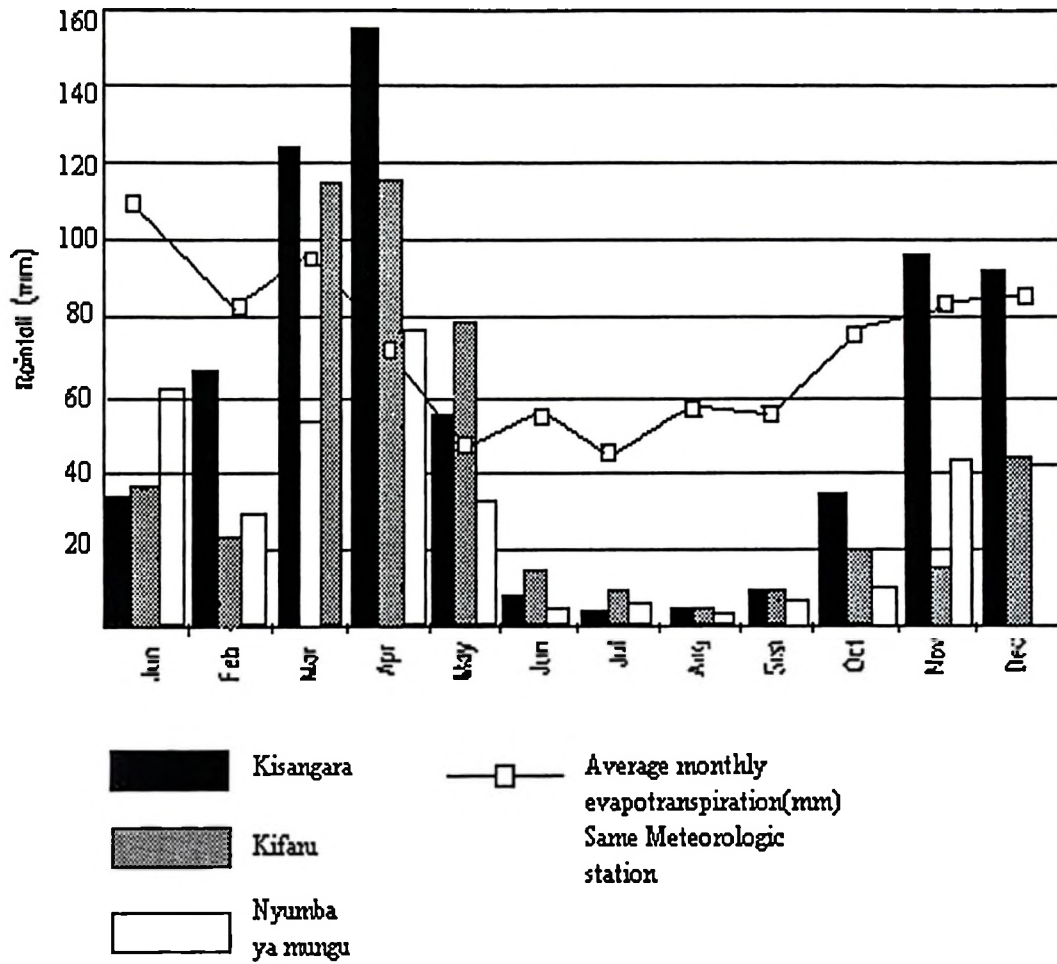
### **3.1.2 Climate**

#### **3.1.2.1 Rainfall**

Climate of the western Pare lowlands is semi arid. The annual rainfall received range from 400mm to 600mm in 4years out of 5years. In the highlands and the eastern lowlands the annual rainfall received range from 800mm-1200mm with the same probability (SWRG, 1993). The rainfall pattern of the western lowlands is bimodal with two rainy seasons, November-January, refereed to as short rainy season commonly known as 'vuli' rains and March-May, referred to as long rainy season commonly known as 'masika'.

#### **3.1.2.2 Evaporation and temperatures**

The potential evaporation in the western lowlands usually exceed rainfall in 5-10 months in a year (Fig. 3.2). In 'vuli' season for example the average evapotranspiration of maize is 500mm while the average rainfall amount during this period is 200mm for wet years and less than 100mm for dry years. The mean minimum temperatures range from 16°C (July-August) to 18°C (January) and mean maximum temperatures range from 26°C (July-August) to 32°C (January).



Source: SWMRG, (1993).

**Figure 3.2 Rainfall distribution at three stations (Kisangara, Nyumba ya Mungu dam and Kifaru) and evaporation of Mwanga District as recorded at Kisangara station.**

### **3.1.2.3 Physiography**

The Western Pare Lowlands (WPLL) in which the study area lies, are located in a semi arid environment. According to De Pauw (1984) the WPLL is classified under one major physiographic region, known as Western Plateau and Mountain Block. This is further divided into two smaller physiographic sub units namely: medium altitude, gently undulating to rolling plains and flat and wide depression. The medium altitude plain is dominated mainly by an undulating topography while the flood plain is characterised by flat and wide topographical depression of semi arid plains developed on young alluvium. The plains are also characterised by a series of scattered hills. The elevation of the area range from 500 to 1200m above sea level.

### **3.1.2.4 Vegetation**

The natural vegetation in the study area reflects both the climate and soils that varies along the slope from the highlands through the mid slope to the lowlands and valley bottoms. The highlands support rainforests of hard woods. Along the mid slope the vegetation is fairly uniform but a bigger portion of the area is presently supporting shrubs, thickets and some pockets of woody trees and grasses. In the lowlands, grasses and a few scattered shrubs and trees, mainly acacia species occur throughout.

### **3.1.2.5 Soils**

Soils in the study area can generally be described based on four topographical zones. The mountainous zone (steep slope), upper middle zone (mid slope), lower middle zone (mid slope), and lowland zone (including valley bottoms). The mountainous zone is characterised by mineral soils consisting of exposed rock outcrops or sometimes overlain by a rock debris which is mainly the result of physical weathering.

Raw mineral soils are confined to very steep slopes and to lesser extent are found along the foot slopes. They have no agricultural value and support only very sparse vegetation.

The upper middle zone consists of reddish-brown to dark reddish brown soils. They have developed from weathered and granulate gneiss bedrock material. They are well drained with low organic matter. The soils in lower middle zone are brown to dark brown and have relatively higher organic matter. They are well drained with good structure, have relatively high natural fertility and moisture holding capacity. These properties make them potentially productive. However, they are shallow and highly susceptible to soil erosion.

The soils in the lowland zone are deep and moderately well drained. Most agricultural activities are concentrated in these lowlands. According to the National Soil Service (NSS,1992), most soils in the lowlands and plains are fine textured young fluvial deposits. They have high levels of available nutrients except for nitrogen. The soils have a strong to very strong alkaline reaction which may inhibit the availability for plant uptake of certain important micronutrients. Furthermore, some soils are extremely sodic with exchangeable sodium percentage (ESP) levels above 35 within 1m depth.

## **3.2 Field layout and preparation**

### **3.2.1 Field description and location**

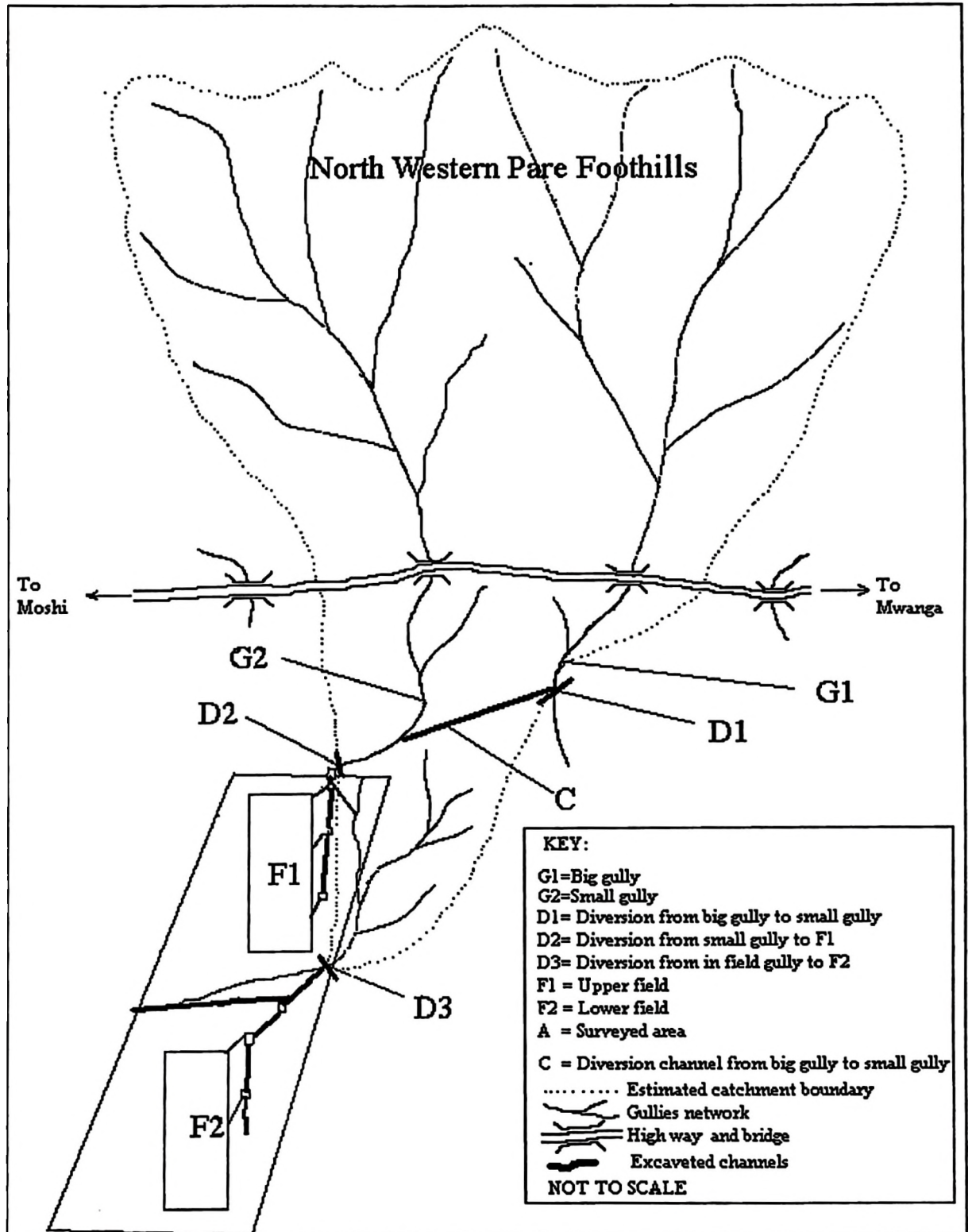
Two fields, (F1 and F2) were prepared for the experiment. On each field soil characteristic survey was done according to Blake (1985) and Kemper and Chepil

(1985). The survey showed that Field F1 is located on fine sand silty loam soils while field F2 is located in silty clay loam soils. The slope of field F1 varies from 4% to 2.5% while the slopes of field F2 varies from 3.5% to 0.5%.

