INVESTIGATION OF IRRIGATION SYSTEM DESIGN AND OPERATIONAL RELATED FACTORS CONTRIBUTING TO LOW SUGARCANE PRODUCTION AT KILOMBERO SUGAR ESTATES

BY

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ABSTRACT

A study was conducted at Kilombero Sugar Company to investigate irrigation system design and operational related factors contributing to low sugarcane production at Msolwa estate.

Climatic, plant and soil factors were used for the calculation of seasonal and monthly crop water and irrigation requirements for different categories of cane planted in different dates and months and results compared with the actual performance of the irrigation system. Further evaluations of system performance were carried out using catch-can test data; number of operational irrigation and drainage structures and equipments; and drainage activities.

Sugarcane yield/water use relationship was investigated by comparison of climatic potential yields calculated using Thompson's (1976) production function and actual yields obtained from different fields. Irrigation Scheduling Information System (IRSIS) computer program was then used to evaluate irrigation actions of the past period using daily rainfall and decade ETo data.

The results showed that the average seasonal irrigation requirement is 28% of the crop water requirement. However the irrigation system is only capable of supplying 27% of the irrigation requirement due to poor maintenance of the system, non-replacement of worn out parts, old age of irrigation equipments and irrigating during day time only.

System performance evaluation results showed that the sprinkler nozzle operating pressure was very low ranging from 1.8 bar to 3.2 bar with a mean of 2.57 bar as compared to the designed pressure of 3.5 bar. This resulted into low values of CU, DU, and PELQ of 72, 59.7 and 55.5% respectively. These figures differed significantly from designed values at 1% level of significance. Water logging problems during the rainy season are indicative of a high degree of neglect of drainage activities over a large area of the estate.

The actual average seasonal sugarcane yield of 82 tonnes cane per hectare differed significantly from the calculated average climatic potential yield of the area of 116.1 tonnes cane per hectare. Regression analysis of the actual yield data with ETcrop gave a correlation coefficient of 0.4 showing that there is almost no linear correlation between the actual Msolwa yields and the amount of water transpired. The reason for this could be the failure of the irrigation system to fully meet moisture requirements of sugarcane.

Evaluation of 1993/94 irrigation schedules showed that the average irrigation depths were less than the average irrigation requirements resulting in low ETa values which, at 5% level of significance differed significantly from ETcrop. This was due to under-irrigation of the evaluated fields.

From the study it can be concluded that the current level of sugarcane production at Msolwa estate is very low and does not match with the climatic potential of the area. This could have been caused by, among other factors, an ineffective irrigation system which failed to supply the required amount of water due to poor operation and maintenance and failure to follow system design recommendations.

DECLARATION

I, KOSSA RUZEBELLE MNYIMVUA RAJABU, 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 been submitted in whole or in part, for a degree award in any other University.

Date 8 - 5 - 1997 Signature Rajabu

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DEDICATION

This dissertation is dedicated to my daughter, Hadija, through whose love and affection, I got encouragement to continue with the study.

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ABBREVIATIONS AND SYMBOLS

Symbol	Definition
AELQ	actual application efficiency of low quarter
Ar	average rate caught during irrigation duration
ASAE	American Society of Agricultural Engineers
av.	average
BAIL	Booker Agriculture International Limited
BD	bulk density
CEC	cation exchange capacity
CN	SCS curve number
CU	coefficient of uniformity
CV	coefficient of variation
Depl	Depletion
DU	distribution uniformity
ECe	electrical conductivity of the soil saturation extract
ECw	electrical conductivity of irrigation water
Eff.	efficiency
EPan	Class A Pan evaporation
ER	efficiency reduction
ET	evapotranspiration
ETa	actual evapotranspiration

ETcrop	potential crop evapotranspiration
ETm	maximum evapotranspiration
ETo	reference crop evapotranspiration
FAO	Food and Agriculture Organization
FC	soil moisture content at field capacity
GTZ	Deutsche Gessellschaft Für Technische Zusammenarbeit
ha	hectare
HSPA	Hawaiian Sugar Planters' Association
I	cumulative infiltration
ILACO	International Land Development Consultants
Inet	net irrigation requirement
Irr D	actual irrigation depth
ISSCT	International Society of Sugar Cane Technologists
I^t	infiltration rate at time t
kc	crop growth factor (crop coefficient)
KSC	Kilombero Sugar Company Limited
KSL	Kagera Sugar Limited
ky	yield response factor
LQ	low quarter catch
MALDC	Ministry of Agriculture, Livestock Development and Cooperatives
max	maximum

me	milliequivalent
min	minimum
MSE	Mtibwa Sugar Estates
MSIRI	Mauritius Sugar Industry Research Institute
p	depletion factor
Pav	average annual rainfall
Pdry	rainfall at 80% probability of exceedance
PELQ	potential application efficiency of low quarter
Pi	rainfall of period i
Pmax	maximum pressure
Pmin	minimum pressure
PPS	pressure pumping station
Pr.av	average pressure
Pwp	soil moisture content at permanent wilting point
q	measured average sprinkler discharge
RAM	readily available soil moisture in given soil depth
R_c	average rate of water caught
RH	relative humidity
R_{1q}	average low quarter rate caught
R_s	average rate applied through sprinklers
RWS	relative water supply
Sa	total available soil moisture

SACCAR	Southern African Centre for Cooperation in Agricultural Research
SAR	sodium adsorption ratio
SCS	Soil Conservation Service
s.d.	standard deviation
SMD	soil moisture deficit
S_1	lateral spacing
S_2	sprinkler spacing
Ta	set duration
TAM	total available soil moisture in given soil depth
tc/ha	tonnes cane per hectare
TLTS	Tate and Lyle Technical Services
TPC	Tanganyika Planting Company
USDA	United States Department of Agriculture
Va	actual volume of water
Vr	target volume of water, supply requirements
Xl	average low quarter depth caught
Ya	actual harvested yield
Ym	maximum possible yield
ZSAES	Zimbabwe Sugar Association Experiment Station

1. INTRODUCTION

The economy of Tanzania is highly dependent on agriculture. Its government has therefore accorded the highest priority to the development of the agricultural sector. Agricultural production is obviously dependent on the weather which in many parts of Tanzania is either unreliable or consistently dry. Rainfed agriculture is therefore associated with risks and limited production. Fortunately however, Tanzania is endowed with vast untapped water resources which could be developed for irrigation.

During the last couple of decades a number of studies have identified areas totalling some 900 thousand hectares that have significant potential for irrigated agriculture (Chapman, 1990). When this figure is compared with the estimated 135 thousand hectares that are currently irrigated (either on large scale state/commercial farms or on small scale traditional or village schemes) it becomes clear that great opportunities remain for continuing irrigation development (Riddell, 1989).

However the estimated potential assumes that water as a resource is available on an ad lib basis. Contrary to this belief it has been found that water levels in many parts of the world are low and getting lower (SPORE, 1995). Rivers have retreated from their banks, lakes are shrinking from their former shores and boreholes are pierced even deeper to tap falling water tables.

Public sector irrigation development in Tanzania has followed three different paths:

(i) the construction of irrigated estates for parastatal operation, e.g. Dakawa, Mbarali, and Kilombero;

(ii) the construction of modern style schemes for smallholder occupation and operation, e.g. Lower Moshi, Ndungu, and Majengo; and

(iii) the rehabilitation or upgrading of traditional irrigation schemes e.g. Mombo, and Musa Mwinjanga. Nevertheless the performance of most irrigation schemes, whatever the category, has been below expectations (Chapman, 1990).

In mainland Tanzania, sugar industry consists of five sugar estates owned by four companies. The companies are Kilombero Sugar Company Limited (KSC) and Mtibwa Sugar Estates (MSE) in Morogoro Region, Kagera Sugar Limited (KSL) in Kagera Region and Tanganyika Planting Company

(TPC) in Kilimanjaro Region.

The Kilombero Sugar Company Limited is one of the parastatal establishments producing much of the country's sugar. KSC is divided into two estates, Msolwa and Ruembe, each with its own factory. However, at Msolwa estate, available records show that sugarcane production per hectare had declined steadily from 117.2 tonnes in 1973 to 62.4 tonnes in 1990 (Msechu, 1992). The production in 1990 was thus only 53% of that of 1973. These production figures are far below the National Maximum Yield Potential which is estimated at 136 tonnes per hectare per annum (BAIL, 1977). The decline in sugarcane yields at Msolwa estate during 1980s (Appendices 1a and 1b) deviated from world wide increase in yield levels as a result of more intensive cultivation and overall improvement in agronomic practices (Kunda, 1996). An estimated 41 million tonnes of sugarcane were harvested annually in Africa South of the Sahara of which about 50% of the cane output were grown under modern irrigation mainly under industrial - style management (FAO, 1986). Annual yields on such estates were in the region of 100 to 125 tonnes cane/hectare.

Low sugarcane production can be as a result of unfavourable climatic conditions, crop diseases, poor sugarcane husbandry practices or ineffective irrigation systems. However, in all the sugarcane growing areas in the country, the average yield losses caused by diseases is estimated at only 8 - 15% (MALDC, 1991) and climatic conditions generally favour the growth of sugarcane (BAIL, 1977). As such, the observed low sugarcane yields can only be a result of poor sugarcane husbandry practices or ineffective irrigation systems or both.