The catchment area extended as far as the Kifaru peak (1020m a.s.l.) on the north western Pare mountains. The catchment is characterised by grazed scattered thorn bushes with rocky surfaces at the upper slopes (more than 20% slope) and highly weathered red alfisols at lower slopes (slopes 4 - 20%). The relative location of the experimental area in relation to the catchment area is as shown in Fig. 3.3.

### **3.2.2 Topographical survey**

A topographical survey of the area that covered the fields was prepared using an engineers quick setting spirit level. A 10m×10m grid system was adopted for the survey. The survey data was used to draw a contour map of the area (Fig. 3.4)



**Figure 3.3 Sketch map of the catchment area**

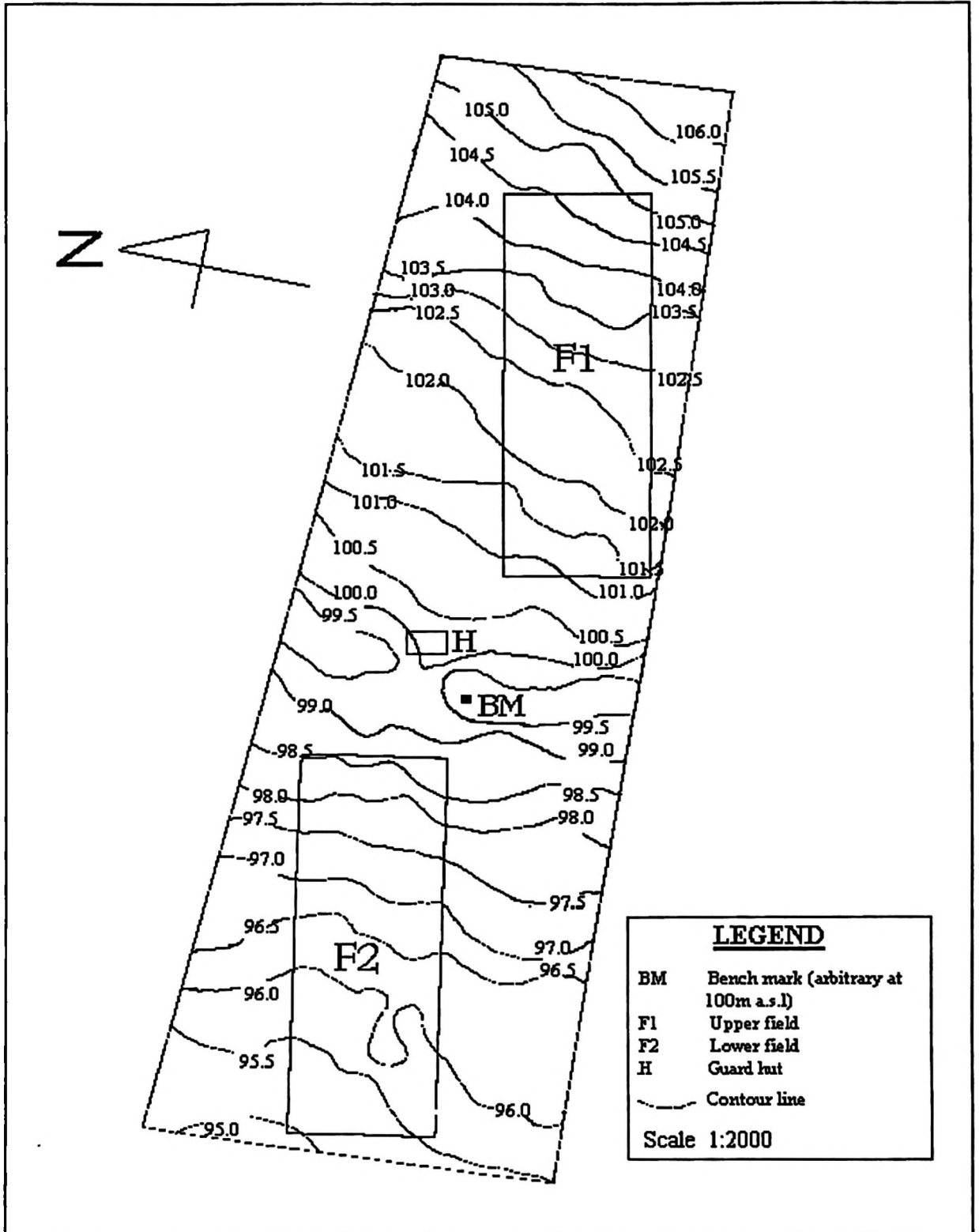


Figure 3. 4 Contour map of the study area.



### **3.2.3 Field layout**

The field layout is shown in Fig. 3.5. The field F1 was divided into nine plots each measuring 50m by 15m. Similarly field F2 was divided into nine plots each measuring 50m by 15m.

### **3.2.4 Experimental design and treatments**

A completely randomised block design (CRBD) was adopted with three treatments and three replications. Blocks were arranged along the general slope and replications across the general slope as shown in Fig. 3.5. The treatments were as follows.

FC = Flat cultivation without water conservation or run-on.

WC = Flat cultivation with water conservation but without run-on from external catchment.

WCIR = Flat cultivation with water conservation plus run-on from external catchment.

From Fig. 3.5, it can be seen that there was bias in allocating treatment WCIR. This was due to financial constraints which limited the costs for channel lining. The channel that conveyed water to treatment WCIR had to be lined to avoid water losses through seepage.

The statistical model adopted for this design according to Freese, (1980) was as follows:

$$R_{ij} = \mu + \beta_i + \tau_j + \varepsilon_{ij} \quad (7)$$

Where:-

$R_{ij}$  = Response.

$\mu$  = General effect.

$\beta_i$  = Block effect

$\tau_j$  = Treatment effect

$\varepsilon_{ij}$  = Random error

Analysis of variance was used to test whether the different water application techniques had significant effect in soil moisture content, plant population, crop growth and maize grain and biomass yields responses .

### **3.4 Land and crop management**

#### **3.4.1 Land preparation**

Land preparations which started on 5/11/1997 and included primary tillage using a 65hp tractor pulling a three disc plough adjusted to plough at a depth of 30cm. Secondary cultivation and bunds making was done manually. Plots were enclosed with earth bunds of 45cm height and 60cm bottom width. Contour bunds of 30cm high and 30cm bottom width were laid down in the treatments WC and WCIR at an interval of about 5m or less provided the elevation differences between the upstream and downstream ends of each basin did not exceed 10cm (Melvyn, 1993). This was achieved by the use of an A-frame. Each contour bund was provided with a spillway

at one of the ends to allow run-on water to spread over the enclosed basin. Dimensions of spillways were set according to Ambira (1986).

### **3.4.2 Crop management**

#### **a) Sowing**

Sowing maize was done on 18/11/1997 at a spacing of 30cm plant to plant and 75cm row to row spacing. Maize variety used was cativar TMV1 with ripening duration of 120 days. TSP fertiliser was used during planting at a rate of 20kg/ha.

#### **b) Post sowing operations**

Two weeding operations were done at a 14 days and 50 days after planting. Thinning was done 24 days after planting to leave one plant per hole. Top dressing with fertiliser SA 21% at a rate 10kg /ha was done 56 days after planting. Harvesting was done 111 days after planting on 14/3/1998 when over 98% of crop leaves had dried.

## **3.5 Instrumentation and measurement**

### **3.5.1 Rainfall**

Daily rainfall (amount, duration and intensity ) was monitored at the site with a daily rain gauge and two computerised data logging rain gauges (DLR) of 0.2mm and 0.203mm per tip capacity. The daily rain gauge was installed at the middle of the fields. The DLR gauges were installed one on each of the fields. The DLR gauges were logging at 2min intervals and the data was downloaded at 7 days interval.

### **3.5.2 Runon from external catchment**

#### **(a) Runon measurement**

Runon flow rates onto the fields was monitored using standard H-flumes. Three H-flumes were installed with computerised data loggers. The first H-flume (H1) with maximum discharge rate of 900l/s was installed to monitor the total runon harvested to the cropped fields. The second H-flume (H2) with maximum discharge rate of 300l/s was installed to monitor runon harvested onto field F1. The third H-flume (H3) with maximum discharge rate of 300l/s was installed to monitor the runon harvested onto field F2. The relative locations of the flumes is shown in Fig. 3.5.

#### **(b) Runon metering and distribution**

Spillways were constructed at both H2 and H3 as shown in Fig. 3.5. The spillways were designed following the Butcher Method (Leliavsky, 1965). Spillway dimensions were set such that at the flume discharge rate should not exceed 225l/s ( $\frac{3}{4}$  of its maximum discharge rate) when the discharge rate at the H1 was maximum (900l/s). Runoff water spilled off the spillway at H2 was directed into a natural drain which drained water to H3 at field F2. Weir type junction boxes B1 and B2 were constructed to distribute runon to plots with treatment WCIR at a ratio of 1:2 and 1:1 respectively for each field. The relative locations of the junction boxes is shown in Fig. 3.5.

Water from flumes H2 and H3 was conveyed to the cropped fields through lined channels to ensure that no water losses occurred through seepage between the flumes and the cropped fields.

### 3.5.3 Effective applied water

Effective depth of water applied to cropped fields was calculated for each daily total rainfall and runoff event that occurred during the growing period. It was later converted into decade values and compared to corresponding values of crop water demand for maize in the same period. The effective depths of water applied to cropped fields were calculated using equation (8) which is a general equation for effective depth of application  $D_e$  (mm).

$$D_e = D_g - R_o \quad (8)$$

Where:-

$R_o$  = Runoff depth from CB in one water application event (mm).

$D_g$  = Gross water applied in one water application event (mm).

For plots with supplementary irrigation

$$D_g = p + R_n$$

Where:-

$R_n$  = Total runoff diverted to the CB during the rainfall event (mm)

$p$  = Total event rainfall amount on the CB

#### 3.5.3.1 Cropped field runoff Model

Runoff from cropped fields was calculated using the runoff model derived by the author and is described below. The model was derived basing on the following assumptions:-

- (a) Water application rate was uniform over each event of application.
- (b) Applied depth of water was uniform over each cropped basin in WC plots.

- (c) The lowest rainfall amount to initiate runoff was 8mm ( Hatibu, et al 1995, Kitheka 1994; Ambira, 1986)
- (d) The maximum ponding depth was half the height of basin spillway.
- (e) Runoff coefficients by Critchley and Siegest (1991) for showers less than 15mm and by Ambira (1986) for showers greater than 15mm were applicable only to plots with FC treatment.
- (d) The rate of soil water intake was uniform over the basin area and over the application duration.

The model considered runoff from each treatment separately together with the limiting conditions.

- (i) The runoff depth  $R_o$  from plots with treatment FC was calculated using equation (9).

$$R_o = D_g * r_e \quad (9)$$

Where:-

$$D_g = P$$

P = Rainfall amount (mm)

$r_e$  = Runoff coefficient as a function of rainfall amount, duration, intensity and antecedent soil moisture.

But  $R_o = 0$  for  $P < 8\text{mm}$  and  $I < i_b$

Where:-

I = Rainfall intensity (mm/hr)

$i_b$  = Basic infiltration rate (mm/h)

(ii) The runoff depth  $R_o$  from plots with water conservation is given by equation (10)

$$R_o = (I - i_b) * (t_p - T_p) \quad (10)$$

Where:-

$t_p$  = Rainfall duration (hr)

$T_p$  = Time to full ponding of a basin (hr)

$$T_p = D_p / I \quad (11)$$

Where:-

$D_p$  = full ponding depth (mm)

Equation (10) is valid in the following conditions:-

$$(1) P > D_p$$

$$(2) T_p < t_p$$

Otherwise:

$$R_o = 0$$

(iii) Runoff depth  $R_o$  from plots with supplementary irrigation.

Three cases depending on rainfall and runoff duration and the relative end times were considered in deriving runoff from plots with supplementary irrigation.

Case 1:  $t_{pe} = t_{ne}$

$$R_o = (P/t_p + R_n/t_n - i_b) * (t_p - T_p) \quad (12)$$

where:-

$t_{nc}$  = runoff end time

$t_{pc}$  = rainfall end time

$t_n$  = runoff duration (hr)

$$T_p = D_p / (A_r - i_b) \quad (13)$$

Where:-

$A_r$  = Water application rate (mm/hr)

$$A_r = P/t_p + R_n/t_n$$

Case 2:  $t_{pc} < t_{nc}$

$$R_o = (P/t_p + R_n/t_n - i_b) * (t_p - T_p) + (R_n/t_n - i_b) * (t_{nc} - t_{pc}) \quad (14)$$

Case 3:  $t_{pc} > t_{nc}$

$$R_o = (P/t_p + R_n/t_n - i_b) * (t_p - T_p) + (P/t_p - i_b) * (t_{pc} - t_{nc}) \quad (15)$$

Conditions:-

(1)  $A_r > i_b$

(2)  $D_g > D_p$

Else:

$$R_o = 0$$

### **3.5.4 Soil water content**

Soil moisture content at 10cm, 30cm and 50cm depths was monitored throughout the cropping period by gravimetric method . For convenience of oven drying facilities soil samples were taken every after 12 days. A heavy duty hammer type auger was used to take soil samples. The sampling procedure was such that soil samples were taken from two 1m<sup>2</sup> areas for each plot. Soil samples were taken from four corners of the sampling areas and for each level the samples were treated as described by Petersen and Calvin, (1985).

### **3.5.5 Plant population and crop growth**

#### **(a) Plant population**

Plant population was monitored throughout the cropping period. Plant counting was done through row sampling every one day after soil moisture sampling. Ten rows were sampled for counting in every plot. The first row to be counted was randomly sampled among the first six rows from one end of a plot. The second row was the next sixth row from the first counted row. The third row was the sixth row from the second counted row and so forth until ten rows were counted. Equation (16) was used to obtain the plot plant population  $P$  as a percentage of expected total plot plant population.

$$p = \frac{0.1 p_s \sum_{i=1}^{i=10} r_i}{w} \quad (16)$$

Where:-

$r_i$  = ith row.

$w$  = Plot width (m)

$p_s$  = Plant spacing (m).

In order to monitor and identify the major sources of plant decrease, ten damaged plants were randomly collected from each plot. Plants damaged by termite were easily distinguished from plants damaged by other sources through observation on the plant roots. For each plot plants damaged by termite were counted against those damaged by other sources.

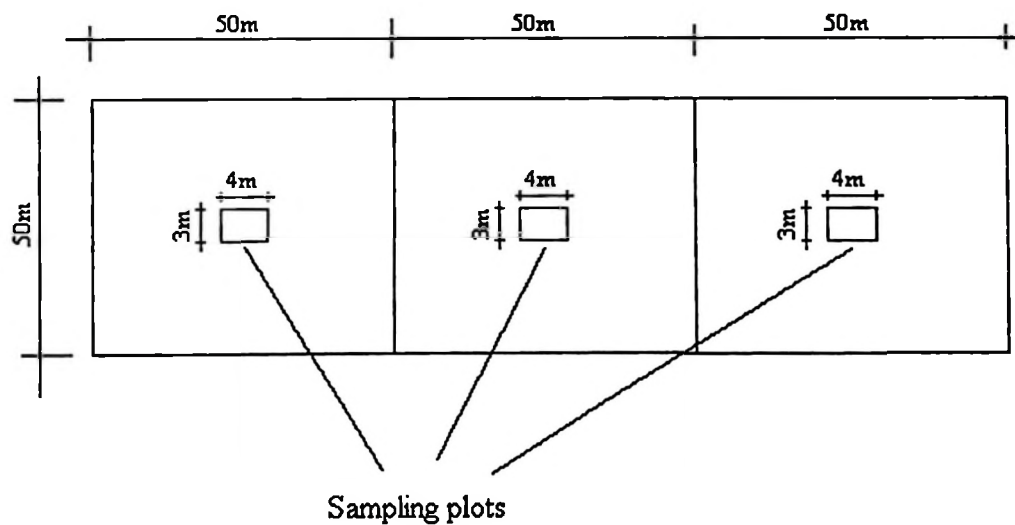
#### **(b) Crop growth**

Crop growth was monitored through out the cropping period by measuring the crop height using a 3m steel tape. Heights of twenty plants per plot were measured on every sampling day. Measurements were made on four plants from five randomly selected rows. The first row was randomly selected among the first 5 rows from one

end of a plot. Then measurements proceeded to every fifth row after the previously measured row.

### 3.5.6 Crop yields

Grain and biomass yields were determined after harvesting. The harvesting procedure was done according to the field and laboratory manual prepared by SWMRG (1993). The sampling plots for harvesting were of 4m x 3m. The sampling plots were replicate three times for each plot as shown in Fig. 3.6.



**Figure 3.6** Layout of sampling plots during harvest

The number of plants and ears from each sampling plot were recorded. Also weight of stems, ears, grains, cobs and leaves from each sampling plots were measured immediately after harvesting using a weighing scale measuring to a nearest 0.01kg.

Three sub samples were taken from each of the harvested entities (grains, cobs, stems and leaves). Three sets each of 100 seeds from each plot and three sets of between 100g to 200g samples from the other parameters were oven dried at 70<sup>0</sup>C until they attained constant weights. The oven dry weight was used to extrapolate the dry weight of the harvested materials.

Analysis of variance was performed to determine the treatment and block effects on grain and biomass yields. Variations of grain and biomass yields due to treatment effect was determined using bar charts including error bars.

## **CHAPTER FOUR**

### **RESULTS AND DISCUSSION**

#### **4.1 Applied water on cropped fields**

##### **4.1.1 Direct rainfall**

There were 19 daily rainfall events during the growing period as presented in Fig. 4.1 and Tables 4.1a, 4.1b and in Appendix 1. However rainfall events occurred during the first and second decades were not recorded because rain gauges were not yet been installed. The rain gauge on field F1 recorded a total rainfall amount of 372mm while the rain gauge on field F2 recorded a total rainfall amount of 357mm.

Figure 4.1 shows daily rainfall (average of the two rain gauges) distribution on the cropped fields during the growing period. It is clear from Fig. 4.1 that rainfall distribution was poor. While 61% of the total rainfall amount occurred between the fifth and sixth decades, 19.5% occurred during the seventh decade, 12.3% occurred during the eighth, ninth and tenth decades and only 6.3% and 0.8% occurred during the third to fourth and eleventh decades respectively.

A 16 days dry spell occurred during the last two decades and was the longest during the growing period. Other dry spells during the growing period were 12days, 8days, 7days and two 6days which occurred during the fifth, the seventh, the eighth decades and the third decades respectively. However the season was one of the wettest seasons.

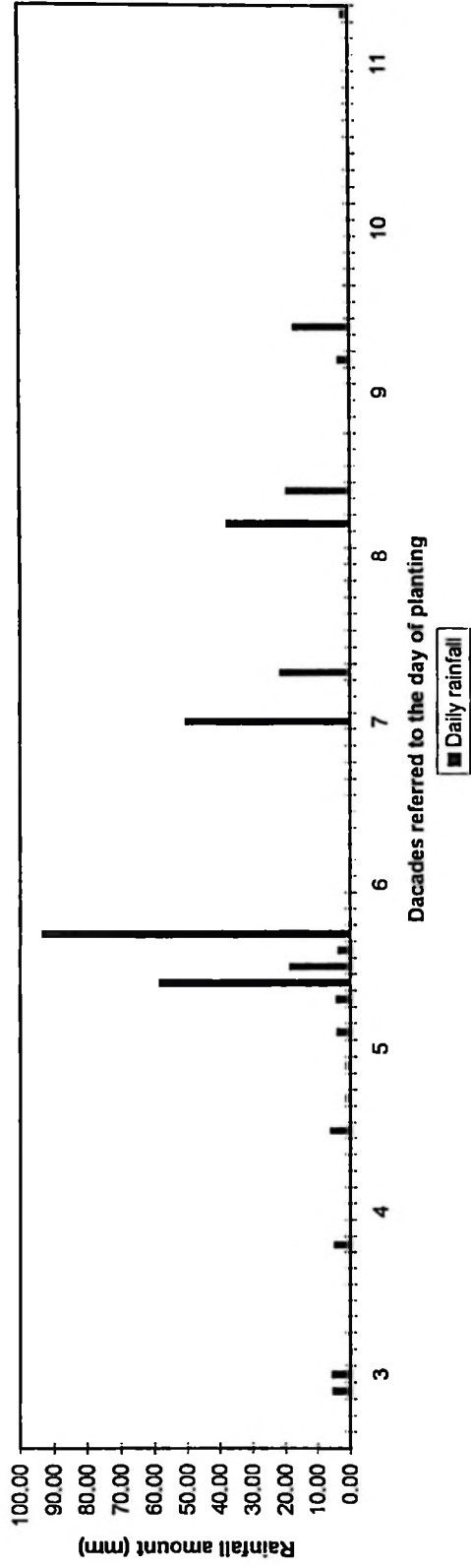


Figure 4.1 Daily rainfall on decades distribution for the 1997/98 short rainy season

**Table 4.1a Effective water applied to field F1 during the 1997/98 short rainy growing season at Kifaru site.**

Date	Days after emergence	Effective depth of water applied to WCIR (mm)	Effective depth of water applied to WC (mm)	Effective depth of water applied to FC (mm)
18/12/97	24	5.70	5.70	5.70
19/12/97	25	5.70	5.70	5.70
27/12/97	33	4.90	4.90	4.90
3/1/98	40	6.30	6.30	6.30
5/1/98	42	1.42	1.42	1.42
7/1/98	44	1.62	1.62	1.62
9/1/98	46	5.48	5.48	5.48
11/1/98	48	2.84	2.84	2.84
12/1/98	49	66.45	63.73	62.11
13/1/98	50	18.43	18.30	16.84
15/1/98	51	4.60	4.60	4.60
14/1/98	52	85.03	74.73	66.50
28/1/98	65	57.72	50.30	40.24
31/1/98	68	28.86	21.30	19.17
9/2/98	77	8.40	2.00	2.00
9/2/98	77	40.00	34.80	27.84
9/2/98	77	3.22	1.00	1.00
11/2/98	79	30.70	21.10	18.99
19/2/98	87	4.30	4.30	4.30
21/2/98	89	23.60	18.40	16.56
12/3/98	108	25.70	2.50	2.50
<b>Total</b>		<b>430.97</b>	<b>351.02</b>	<b>316.61</b>