A survey done on sugarcane production in existing industry in Tanzania shows that sugarcane estates in the country operate at an overall efficiency of about 80% (BAIL, 1977). Thus, under the present level of management, an annual yield of 108.8 tonnes per hectare could be expected if the full moisture requirements of the crop are satisfied. However, records from 1984 to 1994 show that the average sugarcane yields per hectare per annum in irrigated fields at Msolwa estate is 71.33 tonnes as compared to 71.09 tonnes for rainfed areas (estate records). This insignificant difference in sugarcane yields between irrigated and rainfed areas and the general decline of sugarcane yields is thus suspected to be mainly caused by an ineffective irrigation system as evidenced by signs of moisture stress on the growing cane. MALDC (1991) observed that seasonal droughts and shortages in water supply for irrigation have been responsible for some losses in sugarcane yields and quality. Rainfall is usually erratic, and its monthly distribution very irregular. Hence, when use of irrigation water is not optimal because of frequent downtime or poor supervision and failure to follow design recommendations, annual sugarcane production must be liable to drop.

It is against this background that a need to conduct a thorough study to investigate Msolwa estate irrigation system design and operational factors contributing to declining sugarcane yields is manifested.

The main objective of the study was therefore to investigate irrigation system design and operational related factors contributing to low sugarcane production at Msolwa estate.

The specific objectives were:-

(1) To find out if irrigation is really necessary for commercial sugarcane production at Msolwa estate;

(2) To conduct measurements that would facilitate the calculation of irrigation efficiencies, infiltration characteristics, available soil water and irrigation scheduling parameters;

(3) To compare the present state of system operation with what was originally designed for;

(4) To evaluate the adequacy of irrigation and establish the relationship between water use and crop yield; and

(5) To set out optimal irrigation schedules as per prevailing conditions.

2. LITERATURE REVIEW

2.1 Sugarcane agronomy

2.1.1 Introduction

The present area under sugarcane *(Saccharum officinarum)* is 13 million ha with a total commercial production of about 700 million tonnes of cane per year (Doorenbos and Kassam, 1986). Most of the rainfed and irrigated commercial sugarcane is grown between 35^0 North and South of the Equator.

2.1.2 Climate

Sugarcane is considered essentially as a tropical plant and temperature, light and moisture are the principal factors that control cane growth (Lakshmikantham, 1983). Humbert (1983) and Doorenbos and Kassam (1986) reported that the crop flourishes under a long, warm growing season with a high incidence of radiation and adequate moisture, followed by a dry, sunny and fairy cool ripening and harvesting period.

Optimum temperature for sugarcane growth ranges between 22^{0}C and 30^{0}C (Doorenbos and Kassam 1986). In Tanzania optimum growth is achieved with mean daily temperatures between 24°C and 30°C (MALDC, 1991).

2.1.3. Soil

Doorenbos and Kassam (1986) reported that sugarcane does not require a special type of soil. The best soils for sugarcane are those that are more than 1 m deep, well aerated with ground water deeper than 1.5 - 2.0 m. However, sugarcane is relatively tolerant to periodic high water tables and Oxygen deficit (Doorenbos et al., 1979; Humbert, 1983).

In Tanzania, sugarcane plantations are found in lowland areas in the Coast, Lake Victoria Basin and river valleys in which typical soil types are alluvial/colluvial or sandy loam to clay which are deep and well aerated (MALDC, 1991). The optimum soil pH is 6.5 but sugarcane will grow in soils with pH in the range of 5 to 8.5 (Doorenbos et al., 1979; Doorenbos and Kassam, 1986; Fute, 1992).

2.1.4 Growth cycle

Generally speaking sugarcane is planted in the spring and the normal length of the total growing period varies between 9 to 24 months (Lakshmikantham, 1983), but it is generally 15 to 16 months (Doorenbos and Kassam, 1986). Lakshmikantham (1983) reported that in Cuba and West Indies the crop is harvested from January to June. In countries in South and Central America crops of 12 to 18 months age are harvested in the period November-December to April-May. Countries to the South of the Equator including Tanzania grow canes which are generally harvested in the period of June to December. Countries like Hawaii harvest cane throughout the year and the crops are about 24 months old at harvest (International Sugar Journal, 1940).

Plant (first) crop is normally followed by two to four ratoon crops, and in certain cases up to a maximum of eight crops are taken, each taking about one year to mature.

2.1.5 Water requirements of sugarcane

Water is the lifeblood of agriculture (Humbert, 1983). Yields of cane and sugar are the highest where adequate attention has been given to the water requirements. Sugarcane growth is stimulated by moderate quantities of soil moisture and retarded by either excessive or deficient amounts. Adequate available moisture throughout the growing period is thus important for obtaining maximum yields because vegetative growth including cane growth is directly proportional to the water transpired (Nickell, 1968; Clements et al., 1952; Thompson, 1976).

Depending on climate and duration of the crop, water requirements (ETm) of sugarcane are 1500 mm to 2500 mm (Thompson, 1976; Doorenbos and Kassam, 1986; Daka, 1988; MALDC, 1991). Studies in Hawaii and confirmed in Mexico indicate that the daily water requirements of sugarcane vary from 9 mm per day in the hot, dry summer months to 2.5 mm per day in the cold, cloudy winter months (Lakshmikantham, 1983).

Lysimeter data for crops of the same variety (NCo 376) in Shakaskraal (South Africa) indicated that the water requirement varied from 1201 to 1496 mm for plantcane of 304 and 362 crop days respectively (Thompson, 1976).

2.1.6 Irrigation of sugarcane

Irrigation of sugarcane falls roughly into three different categories each being associated with distribution of rainfall and quantity of water available. The first is total watering of the crop. Under this category water is applied to the field throughout the growth of the crop. The second category is particular period watering whereby a limited water supply can often be put to good use to establish or maintain crops during a normal, dry seasonal period. Random watering is the last category. This is determined by seasonal conditions. Whenever there are periods of drought, the irrigation of cane takes place.

Sugarcane in various parts of the world is being irrigated by means of surface, sprinkler and drip irrigation techniques (Barnes, 1964; Lakshmikantham, 1983). Furrow irrigation in the cane row and in the inter-row is the most commonly used surface irrigation method and is particularly effective for early plant crop (Doorenbos and Kassam, 1986). Basin and border irrigation methods are generally not well suited to sugarcane (Thompson, 1977).

A recent trend is in the direction of sprinkler and drip irrigation. Steep topography, variable slopes, different soil types, paucity of available water and the need to apply relatively small amounts of water per application all favour the choice of overhead spray irrigation. More recently, the scarcity of labour has led to the installation of solid set, semi-solid set and dragline systems (Thompson, 1977). However, prevailing winds of more than 5 m/s will limit the usefulness of spray guns when used in sprinkler irrigation (Doorenbos and Kassam, 1986).

Experiments to compare the effects of surface, sprinkler and drip irrigation methods have been conducted in Mauritius (MSIRI, 1975), Hawaii, Jamaica, Taiwan and South Africa. Suggestions that drip irrigation might produce yields in excess of those obtainable by other methods have not been substantiated in South Africa (Thompson, 1977). Overhead and furrow irrigations gave similar yields in Hawaii, Jamaica and Taiwan (Lakshmikantham, 1983).

The response of sugarcane to irrigation is greater during the vegetative and early yield formation periods than during the later part of yield formation, when active leaf area is declining and the crop is less able to respond to sunshine.

The overall response to irrigation in South Africa (Cleasby et al., 1965) indicated that sugarcane yields increased in proportion to the water applied. The overall relationship was significantly linear ($r = 0.9484$) and indicated an average response of one tonne cane per acre per inch of irrigation water applied.

In Mauritius, the average response was 0.21 tonnes of cane per centimetre of water applied (MSIRI, 1962). In Puerto Rico 37.14 tonnes of more cane per hectare was realised over unirrigated cane and in Taiwan, an additional yield of 1.2 metric tonnes of sugar per hectare was realised by irrigating sugarcane (Rosenfield (1956); Yeung et al. (1952) as cited by Lakshmikantham, 1983). Application of excess water is not conducive to optimum yields. From Hawaii it was reported that a sizable amount of dead cane was found in plots receiving excess water (HSPA, 1961).

Early scientific methods of irrigation control of sugarcane were based on soil moisture requirements (Thompson, 1977). The use of tensiometers was succeeded more generally by the use of gypsum blocks (Cornellison and Humbert, 1960). In more recent times, however, an agrometeorological approach has been adopted (Thompson, 1960) and the U.S Weather Bureau Class A Pan is now most commonly used to assess crop water requirements (Thompson and Collings; (1963), Thompson et al. (1963)) as cited by Thompson, 1977; Cackett, 1984). The technique involves the carrying out of a soil moisture profit and loss account for each field on a farm or estate, taking rainfall, irrigation, evapotranspiration and the soil moisture reservoir into consideration.

The advantages of the system are that the approximate water requirements of each field can be assessed each day; irrigation priorities for all fields can be determined; an irrigation program (subject to revision only in the event of significant amounts of rain falling) can be arranged for at least a week in advance; and decisions concerning the starting and stopping of irrigation can be made logically (Thompson, 1977).

2.1.7 Drainage

Drainage is as important as irrigation to sugarcane. While sugarcane loves moving water, it cannot withstand stagnant water (Humbert, 1983). Water stagnation impairs root function and consequently cane yields are lowered. The effects of water stagnation depend upon time of onset as also the duration of water logging.

The simplest method of draining excess water and which is largely followed in Tanzania is to dig open channels in a field. In several countries where cane is grown in heavy clay soils and clay loam soils, tile and mole drains are usually set up under ground respectively (Humbert,1983).

2.1.8 Soil water availability and uptake

Thompson (1976) and Ellis (1984) describe factors which affect the availability of soil water to the crop as:

- the depth of the soil profile;
- the soil moisture release characteristics of the soil;
- the moisture holding capacity of the soil;
- the rooting depth of the crop;
- the water intake rate of the soil; and
- the evaporative demand of the atmosphere.

Other factors such as internal drainage characteristics (permeability), salinity and sodicity are also involved.

(i) Depth of the soil profile

To have good crop growth on a relatively shallow soil, irrigation would have to be practised frequently. This is both laborious and costly and as such soils selected for irrigated sugarcane production should preferably be more than one metre deep (Thompson, 1976; Doorenbos et al., 1979;).

In a deep soil (> 1 m) approximately 40% of the sugarcane water requirements will be extracted from the top 25% of the soil (Ellis, 1984). A shallow soil or one with an impervious layer will result in a more superficial rooting habit with high rooting density in a shallow soil volume.

(ii) Soil moisture release characteristics

Soils differ in the strength with which they retain moisture between the upper and lower limits of available moisture (Hill, 1964, 1965; Johnston, 1973; Ellis, 1984). These differences are primarily a function of soil texture. Hill (1964) made observations on various soils in South Africa and reported that at low tensions sandy soils can provide more water more quickly at the soil-root interface than clay, whereas at higher tensions the reverse occurs.

(iii) Moisture holding capacity of the soil

The amount of water that can be held by the soil at field capacity and permanent wilting point depends very much on its texture (Jensen, 1983; Ellis, 1984; James, 1988). Cackett (1984) reported that for any given volume, a soil with a high clay content will have more particles with a greater surface area and a higher proportion of fine pores than a sandier soil. Consequently, a clay soil will retain more water and retain it more tightly, as much of the water will be held as hygroscopic water on the particle surface.

It should, however, be noted that besides soil texture, the bulk density and organic matter of a soil can raise its moisture holding capacity (Ellis, 1984).

Table 2.1: Water extraction pattern by sugarcane roots in a deep soil

Depth (cm)	Water extracted (%)
0 - 30	40
30 - 60	30
60 - 90	20
> 90	10

Source: Ellis (1984)

(iv) Rooting depth of the crop

Providing that soil depth is not a limiting factor, rooting depth varies with soil type, moisture distribution and aeration (Lee and Weller, 1927; Baver et al., 1962). Sugarcane trials carried out on heavy clay soils in a sugar estate at Nakambala (Daka, 1988) revealed that deeper rooting was observed under a wetter profile as it gives an easy way to root penetration as compared to a drier one. The results also showed that root development was progressive with time. The extent of root development is however limited by the workability of the soil.

Lee and Weller (1927) found that in irrigated cane with deep furrows, more than 50% of the roots occur in the upper 20 centimetres of the soil, and that more than 85% of the roots occur above the 70 centimetre depth. Studies by Van Dillewijn (1952) showed that with all cane approximately 7 months old, at least 82% of the total number of the roots were present in the upper 41 centimetres of the soil.

Field observations showed that the average root depth of a fully grown cane at Msolwa estate is 75 cm (Table 2.2). This final root depth is reached after 5½ and 3½ months for plantcane and ratoons respectively. It is assumed that root growth goes linearly with time.

(v) Water intake rate of the soil

Infiltration rate quantifies the rate of water acceptance by a soil and is an important factor when considering irrigation rates in both surface and sprinkler irrigation systems (Hill, 1964; Jensen, 1983; Ellis, 1984; James, 1988). Hill (1964) found that when the soil is dry water penetration is rapid initially but declines with time and tends towards a constant rate called the basic infiltration rate, which is determined by soil properties such as texture, structure and type of clay (Table 2.3)

(vi) The evaporative demand of the atmosphere

This depends on the prevailing climatic factors such as radiation, temperature, relative humidity and wind. Evapotranspiration will be greater on sunny days due to more radiant energy made available to the crop than on cloudy days. Higher temperatures, low relative humidity values of air and strong winds can all increase the rate of water loss from the soil by evapotranspiration.

Thompson (1976) reported that for full canopied sugarcane in Northern areas of South African cane belt, the average daily potential crop evapotranspiration varied from a maximum of 7.6 mm in January to a minimum of 3.3 mm in July due to differences in temperature in the two months.

Table 2.2: Relationship between age of cane and rooting depth at Msolwa estate

Age (months)	Rooting depth (cm)	
	Plant cane	Ratoon cane
0 - 1.5	25	25
2	25	37.5
2.5	25	50
3	33	62.5
3.5	42	75
4	50	75
4.5	58	75
5	67	75
5.5	75	75

Source: Povel (1976)

Table 2.3: Typical infiltration rates of soils

Soil texture	Inf. rate (mm/h)	Rating
Coarse sand	> 20	Rapid
Sandy loam	15 - 20	Mod. rapid
Sandy clay loam	5 - 15	Moderate
Sandy clay	5 - 10	Slow
Clay	5	Very slow

Source: Ellis (1984)

2.2 Potential crop evapotranspiration (ETcrop)

Evapotranspiration (ET) represents the quantity of water which must be applied at suitable intervals to maintain a suitable soil water balance favourable to plant growth. The importance of this concept in sugarcane production is evidenced by several ET studies using field-installed lysimeters (Campbell et al., 1959; Chang, 1961; Cowan and Innes, 1956; Thompson et al.,1963).

The loss of water by evapotranspiration from a field of sugarcane can best be explained by dividing the annual growth cycle into five distinct stages (Thompson, 1976;

Cackett, 1984) as follows:

Stage 1 - Fallow land or bare soil

This stage includes uncropped land that may be clean or weedy, newly planted land before crop emergence, and recently harvested fields before leaf emergence of the ratoon.

Water loss from bare soil is influenced by (a) the evaporative demand of the atmosphere; (b) the frequency of wetting, with loss being reduced when the surface is dry; and (c) the presence of weeds, which can increase water loss substantially (Benninga (1976) as cited by Thompson, 1976).

Thompson (1976) observed that water loss from a bare soil varies also between soil types, with clay soils losing more surface moisture than sandy soils. Results from lysimeter experiments at Shakaskraal and Pongola (South Africa) (Thompson, 1976) indicated that evaporation from bare wet soil was 39% of Class A Pan evaporation. Lysimeter data obtained in Mauritius (Hardy, 1966) suggest that after harvest ET should be estimated as 40% of pan evaporation.

Stage 2 - Partial canopy

Evapotranspiration increases progressively as the crop foliage develops and intercepts more radiant energy, and as root growth expands through the soil profile to enable the crop to exploit a greater volume of soil moisture.

Results for the plant and first ratoon crops from the lysimeter experiments at Shakaskraal and Pongola (Thompson, 1976) where canopy development was measured by means of vertical sightings (Cackett, 1964) indicated that ET increased from 39% in the absence of any crop foliage to 100% of Class A Pan evaporation when the estimate of canopy formation was 88%.

Other studies by Blaney and Criddle (1950) and Penman (1948) on evapotranspiration and particularly the investigation by Chang (1961) and Thompson et al. (1963) on water requirements of sugarcane have suggested the use of (ET/EPan) ratio as a basis for estimating potential evapotranspiration for sugarcane irrigation.

Findings by Campbell et al. (1959) indicated that the crop cycle of sugarcane may be conveniently divided into four irrigation periods as shown in table 2.4 in which different ET/EPan ratios apply for estimating ETcrop.

Factors relating ET and crop growth stage developed at Msolwa estate (Povel, 1976) are included in appendix 5.

Table 2.4: Various ET/EPan ratios for estimating ET at various stages of growth in the crop cycle

Period in crop use	Age (months)	ET/EPan
1. Partial canopy		
Planting to:		
1/4 full canopy	0.0 - 2.5	0.4
1/4 to 1/2 full canopy	2.5 - 3.5	0.6
1/2 to 3/4 full canopy	3.5 - 4.5	0.8
3/4 to full canopy	4.5 - 6.0	0.9
2. Peak use	6.0 - 17.0	1.0
3. Early senescence	17.0 - 22.0	0.7
4. Ripening	22.0 - 24.0	No irrigation

Source: Campbell et al. (1959)

Stage 3 - Full canopy (unlodged cane)

Evapotranspiration during this stage of growth consists almost entirely of transpiration, with evaporation from the soil under the crop comprising less than 5% of total water loss (Cackett, 1984). This is the stage when all available radiation is intercepted by the crop so that transpiration loss is at a maximum, and no matter how much taller the crop grows it cannot use more water. Thus full canopy represents the period of maximum soil water loss and the period of peak water demand by the crop.

Work done in many countries on sugarcane has shown that water loss during the full canopy period is very closely related to water loss from Class A evaporation pan. It was shown in Jamaica (Cowan and Innes (1956) as cited by Kaiza, 1988) that evaporation from an open water surface placed beneath the crop canopy was only 10% of that from a freely exposed surface. Taking into account the mulching effect which further inhibits evaporation from the soil surface, it may reasonably be assumed that evaporation on average comprises less than 5% of ET during the period of full canopy (Thompson, 1976).

Monthly data obtained by means of non-weighing lysimeters at Shakaskraal and Tongaat (Thompson, 1965; Thompson et al. 1963) and calculated figures for Hawaii (Chang, 1961) and Mauritius (Hardy, 1966) show that a mean ET/Epan ratio close to 1.0 has been obtained under a wide range of climate and with several different varieties of sugarcane.

Even on a daily basis during the period of full canopy in a plant crop at Pongola, the ET/Epan ratio was satisfactorily and consistently close to 1.0 (South African Sugar Association Experiment Station, 1968).

Stage 4 - Lodged cane

Research has shown that there is significant reduction in evapotranspiration following lodging, and that this effect persist for up to 3 months after the crop has fallen (Cackett, 1984). The extent of this reduction depends on whether lodging is total or only partial, and it is due to a reduction in leaf canopy and exposure to radiation of dead leaves and stalks which do not transpire.