**Table 4.1b Effective water applied to field F2 during the 1997/98 short rainy growing season at Kifaru site.**

Date	Days after emergence	Effective depth of water applied to WCIR (mm)	Effective depth of water applied to WC (mm)	Effective depth of water applied to FC (mm)
18/12/97	24	5.40	5.40	5.40
19/12/97	25	5.80	5.80	5.80
27/12/97	33	5.20	5.20	5.20
3/1/98	40	6.40	6.40	6.40
5/1/98	42	1.60	1.60	1.60
7/1/98	44	1.60	1.60	1.60
9/1/98	46	3.20	3.15	3.20
11/1/98	48	6.20	6.20	6.20
12/1/98	49	64.43	52.80	42.24
13/1/98	50	19.69	19.60	18.03
15/1/98	51	3.40	3.40	3.40
14/1/98	52	87.34	73.31	64.54
28/1/98	65	55.86	51.40	41.12
31/1/98	68	22.60	22.60	20.34
9/2/98	77	14.00	2.40	2.40
9/2/98	77	36.90	35.30	28.24
9/2/98	77	1.20	1.20	1.20
11/2/98	79	23.40	18.60	16.74
19/2/98	87	3.00	3.00	3.00
21/2/98	89	31.33	16.80	15.12
12/3/98	108	6.70	2.40	2.40
<b>Total</b>		<b>405.26</b>	<b>338.16</b>	<b>294.17</b>

#### 4.1.2 Run-on harvested from gully diversion

Total run-on harvested from external catchment through gully flow during the growing season was 5262m<sup>3</sup>. That which was delivered to fields F1 and F2 were 2037m<sup>3</sup> and 502m<sup>3</sup> respectively. Runon harvesting data is shown in Appendix 1. This indicate that only 50% of runoff diverted from gullies were conveyed to the cropped fields. This was due to the expected low conveyance efficiency of the natural water way (small gully) which conveyed spilt off water from flume H2 at field F1 to flume H3 at field F2. However, although there was a great achievement in harvesting the runoff from the catchment, silt deposition in delivery channels was a big problem. Labour required to attend the system had to be increased three folds to take care of the huge silt deposited in the channels after every runon event.

The total runon diverted from the gullies would have been larger than observed if all the runoff from the gullies was collected. In some events, the runoff flow in the big gully was so big that some of it went over the diversion weir. Some of the runoff was observed to have escaped through various weak points along the canal that was dug to join the two gullies. There was also a problem of heavy sediment loads carried in the harvested water from the gullies. The sediment loads were not quantified. However, the runon conveyance system was regularly desilted.

The generated runoff was also poorly distributed. For example, 86% of the total run-on depth on field F1 was generated by 3 runon events which were 25% of the total

run on events. In field F2 83% of the total run on depth were generated 3 runoff events which were 30% of the total runoff events in the field.

#### **4.1.3 Effective water applied to cropped fields**

Effective water applied to cropped fields to each treatment, calculated using the runoff model described in chapter three, is shown in Tables 4.1a and 4.1b. It was observed that the effective water depth applied on field F1 was 31%, 94% and 85% of the total depth of water applied on treatments WCIR, WC and FC respectively. While on field F2 the effective depth of the applied water was 69.8%, 94% and 82% of the total depth of water applied on treatments WCIR, WC and FC respectively.

The results from the runoff model shown in Appendix 1 indicate that more available water was wasted from treatment WCIR through runoff and least water was wasted from treatment WC. From Tables 4.1a and 4.1b estimated water depths wasted through runoff from field F2 were 175mm, 18.94 and 62.93mm for treatments WCIR, WC and FC respectively, while on field F1 the estimated water depths wasted through runoff were 877mm, 21.24mm and 55.62mm from treatments WCIR, WC and FC respectively. This also shows that incident rainfall was captured more efficiently in both treatments WCIR and WC than in treatment FC as was expected. The percentage of effective depth of applied water on treatment WCIR on field F1 was lower than that on treatment WCIR on field F2. That was due to too larger runoff water depths applied on field F1 than that applied on field F2.

#### **4.1.4 Effective water applied on cropped fields in relation to potential crop water requirement of maize**

Generally, as shown in Figures 4.2a and 4.2b, the effective water applied to cropped fields were higher than the potential crop water requirements during the vegetative stage (decades 3 to decade 6). During the establishment (decade2), maturity (decade 7) and grain filling (decade 8 to decade 9) stages, water applied on cropped fields was lower than the potential crop water requirements in both fields.

Table 4.2 shows the ratios of the effective depth of water applied ( $De$ ) on the cropped fields to the potential crop water requirement ( $ET_m$ ), expressed as  $De:ET_m$ , of maize crop during the 1997/98 short rainy season. It was noted that during the vegetative, maturity and grain filling stages the  $De:ET_m$  ratios were generally higher in WCIR treatment than those in WC and FC treatments in both fields. However, the  $De:ET_m$  ratios during maturity and grain filling stages in treatments WC and WCIR for field F1 were almost the same and higher than those in treatment FC. While for field F2 the  $De:ET_m$  ratios during the same periods in treatments WC and FC were almost the same and lower than those in treatment WCIR.  $De:ET_m$  ratios were almost the same during those stages in both fields. During the vegetative stage the  $De:ET_m$  ratios in treatment FC was lower than the ratios in treatments WC and  $De:ET_m$  ratios in WCIR were higher than the ratios in treatment WC for both F1 and F2 fields. The  $De:ET_m$  ratios in treatments WC and WCIR during the vegetative stage were almost the same. During the establishment stage the  $De:ET_m$  ratio was almost the same in all treatments in the both fields. The  $De:ET_m$  ratios were higher than unity during the

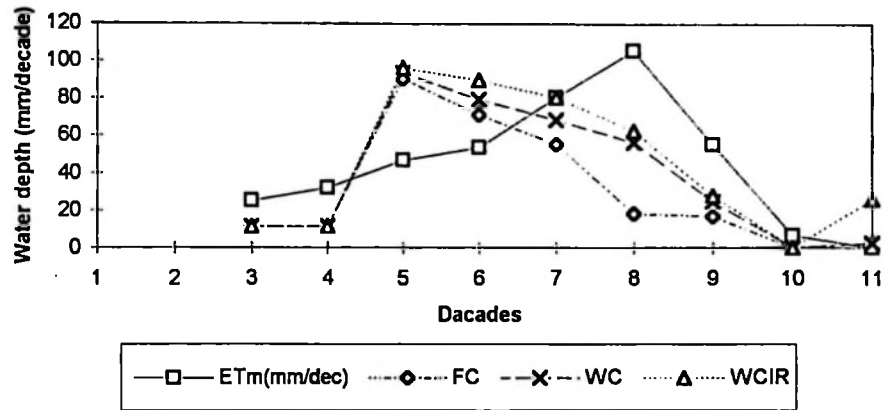
vegetative stage in all treatments due to rainfall with large amounts which occurred during this stage.

**Table 4.2 Ratios of applied water depth to potential water requirement (De:ETm) of maize for the three treatments at different growing stages during the 1997/98 short rainy season.**

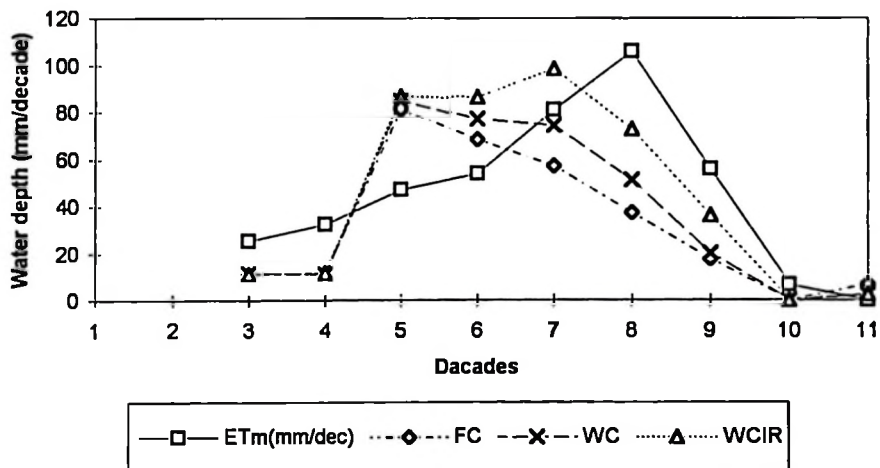
Growth stage	Field F1			Field F2		
	FC	WC	WCIR	FC	WC	WCIR
Establishment	0.46	0.46	0.46	0.45	0.46	0.45
Vegetative	1.07	1.17	1.27	1.02	1.13	1.26
Maturity	0.17	0.54	0.59	0.35	0.48	0.69
Grain filling	0.15	0.22	0.25	0.16	0.18	0.33

However during the maturity and grain formation stages the De:ETm ratios were higher in WCIR treatment than those in WC and FC treatments. But in treatments WC and FC, De:ETm ratios were almost the same during those stages in both upper and lower fields. During the vegetative stage the De:ETm ratio in treatment FC was lower than the ratios in treatments WC and WCIR. The De:ETm ratios in treatments WC and WCIR during the vegetative stage were almost the same. During establishment stage the De:ETm ratio was almost the same to in all treatments in the upper and lower fields.

The De:ETm ratios were more than unit during the vegetative stage in all treatments due to rainfall with large amounts which occurred during this stage. During this period the fields received a total of 220mm which is more than 60% of the total rainfall amount that occurred during the growing period. The higher De:ETm ratios in treatment WCIR than those in treatments WC and FC reflected the significance of supplementary irrigation which was applied only in treatment WCIR.



**Figure 4.2a** Effective water depth applied on field F1 in relation to crop water requirement of maize during the 1997/98 short rainy season at Kifaru village



**Figure 4.2b** Effective water depth applied on field F2 in relation to crop water requirement of maize during the 1997/98 short rainy growing season at Kifaru village

## **4.2 Soil moisture content variation during the growing period**

### **4.2.1 Root zone moisture content (depth 0-50cm)**

Figures 4.3a and 4.3b show the root zone soil moisture content which varied from 15% to 34% in field F1 and from 19.5% to 43.5 % in field F2. Summary of the results obtained from the DNMRD on the treatment means of the root zone soil moisture content for fields F1 and F2 are shown in Appendix 4. Generally soil moisture in field F2 root zone was higher than that in field F1. This was expected because soils of field F2 are dominated by silty clay loam while those in field F1 are dominated by clay sandy loam. From Figures 4.3a and 4.3b it can be seen that soils in treatment WCIR were generally wetter than soils under treatments WC and FC. Soils in treatment FC were generally drier than those in treatments WC and WCIR in field F1 and F2. This was due to treatment effect.