Thompson (1976) reported that lysimeter experiments conducted at Pongola showed 25% reduction in consumptive use of water caused by lodging of full canopied sugarcane. Cackett (1984) pointed that the irrigation demand of a lodged cane could fall to about 80% of the maximum demand of an upright cane at full canopy.

Stage 5 - The ripening period

During this stage, in commercial fields, it is deliberately intended that crops should have an inadequate supply of water either to ensure at harvest that the tractors and trailers do not cause unnecessary soil compaction, or to slow down growth and thus increase the sucrose content of the stalks (Thompson, 1976; Cackett, 1984; Kaiza, 1988). Drying-off thus represents a reduction of water use during the pre-harvest, ripening period, because the declining moisture status of the soil leads to reduced moisture availability and reduced transpiration rates.

Thus the pattern of water use by sugarcane is a change from 40% of pan evaporation after harvest to 100% at full canopy, and thereafter it remains constant at this peak level unless; (a) the transpiring surface is materially altered, which happens after lodging; and (b) soil moisture availability is restricted, which occurs during the drying-off period.

During the pre-canopy period, crop water use can be estimated by deriving alternate values in the range from 40% to 100% of pan evaporation. The percentage of pan evaporation that is used at any particular growth stage is known as the *pan factor* or *crop factor*, and it is normally expressed as a fraction of pan evaporation rather than as a percentage. Thus crop factors vary from 0.4 to 1.0 in accordance with crop canopy changes, and for practical purposes the change in water use over this range is assumed to be linear.

2.3 Water supply and crop yield

Water is essential for crop production and best use of available water must be made for efficient crop production and high yields. This requires a proper understanding of the effect of water on crop growth and yield under different growing conditions.

The relationship between crop yield and water supply can be determined when crop water requirements and crop water deficits, on the one hand, and maximum and actual crop yield on the other can be quantified (Doorenbos et al., 1979). Water deficits in crops, and the resulting water stress on the plant, have an effect on crop ET and crop yield. Water stress in the plant can be quantified by the rate of actual evapotranspiration (ETa) in relation to the rate of maximum evapotranspiration (ETm) (Doorenbos and Kassam, 1986; Raes et al., 1988). When crop water requirements are fully met from the available water supply then ETa = ETm; when the supply is insufficient, ETa < ETm.

In order to quantify the effect of water stress Doorenbos and Kassam (1986) came out with the following relationship between relative yield decrease and relative ET deficit:

$$(1 - Ya/Ym) = ky * (1 - ETa/ETm) \tag{1}$$

where,

Ya = actual harvested yield

Ym = maximum harvested yield

ky = yield response factor

ETa = actual evapotranspiration

ETm = maximum evapotranspiration

The relationship refers to high producing varieties, well adapted to the growing environment, growing in large fields where optimum agronomic and irrigation practices, including adequate input supply, except for water are provided. This is so because the relationship is also affected by other factors, such as crop variety, fertilizer, salinity, pests and diseases, and agronomic practices.

2.3.1 Sugarcane yield/water use relationship

Thompson (1977) reported that the accumulated results of irrigation experiments had, by 1968 led to the conclusion that a linear relationship between crop water use and sugarcane yield might exist. After studying results of various experiments, he found that the mean yields likely to be obtained under irrigated conditions in South Africa could be estimated as follows:

$$Y = EPan * 0.09 * 0.7 \qquad (2)$$

where,

Y = expected mean annual yields (tonnes cane (tc)/ha)

EPan = (mean annual Class A Pan evaporation (mm))* 0.8

- the factor 0.8 allows for the periods of incomplete canopy, fallow periods, drying off periods and possible differences between ET from a fully canopied sugarcane crop and Class A Pan evaporation;
- the factor 0.09 represents the target of 9 tc/ha per 100 mm EPan which has been obtained experimentally; and

- the factor 0.7 represents the 70% mean likely grower performance in relation to experimental results. In Tanzania this factor is 0.8 (BAIL, 1977).

However, a general and useful relationship between cane yields and consumptive use of water requires inclusion of data from various localities in the sugarcane growing world in the statistical analysis. Thompson (1976) compiled results of experiments with sugarcane, where different amounts of water were applied by various plots in a number of countries (there were 91 sets of data for ETcrop and tonnes cane per hectare). The results are shown in appendix 6. Using the compiled sets of data he came up with the following linear regression equation for tonnes of cane:

$$Y = 9.69 * (ETcrop/100) - 2.4 \qquad (3)$$

where,

Y = yield (tonnes cane (tc)/hectare)

ETcrop = potential crop evapotranspiration (mm)

The correlation coefficient (r) was 0.95 and there was no significant evidence of deviation from linearity. The standard error of an estimate of yield was ± 15.5 tc/ha.

2.4 Performance evaluation

2.4.1 Introduction

In the past, increases in agricultural production have come about through expansion of land under cultivation, crop intensification and yield improvements. There are signs, however that water will become a limiting factor in all the three methods of expansion (Marealle, 1994). In the face of rapid population growth, irrigation will play an important role in the effort to increase and sustain food and cash crop production. Effective crop production under irrigation requires adequate management and efficient use of irrigation water, particularly in poorer countries, where the greatest potential for increasing crop production is often to be found in irrigated agriculture (FAO, 1986). However, many major irrigation projects in Africa South of the Sahara have shown serious operational and maintenance problems. Main causes of these problems are weak management, lack of qualified and trained technical personnel, competition from the many other activities for which the institutions are responsible and lack of funds (FAO, 1986). Projects tend not to have adequate facilities to maintain operation and maintenance of equipments.

The generally short-sighted approach to project operation and maintenance has caused many systems to deteriorate to the point where complete rehabilitation has become necessary (FAO, 1986). Consequently there has been a noticeable interest in studying existing irrigation schemes in order to identify any areas needing improvement.

2.4.2 Performance of irrigation systems

Performance of any irrigation system can be defined as the degree of achievement of the system objectives which can best be distinguished as 'output', 'impact' and 'management' objectives (Manor, 1990). The output objectives are directly related to the functioning of the irrigation system and can be measured with reference to the maximum utilization of the available water resources, reducing waste to a minimum and meeting the water requirement of a given cropping pattern. Impact objectives are more direct and have long-term implications for agriculture. Management objectives can be measured with reference to among other things, equity, adequacy and dependability of water delivery.

Abernethy (1991), gives various reasons for measuring schemes' performance. They include internal and external reasons to the system. The internal reasons are those whereby, those who operate and manage the system monitor its performance so that they can better identify any area needing improvement whereas the external reasons are those in which people who are not direct participants in the irrigation system want to know how well it performs so as to verify the success of the system.

Manor and Chambouleyron (1991), discuss important technical indicators to be considered while evaluating performance of irrigation schemes. These are: (a) productivity; (b) irrigated area ratio; (c) irrigation efficiency; and (d) water delivery performance.

Productivity is measured in terms of yield per unit area or yield per unit volume of water. Any irrigation scheme should strive to attain maximum production. Irrigated area ratio is measured in terms of the area irrigated. Once an irrigation scheme is constructed, it is desirable that its area be irrigated by at least 100%.

The purpose of measuring irrigation efficiency is to estimate water losses which take place during the irrigation process. A well performing irrigation scheme maintains irrigation efficiencies well above recommended values. Water delivery performance refers to whether irrigation water is distributed among farmers uniformly (equity), and in required amounts (adequacy). Water delivery performance has a strong influence on the productivity of any irrigation scheme (Oad and Sampath, 1991).

Several other researchers have proposed more performance measures (Oad and Sampath, 1991; Abernethy, 1986). Of these measures, dependability of water, uniformity of distribution, durability or sustainability of the system and cost have been cited.

Evaluation of any irrigation system is the analysis of that system based on the measurements taken in the field under the conditions and practices normally used including also on-site studies of possible modifications (Merriam and Keller, 1978). Evaluations involve measuring conditions at one or more points in a field selected to be representative.

The principal objective of evaluating an irrigation system is to identify alternatives that may be both effective and feasible in improving the system's performance (James, 1988). Oad and Marconick (1989) as cited by Marealle (1994) described two main methods used in studies to assess the performance of irrigated agriculture in several developing countries. These were diagnostic analysis and rapid appraisal. Diagnostic analysis was characterized by long term collection of quantitative field data mainly at the farm level. Rapid appraisal studies involved collection of mainly qualitative data from all levels of the system and sought to provide and analyze information as quickly and cheaply as possible, in order to improve the system performance. In this study, both output objectives and technical performance indicators were evaluated by using diagnostic analysis techniques.

3. METHODOLOGY

3.1 Description of the study area

3.1.1 Location

The Kilombero Sugar Estates and factories are located in the Msolwa and Lower Ruembe valleys (Figs. 2 and 3) between latitudes 7°30′ and 7°50′ South and longitudes 36°50′ and 37°10′ East in Morogoro Region of Tanzania (Fig. 1).

The altitude of the estates is around 300 m and most of the land slopes gradually from West to South East with gradients generally less than 0.5%.

3.1.2 Climate

3.1.2.1 Rainfall and evaporation

There are eight rainfall measuring stations at Msolwa estate. Records have been maintained since 1961. The mean annual rainfall over the 35 year period is 1347 mm. Annual rainfall ranged from a low of 885 mm in 1969 to a high of 1998 mm in 1979 ; the variation coefficient of annual rainfall is 20%.

The mean monthly rainfalls presented in appendix 2 indicate pronounced dry and wet seasons. The months of June through October have a mean monthly rainfall of 21.3 mm as compared to the months of November through May which have a mean monthly rainfall of 177.3 mm. Whilst the end of the rains is sharply defined (May), the onset of the rains varies from year to year.

The average annual evaporation over 34 years is 1858.5 mm, and both the annual and monthly variation coefficients of the data are low (Appendix 3). Pan evaporation gives a valuable indication of the yield potential of an area because it relates to potential evapotranspiration.

The moisture deficits calculated using average evaporation and rainfall data are presented in figure 4. Significant moisture deficits are evident in the months of June to December. The annual total moisture deficit is of the order of 511 mm. The crop moisture requirements are generally satisfied by rainfall between the months of January and April. Irrigation is required to maximize growth during the remainder of the year and to allow planting operation to take place in the dry months.

3.1.2.2 Temperature and sunshine hours

The temperature regime presented in appendix 4 is very favourable for cane growth. Cane growth and stalk elongation will be greatly favoured by the temperatures in October through April, and the low mean temperatures during May to September will significantly improve juice quality.

The annual sunshine hours of over 2200 are very satisfactory for good cane growth.

The mean climatological data of the study area are presented in appendix 4.

3.1.3 Geology and soils

The valleys of the Msolwa and Ruembe rivers are part of the rift valley system found throughout East Africa. Along the Western margin of the Kilombero Estates the hilly and mountainous terrain of central Tanzania is separated abruptly by a North-South fault system from the valley to the East. The raised block to the West which constitutes the Gologolo and Migomberama mountains consists of igneous rocks of the Usagaran system of the Basement Complex.

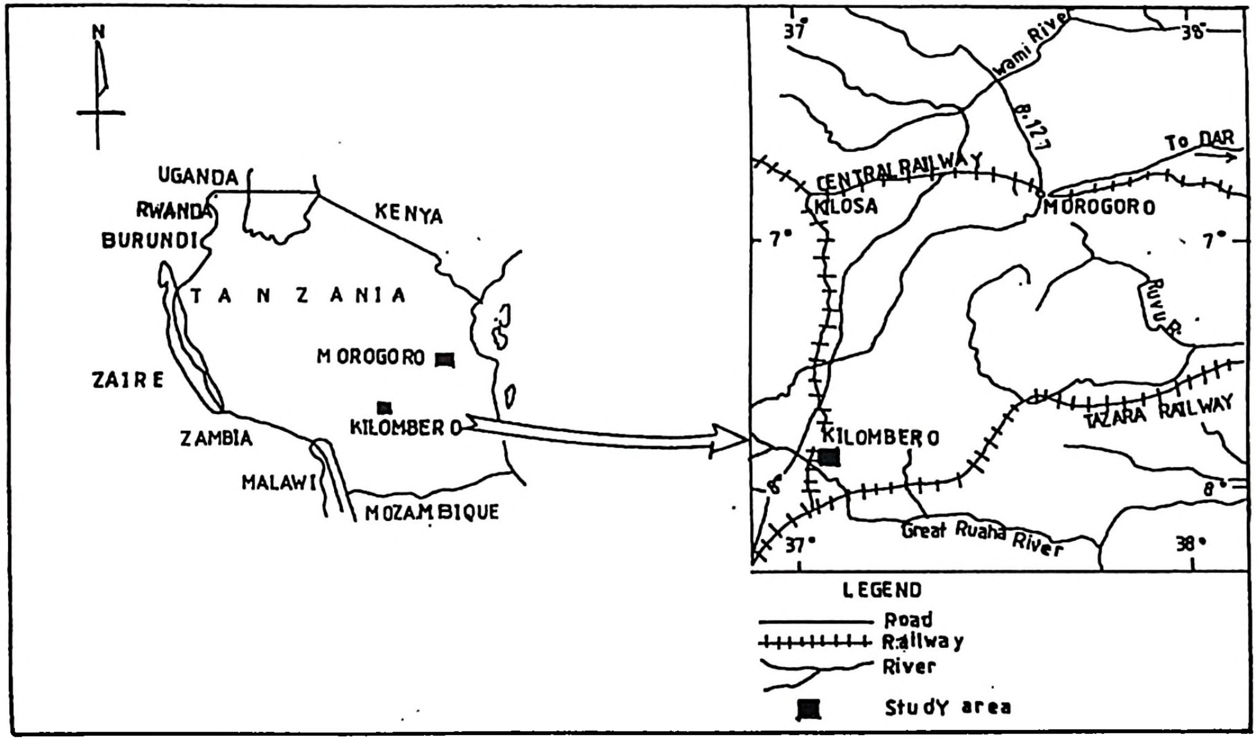

Figure 1: Map showing the location of the study area

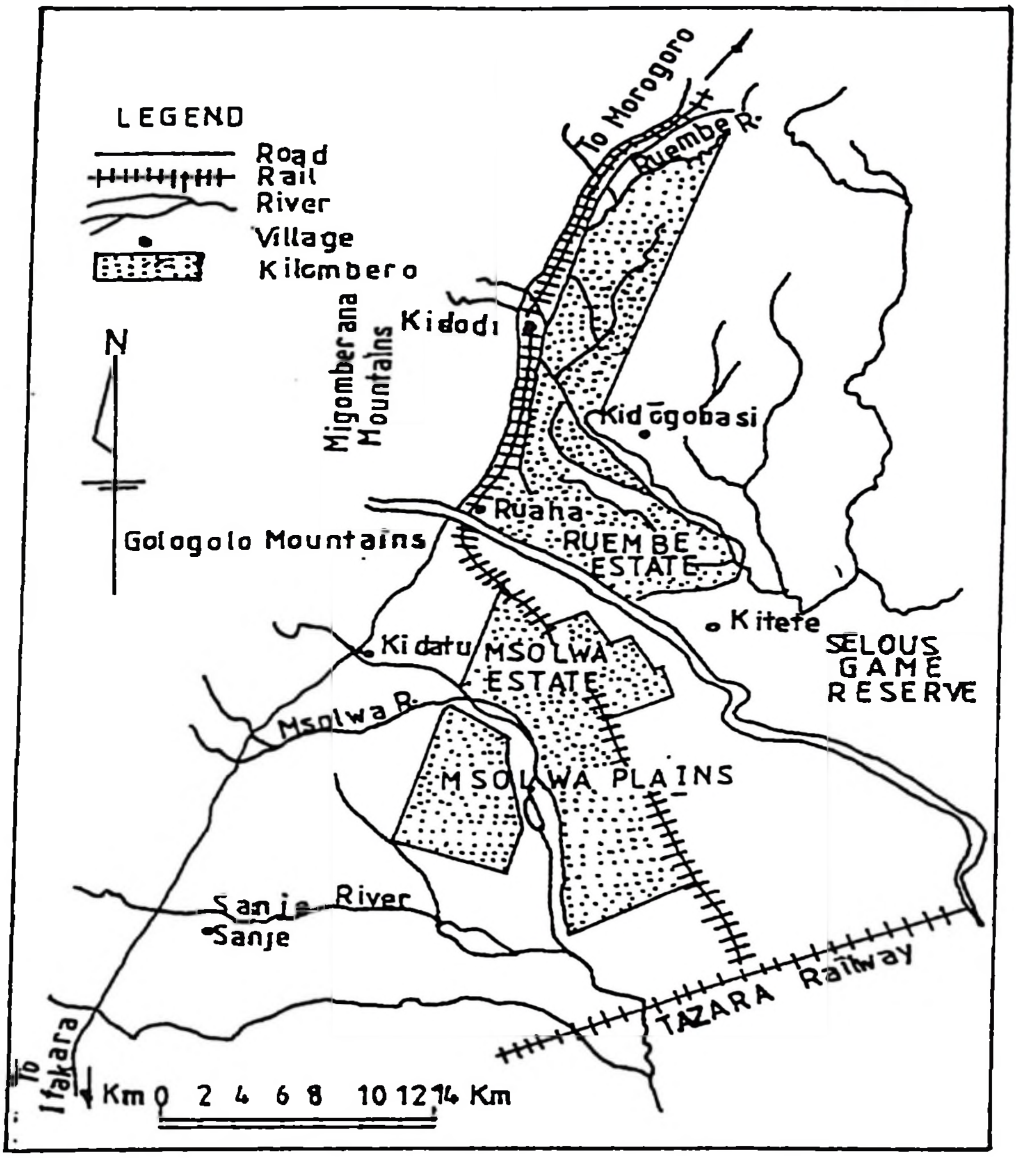

Figure 2: Existing sugar estates: Msolwa along the Msolwa plains and Ruembe along the Ruembe river valleys