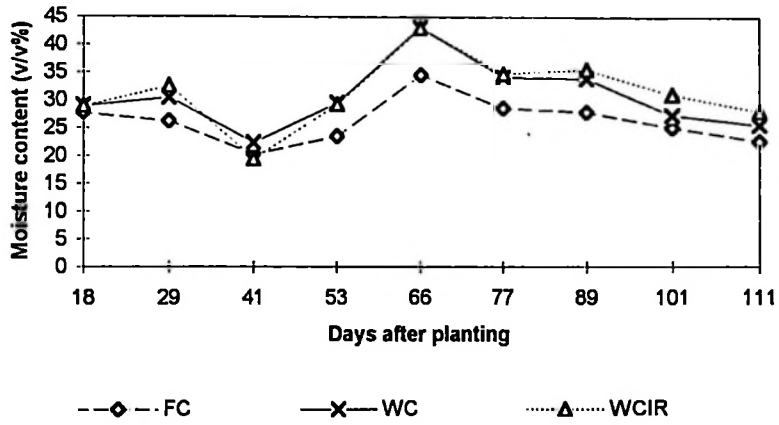
At the beginning of the growing period (decade 1 to decade 3) there was no much difference in root zone soil moisture content in all the three treatments in both fields F1 and F2. During this time treatment WCIR had not yet been imposed. Land preparation which was the same for all treatments had more influence on the moisture status than was treatment effect.

Similarly from the sixth to the eighth decades there was no significant difference in soil moisture content between soils under treatment WC and those under treatment WCIR in field F2. That was due to the effect of high rainfall amount (248mm), low rainfall intensity (16mm/hr on average) and the high water holding capacity of soils in

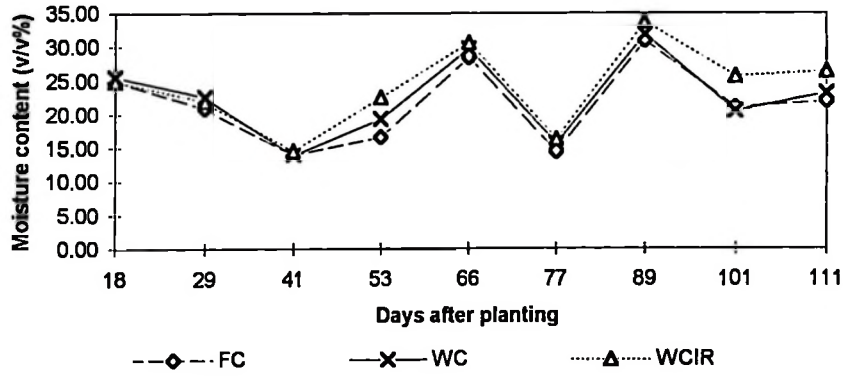
field F2. However, soil moisture content in treatment FC were lower than those in treatments WC and WCIR in field F2 during the same period. This was due to treatment effect combined with the low infiltration rate (2mm/hr) of the soils.

Soil moisture content in field F1 was not significantly different almost throughout the growing period except during the ninth to eleventh decades. This was probably due to the higher rainfall amount ( 357mm in three months) with generally low intensity (16mm/hr on average) and a fairly better soil infiltration rate (5mm/hr for clay sandy loam). Soil moisture content in treatment WCIR was significantly higher than in both treatments FC and WC in field F1 during the ninth to eleventh decades. This was expected because treatment WCIR in field F1 received twice as much more applied water than that applied in treatments WC and FC in the same period.

It was observed that there was no significant difference in the root zone soil moisture content between treatments WCIR and WC in field F2. But treatment FC had significantly lower root zone soil moisture content when compared with the other two treatments. As described in the previous sections, soils in field F2 are dominated by silty clay loam. They have poor infiltration rates (1.5mm/hr) and higher water holding capacity (up to 55% v/v). Due to these characteristics and the high rainfall amount which occurred during the growing season , treatment FC in field F2 probably lost much of the rain water through runoff. Conversely those plots with treatment WC and WCIR stored more water in the root zone due to the effect of prolonged ponding. This is evident in Figure 4.3a.



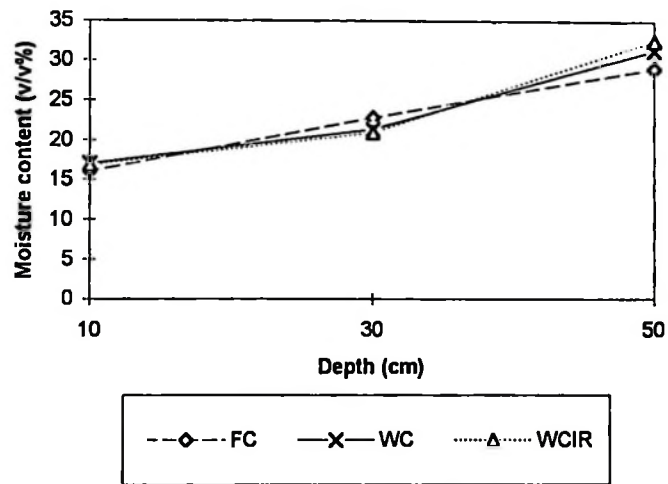
**Figure 4.3a** Root zone soil moisture variation during the growing season in Field F2



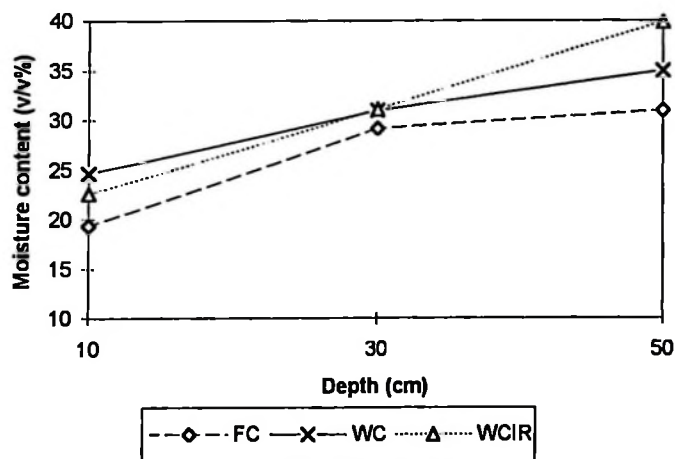
**Figure 4.3b** Root zone soil moisture variation during the growing season in Field F1

#### **4.2.2 Soil moisture variation with depth at different growing stages**

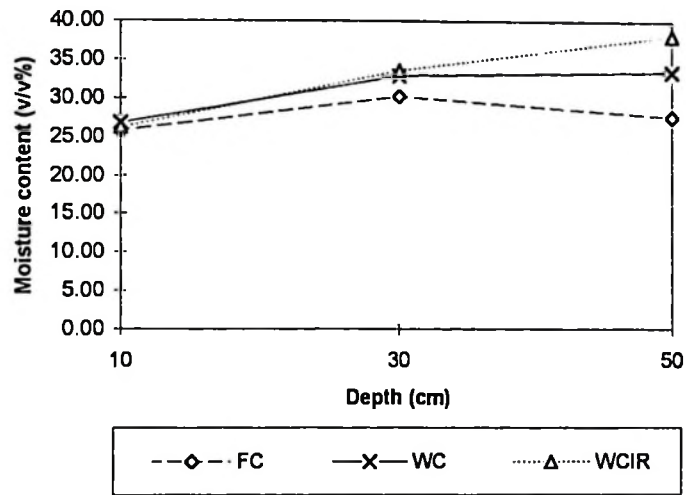
Figures 4.4a to 4.4d show soil moisture variation with depth at vegetative and maturity stages. During the vegetative stage soil moisture in both three treatments was not significantly different at all three depths (10cm, 30cm and 50cm) in field F1. However, soil moisture content increased with depth. Soil moisture content in field F2 during this stage was significantly lower in treatment FC than in treatments WC and WCIR. This shows that treatment effect was more significant in field F2 than in field F1. The trend of soil moisture to increase with depth as shown in all Figures 4.4a to 4.4d suggest that much applied water probably percolated into deeper soils. Treatment WCIR had the highest depth of deep percolated water and treatment FC had the least depth of deep percolated water. However, while there was no significant treatment effect on deep percolated water in field F2, treatment effect on deep percolated water was significant in field F1. This was probably due to variation in soil properties between the fields as explained earlier.



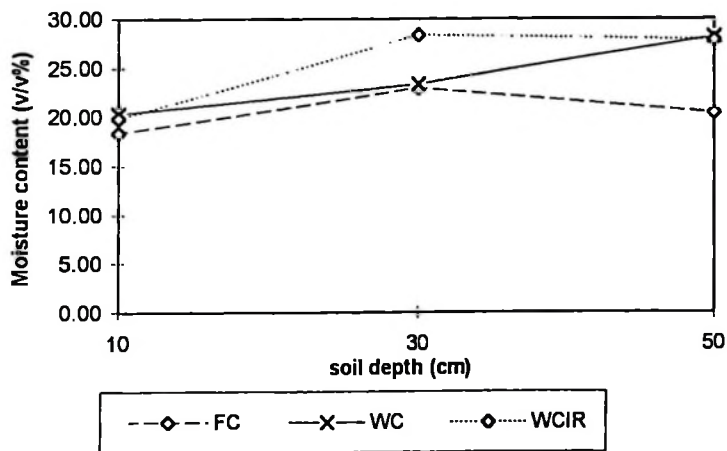
**Figure 4.4a** Moisture content variation in field F1 root zone during the vegetative stage.



**Figure 4.4b** Soil moisture variation in field F2 root zone during the vegetative stage



**Figure 4.4c** Soil moisture variation across field F2 root zone during the maturity stage



**Figure 4.4d** Moisture content variation across root the zone in field F1 during maturity stage.

### **4.3 Crop development**

#### **4.3.1 Plant population**

Figures 4.5a and 4.5b show that there was a decreasing trend in plant population in the fields during the growing period. In field F1, plant population decreased from 97%, 97.8% and 97% on the 11th day after planting to 91.2, 90.7% and 89.5% at harvesting date in treatment WCIR, WC and FC respectively. In field F2, plant population decreased from 98%, 96% and 97% to 90%, 91% and 91.2% in treatment WCIR, WC and FC respectively during the same period.

One of the major sources of plant decrease in the fields were termite infestation, weevil attack and vermin. Termite infestation was evident on the attacked roots of the damaged plants. Table 4.3 shows that 75% of crop damage in field F1 and 65% in the field F2 was due to termite infestation. Analysis of variance on plant population showed that treatment effect had significant influence on the decrease in plant population. Results from the DNMR test for the LSD at  $\alpha = 0.05$ , summarised in Tables 4.4a and 4.4b, show that plant decrease in plots with treatment FC was significantly higher than plant population decrease in plots with treatment WC and WCIR.