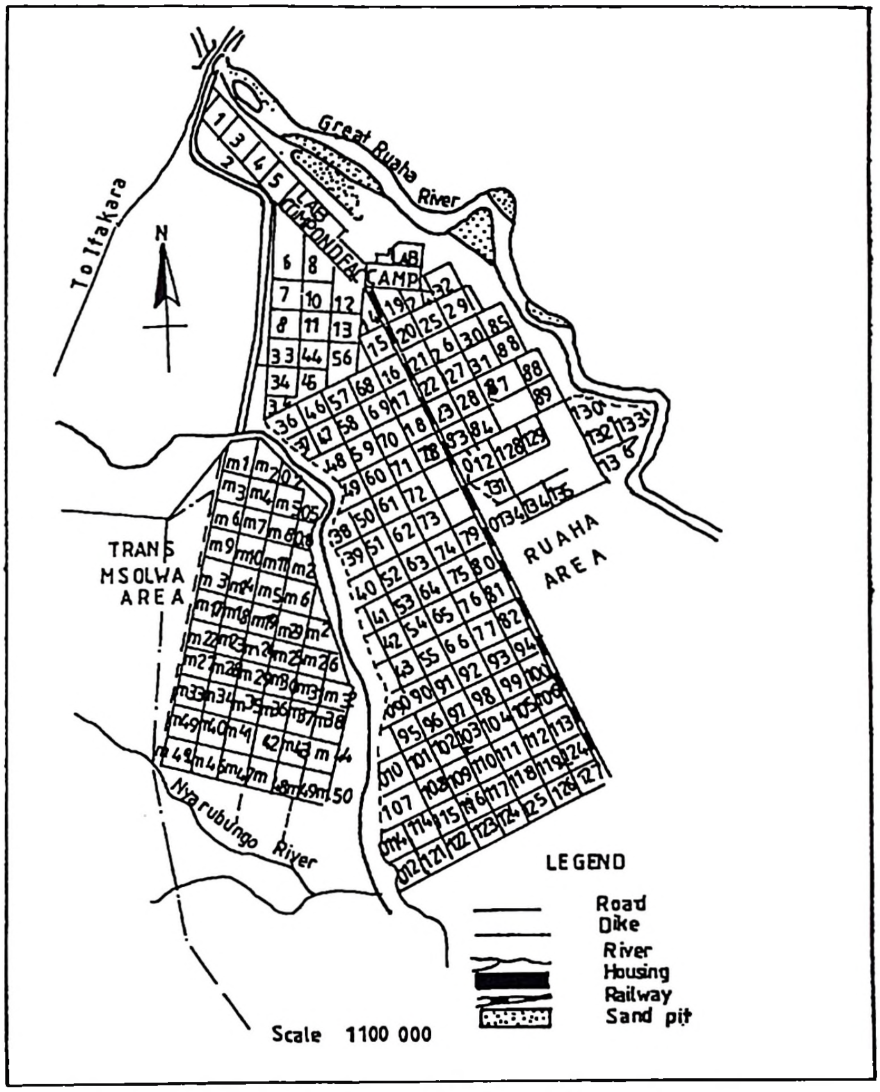

Figure 3: Msolwa Sugar Estate: Location of sugarcane fields

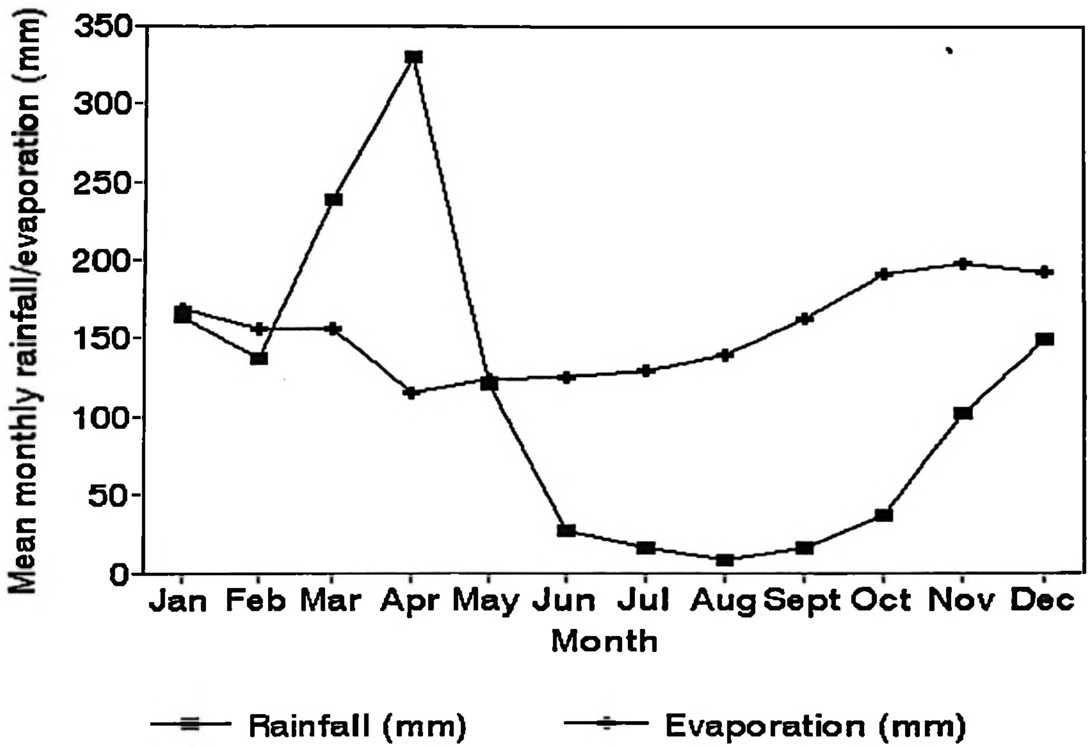

Figure 4: Rainfall and evaporation (mm) at Msolwa estate (34 - year mean data)

The soils of Kilombero are derived principally from the alluvial deposits laid down by the Ruaha, Msolwa and other streams running down from the scarp. They are generally very young and there is a considerable variation in soil texture within small areas sufficient to cause difficulties in the management of field drainage and irrigation. Four main soil textural groups do exist at Msolwa estate (Msambo, 1977). These are as follows:

- coarse textured sandy loam soils;
- medium coarse sandy loam and fine sand soils that make up most of Ruaha fields;
- medium fine soils consisting of clay loam soils which make up the Msolwa area; and
- fine soils consisting of clay loam, silty clay loam and very fine sandy clay loam particles.

The lighter and medium textured soils allow good root development and are easy to manage and thus high yields are produced under adequate irrigation. The very heavy soils are especially difficult to manage and do not allow good root development (a large area approximately 1 000 ha has been abandoned due to poor cane growth).

The soils of Kilombero are rich in those primary minerals containing potassium, and are not excessively acid. Soil alkali is not a major problem.

3.1.4 Topography, natural vegetation and land use

The height of the mountains of the Kilombero escarpment ranges between 915 to 2440 m above mean sea level. The Gologolo mountains and the Migomberama mountain slope very steeply towards the Msolwa and Lower Ruembe valleys with a gradient of 40% and 20% respectively.

Prior to the establishment of the sugar estates a large proportion of the alluvial soils was covered by a tree bush savanna with small areas of alluvial savanna. Substantial areas with natural vegetation still exist around the margins of the estate; these are rapidly disappearing however as the pressure for land in the valley continues to rise.

The plains of the valleys and the hilly plateau, the Selous Game Reserve are entirely covered with grass and scattered trees (Miombo woodlands). The slopes of the Kilombero escarpments are mainly covered with Miombo woodland, locally alternated with rainforest. In the more open areas the tree cover is dominated by a variety of Acacia species. Large areas of land not used for sugarcane cultivation are used to grow subsistence crops such as rice, maize, bananas, cassava, sorghum, vegetables, peppers and beans.

3.1.5 Pests and diseases

Kilombero is relatively free of pests causing economic damage (BAIL and TLTS, 1977). The only fungal disease present of commercial significance is smut, *Ustilago scitaminea*. This disease is of great importance as it not only causes substantial crop yield losses, but also restricts variety selection (estate records).

3.1.6 Hydrology

The main water resources are the Great Ruaha and Msolwa rivers. The water rights apportioned to Kilombero Sugar Company amount to 6 m^3/s from the Great Ruaha River and 3 m^3/s from the Msolwa River.

The area is traversed by a number of minor streams. The Sanje and Nyarubungo Rivers are important as flood protection is required from these streams in addition to the large rivers, the Msolwa and the Great Ruaha.

3.2 Description of the irrigation system studied

3.2.1 Layout of the irrigation system

The river pumping station is situated on the right bank of the Great Ruaha river. The pumping station is equipped with four pumps with a total installed capacity of 3900 l/s. The pumps are driven by electric motors and are installed vertically.

At Msolwa estate cane lands are gently sloping downwards from the river pump station to the fields farthest away.

This topographical feature permitted the use of open channels for the distribution network. At the same time it opened up the possibility of positioning the pressure pump stations almost in the centre of the sections which they respectively serve.

By a system of canals the water is distributed over the five reservoirs and the factory. Parts of the canal system are concrete lined. At a distance of 1600 m from the pumping station the main canal splits into the Msolwa and Ruaha main canals (Appendix 18). At this point a sill is installed and the water flow available for irrigation can be measured.

Most of the structures (weirs and movable gates) in the main canal are designed for the control of the water level in it. The movable gates are all installed downstream of the offtake for a reservoir, while the weirs are to reduce the flow velocity in the canal where the slope is too steep. The water flow into each reservoir is controlled with a Romijn weir which can also be used to measure the flow.

At the end of the Ruaha main canal a spillway is installed over which possible surplus water can leave the irrigation system without causing harm to this system. On the other end the spilled water in the Msolwa main canal can enter the main drain if required.

The layout of the main irrigation system is included in appendix 18.

3.2.1.1 Reservoirs and pressure pumping stations

Each irrigation section is served by an independent pressure pumping station from which a network of main and hydrant lines reach into the section fields. Each pressure pumping station is served by an open supply channel coming from the river pump station (Appendix 18).

The reservoirs I, II and IV are situated next to the main canals while the reservoirs III and V are connected through a branch canal with the main canal. The shape of all reservoirs is rectangular and in each reservoir a spillway has been constructed to prevent the water level rising too high. When water flows over the spillway it enters the drainage system.

The storage capacity of each reservoir has been designed for about 2 hours maximum gross requirement in order to buffer any lapses in the distribution of irrigation water. Another advantage of these reservoirs is that suspended solids do settle in them and therefore can be prevented from entering the underground system.

A pressure pumping station has been built at each reservoir. In each pumping station four or five horizontal centrifugal pumps are installed.

3.2.1.2 Underground system, sprinkler lines and field layout

The underground pipe system is subdivided into the main supply and the hydrant lines. At the hydrants the portable sprinkler lines can be connected to the underground system. At regular intervals along the sprinkler lines sprinklers are installed and through these water is sprayed over a strip of cane land served by the portable line.

The sprinkler lines are laid out in the same direction as the cane lines which are perpendicular to the permanent in-field drain (natural depression). The hydrant lines are perpendicular to the direction of the sprinkler lines.

The size of a typical field is 480 m by 676 m which equals 32.2 ha net. Each field plot is divided into two halves by the hydrant line, each half being served by one sprinkler line. In order to facilitate access to the hydrants a hydrant road of 6 m wide has been constructed. The layout of a typical field plot is shown in figure 5.

3.2.2 Operation of the irrigation system

3.2.2.1 Setting of the sprinkler lines

The irrigation system is based on a consumptive use of 4.5 mm/day (net.). The system has been designed to meet the peak requirements by the application of 85 mm gross or 63 mm net completed during a 10 hours setting of the sprinkler line. If this application is repeated after 14 days, a water consumption of 4.5 mm/day will be compensated.

The actual consumptive use of the cane varies and depends mainly on the development stage of the plant and the climatic conditions. Should the need arise to meet higher consumptive use at times of severe stress, there is the possibility-built in to increase the compensation rate to 5 mm/day by extending the sprinkler setting to slightly more than 11 hours.

The system has been designed for day and night irrigation on the condition that the sprinkler lines will not be shifted during night time. The practised irrigation schedules for plantcane, seedcane (nurseries) and ratoons are as shown in appendix 7.

3.2.2.2 Positioning and operation of the sprinkler lines

After every setting of three, five or ten hours the sprinkler line is moved to a new position. The movement of the sprinkler lines is done only during daytime. Irrigation is recommended to start as early as 0700h in the morning in order to utilize all available daylight hours. The system has been designed to commence irrigation under both manual and automatic operations.

From empirical experience at Msolwa estate and appendix 7, it is known that evapotranspiration rates can be set at:

(a) plantcane, germinating - 2.7 mm/day;

(b) plantcane, tillering - 3.3 mm/day;

(c) young ratoon - 3.3 mm/day; and

(d) cane in full growth - 4.5 mm/day

Therefore at a maximum storage capacity in the soil of 63 mm the irrigation interval for cane in full growth is 14 days. In the field the actual interval between irrigations is determined by examining the soil moisture by finger test.

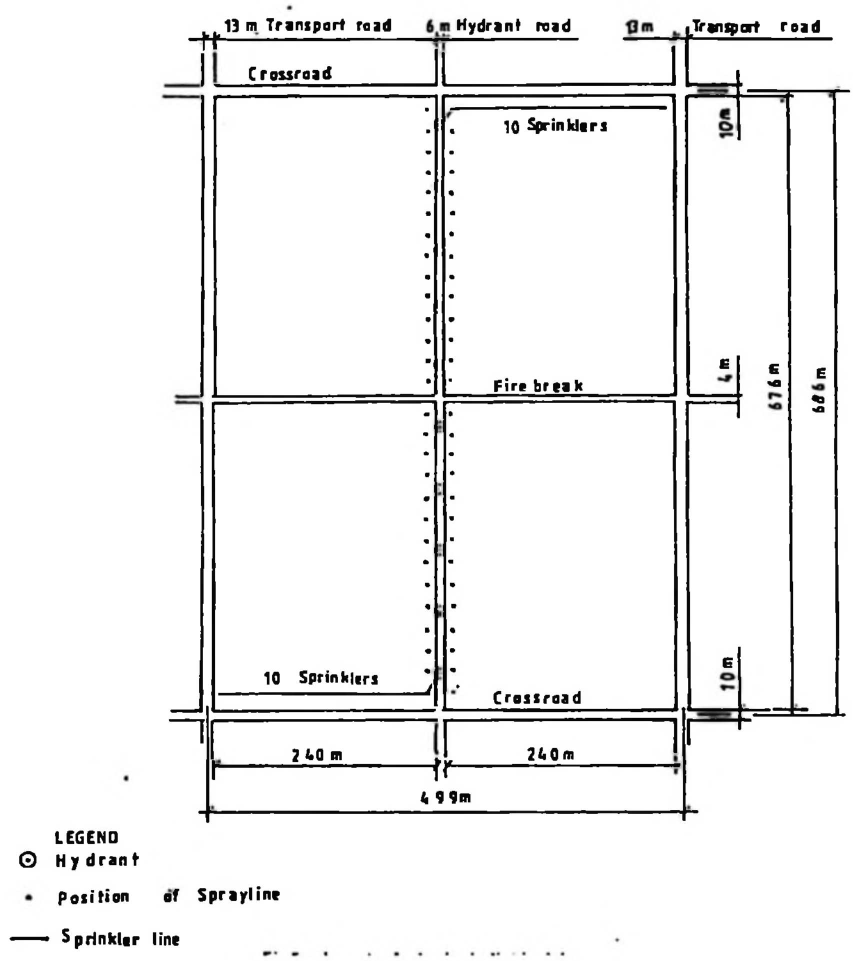

Figure 5: Layout of a typical field plot

3.3 Experimental procedure

3.3.1 Sampling of the fields

A stratified random sampling technique was used so as to eliminate the sampling error. Fields were selected to represent all soil types, pressure pumping stations, field sections, growth stages of the cane and all cane categories.

3.3.2 Determination of crop water requirements

In order to determine if irrigation is really necessary for commercial sugarcane production and to find out to what extent irrigation can support the crop and can add to the production at Msolwa estate, meteorological data from Kilombero were compiled for the years of record. These were later used to determine average monthly crop water requirements and irrigation water requirements using FAO CROPWAT computer program.

3.3.3 Measurements of system performance parameters

Since an individual lateral was tested, catch-cans were placed on both sides of the lateral (Fig. 6). Catch-can data were then mathematically overlapped to simulate precipitation from a complete irrigation at the specific shift distance. Catch-cans were placed on a four metre square grid between the fourth and sixth sprinklers (Merriam and Keller, 1978) in the overlapped area.

Loss of catch due to evaporation was estimated by placing a test container set outside the catch area with expected typical catch depth placed in it at the start and measured at the end to provide an estimate of the loss. All containers were then adjusted by adding this amount.

Tests were run for a duration equal to the duration of an irrigation as per the methods proposed by Merriam and Keller (1978). The volume of water caught in each container was measured by using a one litre capacity measuring cylinder. It was then converted to depth rate by dividing by the area of the container opening and duration of the irrigation. Details of each test were recorded in an appropriate data sheet (Appendix 11).

The data from the tests were used for the calculation of uniformity coefficient (CU), distribution uniformity (DU), potential application efficiency of low quarter (PELQ) and actual application efficiency of low quarter (AELQ)

3.3.3.1 Pump, lateral line and sprinkler operating pressure

The pump operating pressure at the pumping stations was recorded for the entire duration of an irrigation event. Pressure in the lateral line was measured by inserting a pressure gauge at the valve located on the bend connecting the sprinkler line to the hydrant during the beginning and end of an irrigation.

A pressure gauge (0 - 10 bar) with a Pitot tip was used to measure the sprinkler operating pressure at the 1st, 4th, 5th, 6th and last sprinkler during the beginning and end of an irrigation as proposed by Merriam and Keller (1978). Nozzle wear was checked with a drill bit that had the same diameter as the nozzles (7/4.5 mm).

3.3.3.2 Sprinkler discharge

This was measured at the 1st, 4th, 5th, 6th and last sprinkler by slipping a 1.5 m long flexible garden hose over the nozzles to deflect the stream into a container in a specified time. The sprinkler discharge rate was then calculated by dividing the volume of water collected by the time spent in collecting that amount.

3.3.3.3 Wind speed

Wind speed was measured using a three-cup counter anemometer located at the company's weather station. Wind run (kilometres) was recorded at the start and end of an irrigation event. The total wind run was found by subtracting the initial reading from the final reading. Average wind speed during the test was then computed by dividing the total wind run by the time elapsed between the two readings.

3.3.4 Soil Moisture Deficit (SMD)

Prior to an irrigation event, soil samples were taken from every block tested by soil auguring at depths of 0-30 cm, 30-60 cm or 60-90 cm (depending on the age of the cane) for gravimetric moisture content determination. Soil moisture deficit was determined as the difference between average field capacity for that particular soil type and the measured moisture content prior to an irrigation.