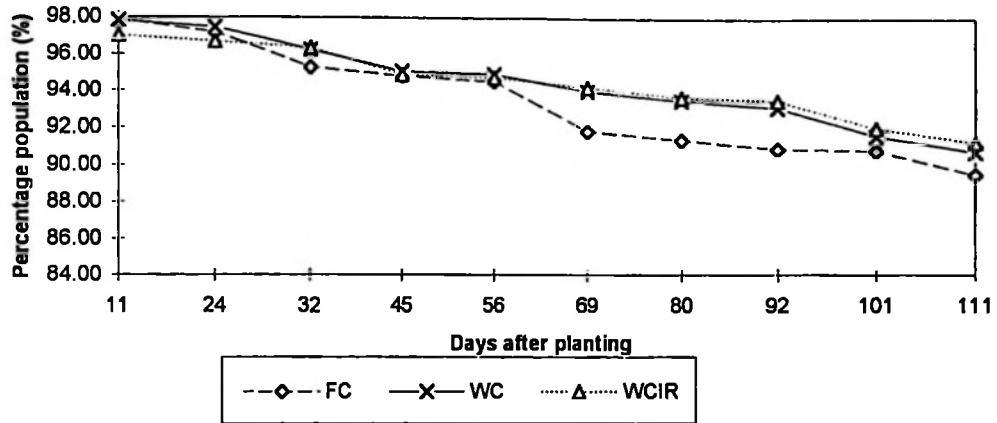


Figure 4.5a Plant population variation during the growing period in field F1

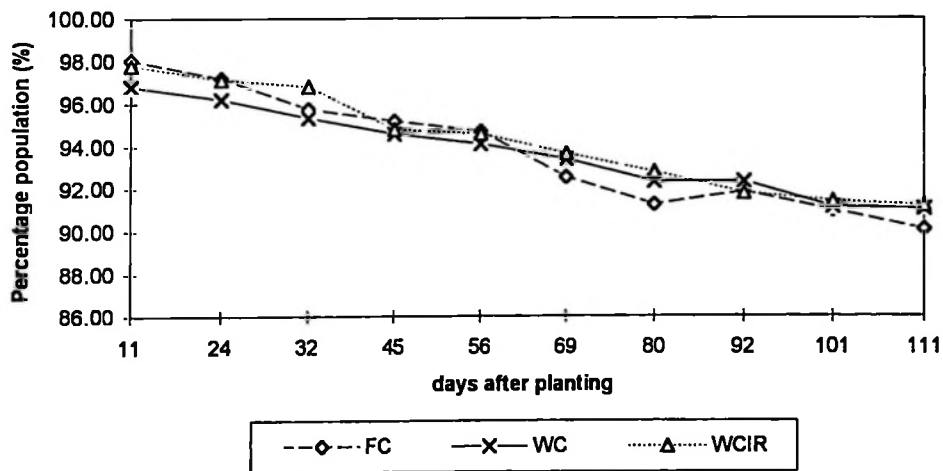


Figure 4.5b Plant population variation during the growing period in field F2

**Table 4.3 Percentage of damaged plants due to termite (t) and other causes (o) during the growing period. (Sample size 10 plants per plot on each sampling day)**

Days from planting (days)	F2						F1					
	FC		WC		WCIR		FC		WC		WCIR	
	t	o	t	o	t	o	t	o	t	o	t	o
11	70	30	90	10	60	40	100	00	50	50	40	60
24	80	20	60	40	30	70	90	10	70	30	90	10
32	60	40	30	70	50	50	80	20	60	40	70	30
45	50	50	80	20	70	30	70	30	100	00	90	10
56	40	60	70	30	60	40	60	40	70	30	80	20
69	100	00	90	10	80	20	80	20	80	20	70	30
80	80	20	70	30	100	00	100	00	90	10	80	20
92	70	30	100	00	90	10	70	30	80	20	70	30
101	60	40	50	50	40	60	80	20	100	00	50	50
Average	68	32	71	29	64	36	81	19	77	23	71	29

**Table 4.4a Duncan's multiple range test on plant population means for field F1 during the growing period due to treatment effect.**

Treatment	Ranked order	DNMRT <sup>a</sup>
	Population <sup>b</sup> (%)	
WCIR	93.8	a
WC	92.2	a
FC	88.1	b

<sup>a</sup> Any two means having a common letter are not significantly different at  $p = 0.05$

<sup>b</sup> Means calculated from 30 no. of observations

**Table 4.4b Duncan's multiple range test on plant population means for field F2 during the growing period due to treatment effect.**

Treatment	Ranked order	DNMRT <sup>a</sup>
	Population <sup>b</sup> (%)	
WCIR	94.1	a
WC	91.2	b
FC	89.1	c

<sup>a</sup> Any two means having a common letter are not significantly different at  $p = 0.05$

<sup>b</sup> Means calculated from 30 no. of observations

Therefore it is clear from this analysis that the trend of plant population decrease followed the trend in soil moisture level. Plots with higher soil moisture level had lower rate of plant population decrease. This can be explained by the fact that termite exhibit a behaviour of feeding on fresh plants when soils become drier. From Figures 4.5b and 4.5c, this fact is more evident between day 69 and 92 after planting. This was the period during which the longest dry spell of 16 days occurred during the growing period.

#### **4.3.2 Plant height**

In general, plant height in the fields did not show significant differences among treatments during establishment stage in both fields F1 and F2. However during vegetative and maturity stages plant heights in treatment FC were generally shorter than plants in treatments WC and WCIR for both fields F1 and F2 albeit more significant in F2 than was in F1 (Figures 4.6a and 4.6b).

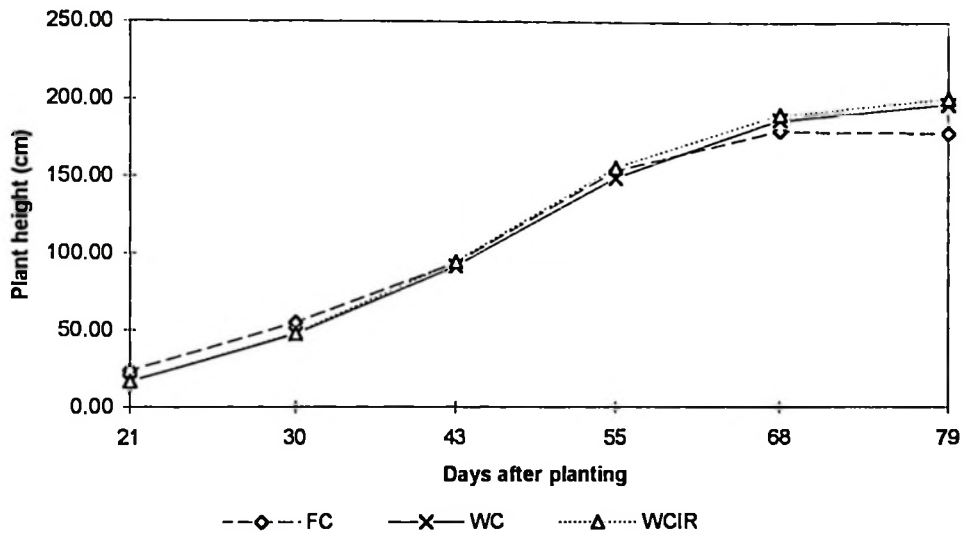


Figure 4.6a Plant height variation in field F1 over the growing period

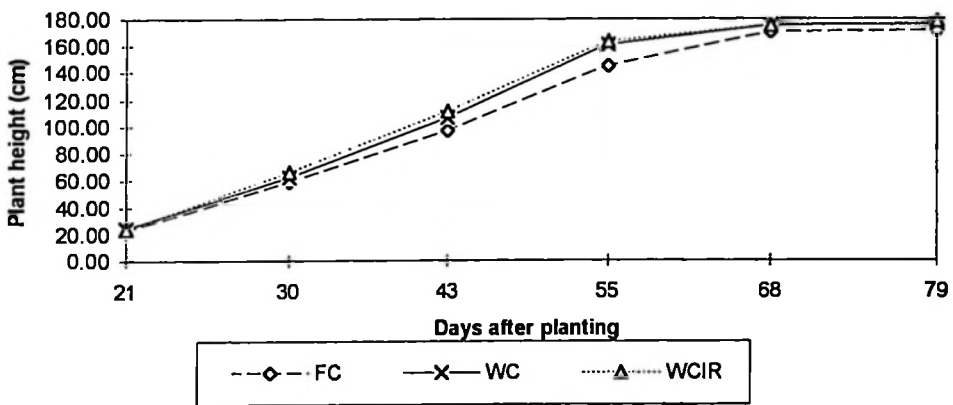


Figure 4.6b Plant height variation in field F2 over the growing period

**(a) During establishment stage**

During this stage the average plant height was 24 cm in both fields F1 and F2. Analysis of variance performed on heights in measurements taken on day 21 after planting showed that treatment factor had no significant effect on plant heights both fields (at  $p = 0.05$ ).

The non significance of treatment FC and WC on plant heights during this stage indicate that land preparation, which was the same in all plots, had dominant effect to the capture of rain water. This is because newly, deep ploughed soils have higher soil water intake rates ( Nyanoka, 1995) and actually treatment WCIR had not yet been imposed.

**(b) During vegetative stage**

During this stage as can be seen from Figures 4.6a and 4.6b, plant height differences between treatments had started showing up in both fields F1 and F2. The average plant height was 109cm and 107cm in fields F1 and F2 respectively. Analysis of variance on plant heights taken on day 30, 43 na 55 from planting showed that treatment factor had significant effect at  $p = 0.05$  on plant heights variation during this stage in both fields F1 and F2.

The DNMR test results on the LSD for mean heights performed at  $p = 0.05$  during that stage (Tables 4.5a and 4.5b), show that treatment FC had significantly shorter plants than both treatments WC and WCIR for field F2 and in F1 plants in treatment

WCIR were significantly taller than those in treatment FC. There was no significant difference between plant heights in treatment WC and FC in field F1.

**Table 7** Table 4.5a Duncan's multiple range test on plant height means on field F1 at vegetative stage due to treatment effect

Treatment	Ranked order	DNMRT <sup>a</sup>
	Plant height <sup>b</sup> (cm)	
WCIR	113.6	a
WC	109.8	ab
FC	100.1	b

<sup>a</sup> Any two means having a common letter are not significantly different at  $p = 0.05$

<sup>b</sup> Means calculated from 9 no. of observations.

**Table 8** Table 4.5b Duncan's multiple range test on plant height means on field F2 at vegetative stage due to treatment effect.

Treatment	Ranked order	DNMRT <sup>a</sup>
	Plant height <sup>b</sup> (cm)	
WCIR	115.9	a
WC	112.7	a
FC	100.8	b

<sup>a</sup> Any two means having a common letter are not significantly different at  $p = 0.05$

<sup>b</sup> Means calculated from 9 no. of observations.

The significant difference in plant heights in treatment FC as compared to treatments WC and WCIR was due to the observed difference in soil moisture content. Plots that had higher moisture content had higher potential to vigorous plant growth. Treatment WC and WCIR had higher moisture content than treatment FC during this stage as explained in section 4.2.1.

**( C )      During maturity stage**

During this stage plants attained a maximum average height of 175 cm and 192cm in field F1 and F2 respectively. Analysis of variance on plant heights measurement taken at 68 and day 79 after planting showed that there was significant difference in plant heights due to treatment effect. The DNMR test results (Tables 4.6a and 4.6b) on the LSD for mean heights performed at  $p = 0.05$  indicate that treatment WCIR had taller plants than plants in treatment WC. However, the difference was not significant in both fields F1 and F2. In field F2 plant heights treatment FC were significantly shorter than those in both treatments WC and WCIR.

These observations show that the long dry spell of 16 days which occurred during the maturity and grain filling stages had the worst effect on plant development in treatment FC but had the least effect on plant development in treatment WCIR. This is also in agreement with soil moisture observations discussed earlier.

**Table 9** Table 4.6a Duncan's multiple range test on plant height means on field F1 at maturity due to treatment effect.

Treatment	Ranked order	DNMRT <sup>a</sup>
	Plant height <sup>b</sup> (cm)	
WCIR	178.3	a
WC	174.6	ab
FC	170.9	b

<sup>a</sup> Any two means having a common letter are not significantly different at  $p = 0.05$

<sup>b</sup> Means calculated from 9 no. of observations.

**Table 10** Table 4.6b Duncan's multiple range test on plant height means on field F2 at maturity stage due to treatment effect.

Treatment	Ranked order	DNMRT <sup>a</sup>
	Plant height <sup>b</sup> (cm)	
WCIR	200.3	a
WC	197.4	a
FC	178.8	b

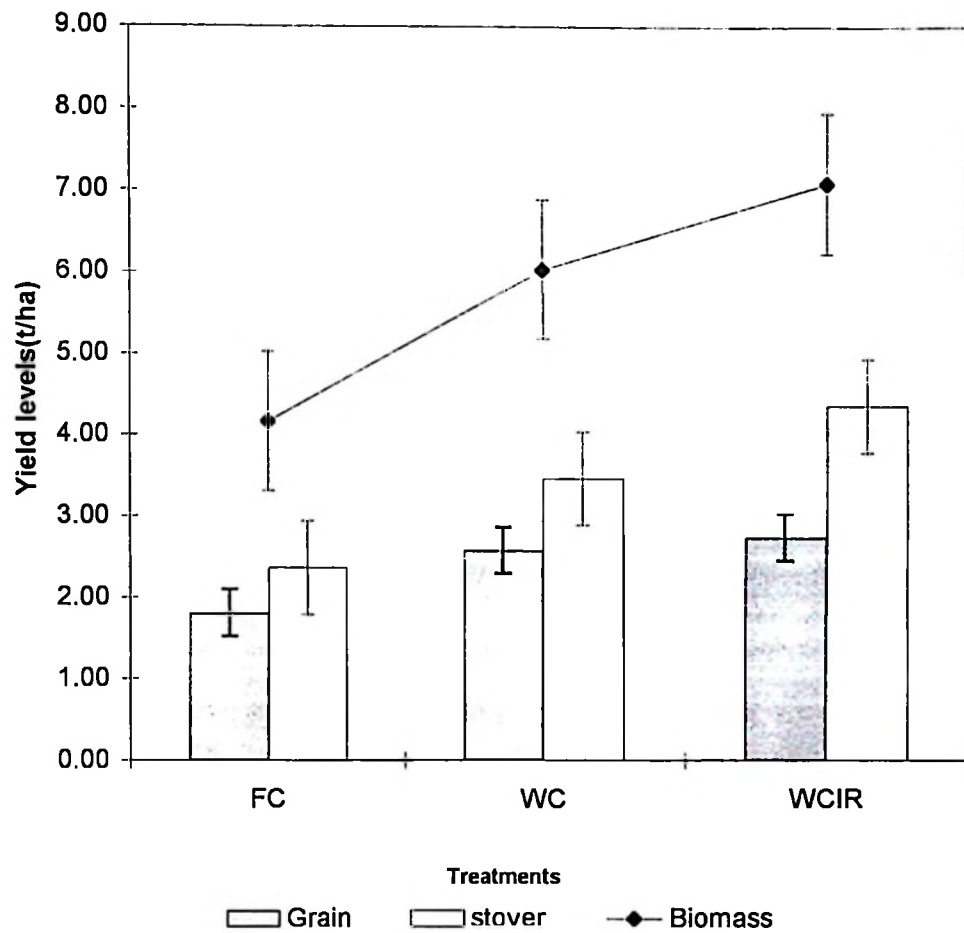
<sup>a</sup> Any two means having a common letter are not significantly different at  $p = 0.05$

<sup>b</sup> Means calculated from 9 no. of observations.

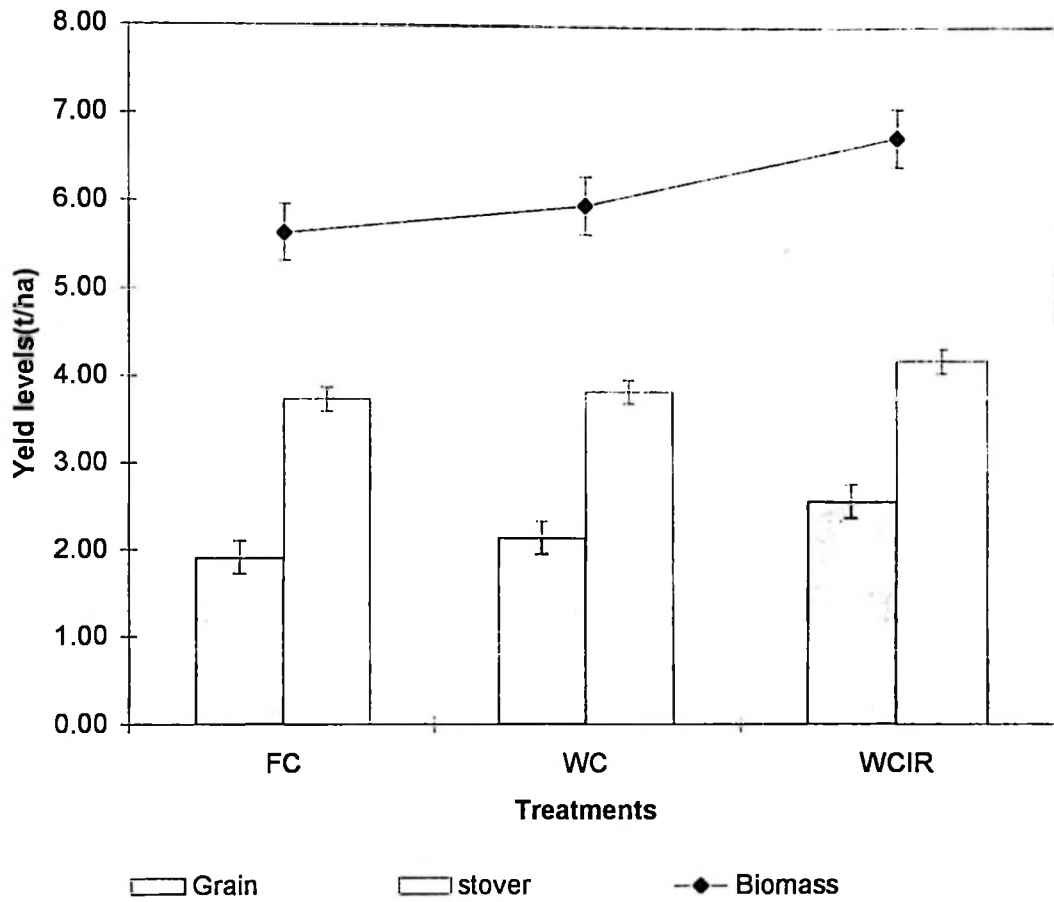
## 4.4 Crop yields performance

### 4.4.1 Biomass yields

The biomass yields from the fields is shown in Figures 4.7a and 4.7b and summarised in Table 4.7. The average biomass yields harvested from field F2 were 7.4t/ha, 6.0t/ha and 4.2t/ha from treatment WCIR, WC and FC respectively. The overall average biomass yield for field F2 was 5.86t/ha. The biomass yields harvested from field F1 were 6.7t/ha, 6.0t/ha and 5.6t/ha from treatment WCIR, WC and FC respectively.



**Figure 20** Figure 4.7a Yield performance of maize grown under three water application levels during the 1997/98 short rain season at Kifaru site field 2. (including error bars at  $p=0.05$ )



**Figure 21**Figure 4.7b. Yield performance of maize grown under three water application levels during the 1997/98 short rains growing season at Kifaru site field F1 (Including error bars at  $p=0.05$ )

#### 4.4.2 Grain yields

Maize grain yields are shown in Figures 4.7a and 4.7b. Overall yields were 1.8 t/ha, 2.5 t/ha and 2.7t/ha from treatment FC, WC and WCIR respectively in field F2 and 1.9 t/ha, 2.1t/ha and 2.5t/ha from treatments FC, WC and WCIR respectively in field F1.

**Table 11 Table 4.7 Grain and biomass yield performance of maize grown under three water application levels during the 1997/98 short rain season at Kifaru site.**

Yield Components	F1			F2		
	FC	WC	WCIR	FC	WC	WCIR
100 seed weight (g)	21.93	22.96	24.49	21.63	24.1	23.92
Grain weight (t/ha)	1.910	2.140	2.500	1.80	2.570	2.730
Biomass weight (t/ha)	5.643	5.963	6.743	4.164	6.034	7.376

Analysis of variance showed that treatments effect was significant on grain yields at  $p= 0.05$  for both fields. However, error bars included in Figure 4.7a show that treatment FC in field F2 had significantly lower grain yields than in treatments WC and WCIR in field F2. However, there was no significant difference between grain yields from treatment WC and those from treatment WCIR. These observations are explained by the observed 100 seed weight which was lower in treatment FC than in treatments WC and WCIR while seed weights from treatments WC were not significantly difference to those from treatment WCIR. The 16 days dry spell which

prevailed during the maturity and grain formation stages might have affected grain yields more diversely for treatment FC than for treatments WC and WCIR. Crops in treatments WC and WCIR might have sustained less moisture stress during that period due to the higher soil moisture stored in the soil.

Figure 4.7b shows that grain yields in field F1 were significantly higher in treatment WCIR than in treatments FC and WC. However, no significant difference was observed between grain yields from treatments WC and FC. These observations can also be explained by the differences observed on the average seed weights as shown in Table 4.7. This indicates that crops in plots with treatment WCIR suffered less moisture stress during grain formation as compared to treatments WC and FC. This was due to the additional runoff flow diverted into treatment WCIR during that period. Treatment WCIR received almost twice effective water depth applied as compared to water depth applied to treatments WC and FC.

## CHAPTER FIVE

### CONCLUSIONS AND RECOMMENDATIONS

#### 5.1 Conclusions

Basing on the results obtained in this study, the following conclusions can be drawn:

1. Although the 1997/98 short rainy season was one of the wettest seasons in Mwangi district, the total rainfall amount was not adequate to meet the water requirements of maize for optimum crop production. However there is a high potential of runoff from marginal areas which is conveyed through gullies which pass through crop fields without being utilised.
2. Water conservation practice improves the depth of effective rainfall. Additional water from gully flow to a field with water conservation measures produce additional improvement on the depth of effective rainfall. However during heavy rains exceeding 40 mm and for dry spells shorter than six days, application of supplementary irrigation from gully flow results into excessive loss of available water through runoff from the cropped fields and through deep percolation. When rains are lighter and spaced with long dry spells there is much improvement on the amount of moisture stored when water from gully flow is applied onto a field with water conservation measures.
3. There is considerable improvements on biomass and grain yields through application of supplementary irrigation from gully flow especially when rainfall distribution is poor. However grain yields are not much improved when total seasonal rainfall amount is high. Generally the application of supplementary

irrigation from gully flow has significant advantage on crop performance when the soils have high water holding capacity.

## **5.2 Recommendations**

The findings of this study have prompted the following recommendations to be made:

1. Adoption of supplementary irrigation using water from gully flow be encouraged in semi arid areas to make use of the runoff water which is wasted each season to improve the available soil water for crop production.
2. Application of supplementary irrigation using runoff water from gully flow will necessarily need much care in the application of the water to avoid water logging and erosion.
3. Water and soil conservation measures are important for effective application of supplementary irrigation using runoff water from gully flow.
4. Assessment of soil hydraulic characteristics is an important prerequisite before a decision to adopt supplementary irrigation using runoff water from gully flow is made.

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## APPENDICES

### Appendix 1: Hydrological data

Hydrology data for field F1 during the 1997/98 short rain growing season at Kifaru site

Date	Days	Rainfall	Rainfall	Runoff	Runoff	Runoff	Runoff	Runoff	Effective	Effective	Effective
	after										
	emerge	Amount	intensity	diverted	onto CB	from	from CB	from CB	depth of	depth of water	depth of
	nce					CB			water	water	water
				from	WCIR	WCIR	WC plots	FC plots	applied to	applied to WC	applied to
				gullies	plots	plots			WCIR		FC
		(mm)	(mm)/hr	(m <sup>3</sup> )	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
18/12/97	24	5.7	3.26	0	0.00	0.00	0.00	0.00	5.70	5.70	5.70
19/12/97	25	5.7	4.89	0	0.00	0.00	0.00	0.00	5.70	5.70	5.70
27/12/97	33	4.9	4.90	0	0.00	0.00	0.00	0.00	4.90	4.90	4.90
3/1/98	40	6.3	9.45	0	0.00	0.00	0.00	0.00	6.30	6.30	6.30
5/1/98	42	1.42	5.68	0	0.00	0.00	0.00	0.00	1.42	1.42	1.42
7/1/98	44	1.62	3.89	0	0.00	0.00	0.00	0.00	1.62	1.62	1.62
9/1/98	46	5.48	3.65	0	0.00	0.00	0.00	0.00	5.48	5.48	5.48
11/1/98	48	2.84	5.68	0	0.00	0.00	0.00	0.00	2.84	2.84	2.84
12/1/98	49	64.7	12.73	1614	283.11	281.36	0.98	2.59	66.45	63.73	62.11
13/1/98	50	18.3	16.89	1.08	0.13	0.00	0.00	1.46	18.43	18.30	16.84
15/1/98	51	4.6	2.30	0	0.00	0.00	0.00	0.00	4.60	4.60	4.60
14/1/98	52	95	10.37	1695	283.11	293.08	20.27	28.50	85.03	74.73	66.50
28/1/98	65	50.3	8.25	1458	280.00	302.58	0.00	10.06	57.72	50.30	40.24
31/1/98	68	21.3	19.72	56.4	7.56	0.00	0.00	2.13	28.86	21.30	19.17
9/2/98	77	2	3.45	57.2	6.40	0.00	0.00	0.00	8.40	2.00	2.00
9/2/98	77	34.8	24.86	37	5.20	0.00	0.00	6.96	40.00	34.80	27.84
9/2/98	77	1	2.50	20.3	2.22	0.00	0.00	0.00	3.22	1.00	1.00
11/2/98	79	21.1	10.99	108.2	9.60	0.00	0.00	2.11	30.70	21.10	18.99
19/2/98	87	4.3	8.60	0	0.00	0.00	0.00	0.00	4.30	4.30	4.30
21/2/98	89	18.4	24.53	34	5.20	0.00	0.00	1.84	23.60	18.40	16.56
12/3/98	108	2.5	3.73	181	23.20	0.00	0.00	0.00	25.70	2.50	2.50
<b>Total</b>		<b>372.26</b>	<b>9.06</b>	<b>5262.18</b>	<b>905.73</b>	<b>877.02</b>	<b>21.24</b>	<b>55.65</b>	<b>430.97</b>	<b>351.02</b>	<b>316.61</b>

Hydrology data for field F2 during the 1997/98 short rain growing season at Kifaru site.

Date	Days after emergence	Rainfall Amount	Rainfall intensity	Runon onto CB	Runoff from CB	Runoff from CB	Runoff from CB	Effective depth of water applied to WCIR plots	Effective depth of water applied to WC	Effective depth of water applied to FC
		(mm)	(mm)/hr	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
18/12/97	24	5.4	3.09	0.00	0.00	0.00	0.00	5.40	5.40	5.40
19/12/97	25	5.8	4.97	0.00	0.00	0.00	0.00	5.80	5.80	5.80
27/12/97	33	5.2	5.20	0.00	0.00	0.00	0.00	5.20	5.20	5.20
3/1/98	40	6.4	9.60	0.00	0.00	0.00	0.00	6.40	6.40	6.40
5/1/98	42	1.6	6.40	0.00	0.00	0.00	0.00	1.60	1.60	1.60
7/1/98	44	1.6	3.84	0.00	0.00	0.00	0.00	1.60	1.60	1.60
9/1/98	46	3.2	2.13	0.00	0.00	0.05	0.00	3.20	3.15	3.20
11/1/98	48	6.2	12.40	0.00	0.00	0.00	0.00	6.20	6.20	6.20
12/1/98	49	52.80	8.66	52.80	41.17	0.00	10.56	64.43	52.80	42.24
13/1/98	50	19.60	18.09	0.09	0.00	0.00	1.57	19.69	19.60	18.03
15/1/98	51	3.40	1.70	0.00	0.00	0.00	0.00	3.40	3.40	3.40
14/1/98	52	92.20	10.07	57.33	62.19	18.89	27.66	87.34	73.31	64.54
28/1/98	65	51.40	8.43	76.40	71.94	0.00	10.28	55.86	51.40	41.12
31/1/98	68	22.60	20.93	0.00	0.00	0.00	2.26	22.60	22.60	20.34
9/2/98	77	2.40	4.14	11.60	0.00	0.00	0.00	14.00	2.40	2.40
9/2/98	77	35.30	24.18	1.60	0.00	0.00	7.06	36.90	35.30	28.24
9/2/98	77	1.20	3.00	0.00	0.00	0.00	0.00	1.20	1.20	1.20
11/2/98	79	18.60	9.69	4.80	0.00	0.00	1.86	23.40	18.60	16.74
19/2/98	87	3.00	6.00	0.00	0.00	0.00	0.00	3.00	3.00	3.00
21/2/98	89	16.80	22.40	14.53	0.00	0.00	1.68	31.33	16.80	15.12
12/3/98	108	2.40	3.58	4.30	0.00	0.00	0.00	6.70	2.40	2.40
<b>Total</b>		<b>357.10</b>	<b>8.98</b>	<b>223.46</b>	<b>175.30</b>	<b>18.94</b>	<b>62.93</b>	<b>405.26</b>	<b>338.16</b>	<b>294.17</b>

**Appendix 2: Crop water requirement of Maize**

Daily crop water demand (ETc mm/day) of maize at Kifaru site during the 1997/98 short rainy season.

Date	Months				
	November	December	January	February	March
1		2.64	6.24	11.21	0.5
2		2.36	8.64	12.54	0.605
3		2.8	4.72	13.87	0.37
4		3.28	2.64	15.2	
5		1.84	2.48	14.06	
6		1.2	2.16	15.77	
7		2.96	3.36	10.68	
8		2.32	7.52	9.54	
9		2.68	7.2	7.86	
10		2.84	9.84	2.1	
11		2.12	4.4	3.78	
12		2.4	2.56	3.66	
13		1.88	2.8	3.72	
14		2	1.84	2.28	
15		1.08	2.8	10.5	
16		1.16	3.2	6.42	
17		2.08	7.52	3.66	
18		2.16	2.86	9.06	
19		10.4	5.06	2.1	
20		9.36	6.27	3.54	
21		12.24	13.09	10.44	
22		5.52	8.25	0.955	
23		5.2	6.71	0.76	
24	4.24	2.48	6.49	0.73	
25	4.36	4.64	3.85	0.545	
26	3.84	5.6	10.01	0.645	
27	5.48	6.4	9.9	0.68	
28	3.6	9.6	5.51	0.695	
29	1.84	4.32	6.84		
30	1.6	9.92	10.925		
31		2.24	9.12		

**Appendix 3: Soil moisture data**

Root zone soil moisture content (v/v%)

Days after planting	Treatments					
	Field F2			Field F1		
	FC	WC	WCIR	FC	WC	WCIR
18	27.83	29.07	28.97	24.89	25.49	24.89
29	26.36	30.53	32.72	20.84	22.61	21.92
41	20.42	22.58	19.63	14.16	14.01	14.73
53	23.77	29.69	29.47	16.73	19.39	22.53
66	34.68	43.14	42.97	28.42	29.70	30.62
77	28.65	34.14	34.75	14.56	15.76	16.46
89	27.91	33.98	35.53	30.87	31.85	33.63
101	25.11	27.29	31.00	21.05	20.45	25.66
111	22.63	25.59	28.00	21.93	23.13	26.37

#### Appendix 4: DMRT Tables for Root zone soil moisture content

Duncan's multiple range test on root zone soil moisture content means for field F1 during the growing period.

Treatment	Ranked order	
	Moisture content <sup>b</sup> (v/v%)	DNMRT <sup>a</sup>
WCIR	24.39	a
WC	22.46	ab
FC	21.51	b

<sup>a</sup> Any two means having a common letter are not different at  $p = 0.05$

<sup>b</sup> Means calculated from 24 no. of observations

Duncan's multiple range test on root zone soil moisture content means for field F2 during the growing period.

Treatment	Ranked order	
	Moisture content <sup>b</sup> (v/v%)	DNMRT <sup>a</sup>
WCIR	31.5	a
WC	30.7	a
FC	26.4	b

<sup>a</sup> Any two means having a common letter are not different at  $p = 0.05$

<sup>b</sup> Means calculated from 24 no. of observations.