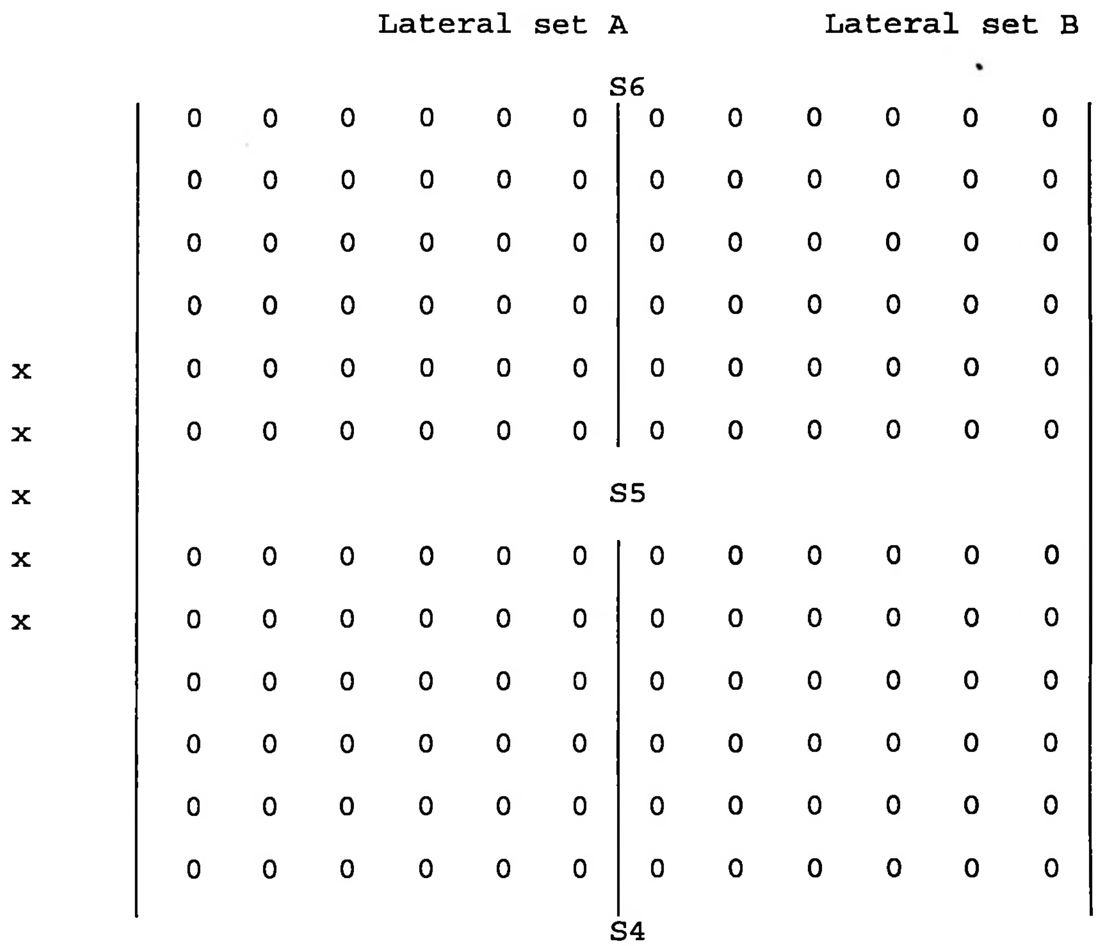

Figure 6: Layout of catch-cans

Key

s = sprinklers

0 = catch-cans

x = catch-cans for evaporation control

note

Direction of water flow is from S4 to S6

3.3.5 Assessment of irrigation water quality

Quality of water used for irrigation was assessed by analyzing five water samples, one from each of the five storage reservoirs as per the methods shown in table 3.1. Samples were collected at several depths and at a number of locations in the reservoirs before making one composite sample per reservoir. The suitability of water for irrigation was determined by comparing the amount of dissolved constituents in water samples against the guidelines for interpretation of water quality in irrigation as adopted from Westcot (1979), Ayers and Westcot (1985) and EUROCONSULT (1989) (Table 3.2).

3.3.6 Assessment of system maintenance.

Maintenance of the irrigation system was assessed by considering the number of operational irrigation and drainage structures and equipments. A survey was done to determine the number of flow measurement and control devices and drainage equipments still in operation. This number was then compared with the required one.

Table 3.1: Methods used to analyze water samples

Parameter	Method of analysis
Soluble cations (Ca^{2+}, Mg^{2+}, Na^{+} and K^{+})	Atomic absorption spectrophotometer
Total soluble salts	Electrical conductivity method
pH	Potentialmetrically by pH meter
Sodium adsorption ratio (SAR)	By calculation using: $SAR = Na+/((Mg^{2+}+Ca^{2+})/2)^{1/2}$

Table 3.2: Guidelines for interpretation of water quality of irrigation

Irrigation problem	Degree of problem		
	None	Increasing	Severe
1. SALINITY			
ECw (mmhos/cm)	< 0.75	0.75 - 3.0	> 3.0
2. PERMEABILITY			
ECw (mmhos/cm)	< 0.5	0.5 - 0.2	< 0.2
3. ION TOXICITY			
Sodium			
surf. irr. (SAR)	< 3.0	3.0 - 9.0	> 9.0
spr. irr. (me/l)	< 3.0	> 3.0	-
Chloride (me/l)			
surf. irr.	< 4.0	4.0 - 10.0	> 10.0
spr. irr.	< 3.0	> 3.0	-
Sulphate (me/l)	< 8.0	-	-
OTHERS	**USUAL RANGE IN IRRIGATION WATER**		
Calcium (me/l)	0 - 20.0		
Magnesium (me/l)	0 - 5.0		
Potassium (me/l)	0 - 2.0		
SAR	0 - 15.0		
pH	6.5 - 8.5		

3.3.7 Soil physical properties

In order to gain information on the physical properties of the soils of the study area, the following measurements were undertaken.

3.3.7.1 Infiltration characteristics

Infiltration rates for the different soil types were measured in the fields using a double ring infiltrometer method, with inner and outer ring diameters of 30 and 60 cm respectively. The rings, 25 cm high overall, were inserted to a depth of 12 cm into the soil. On the heavy textured cracking soils, the soils were pre-soaked in an attempt to seal the surface cracks and thus give a measurement more typical of the anticipated behaviour of the soil under irrigation.

A falling head method was adapted, in which measurements were made from the top of the infiltrometer to the bottom. Immediately after the depth of water in the infiltrometer had fallen to about 7 cm, the infiltrometer was refilled to give a maximum depth of water of about 11 cm. Timings of the readings were adjusted so that greater falls in the head were avoided during the test.

Before starting the experiments, soil samples were taken for soil texture and moisture content determination. The experiments were continued until constant infiltration values were obtained. The majority of the observations lasted for five hours. The water used in the tests was taken from the storage reservoirs serving the respective test sites during irrigation.

3.3.7.2 Field capacity and bulk density

Soil samples for field capacity and bulk density determination were taken from pits 1 m deep dug across the portion of each infiltration test site after a 24 hours period to allow excess water to drain off. The samples were taken using core samplers of known volume (98.2 cm^3) from depths of 10 cm, 20 cm and 30 cm thus giving three samples per pit. The samples were then sealed in containers to avoid moisture loss before being sent to the laboratory for analysis. Bulk density was calculated by dividing the oven-dry weight of the sample by the volume of the core sampler. Field capacity was determined as the moisture content at pF 2 (0.1 bar) using pressure plate apparatus.

3.3.7.3 Permanent wilting point

Soil samples for field capacity determination were also used to determine the permanent wilting point of the soil. Measurements of permanent wilting point were made from disturbed sub samples on a pressure plate apparatus at the laboratory. Six days were allowed for the soils to equilibrate at 15 atmospheres tension. Wilting point was determined as the moisture content at pF 4.2 (15 bar).

3.3.7.4 Available water capacity

In order to know the soil water available for ET by the plant-soil system for the different soils in the study area, measurement of soil moisture content was done on soil samples described in section 3.3.7.2 at both, field capacity and permanent wilting point. Available water capacity for different soil types was calculated as the moisture content between field capacity and permanent wilting point.

3.3.7.5 Soil texture

Soil samples for texture determination were taken from each of the blocks tested for uniformity coefficients and from the infiltration rate test sites. Soil texture was determined by sieve test and the hydrometer method and the data were interpreted with the help of the textural triangle.

3.3.8 Chemical characterisation of soils from fields showing lowest and highest five years average yields.

Five fields with lowest and another five with highest five years average yields were identified from each of administrative sections I to V. From each field, five auger samples were taken at a depth of 60 cm. From each of sections I to V one composite soil sample was made from five fields with lowest yields and the second sample was made from five fields with highest five years average yield. Only one composite soil sample was collected from section VI due to the small size of the area. There was therefore a total of eleven composite soil samples, two from each of the irrigated field sections (sections I to V) and one from section VI which is rainfed.

The variety considered for average yield calculation was NCo 376 since it occupies over 80% of the estate. Soil samples were analyzed in the laboratory using analytical procedures shown in table 3.3.

Table 3.3: Methods used for characterisation of soils

Parameter	Method of analysis
Particle size	Sieving and the hydrometer method
Bulk density	Metallic core procedure
Field capacity and wilting point	Pressure plate apparatus
Soil pH	Potentialmetrically in 1:2.5 soil/water ratio
Total Nitrogen	Kjeldahl procedure
Available Phosphorus	Bray and Kurtz 1
Exchangeable bases	Neutral ammonium acetate saturation method, then determined by atomic absorption spectrophotometry
CEC	Neutral ammonium acetate saturation method
Organic carbon	Wet oxidation method of Walkley-Black
Organic matter	Estimated by multiplying the % organic carbon by Van Bemmelen factor of 1.724

3.3.9 Sugarcane yield/water use relationship at Msolwa estate

In an attempt to establish this relationship, plantcane and first ratoon from all (six) field sections (planted from 1990/91 to 1994/95 seasons) were considered since they receive the best sugarcane husbandry practices as compared to other categories of cane. The variety considered was NCo 376 as it occupies over 80% of the estate. Only cane that was harvested after attaining the age of 12 months (average growing period) was considered.

3.3.10 Evaluation of former irrigation schedules

In order to assess the irrigation actions of the past period, 10 fields were randomly selected for evaluation. The fields represented both plantcane and ratooncane. The irrigation season selected for evaluation was 1993/94 whose cane was harvested in the 1994/95 season. The evaluation was done with the help of Irrigation Scheduling Information System (IRSIS) computer program (Raes et al. 1988)

The climatological conditions of the 1993/94 irrigation season were obtained from the Agronomy Department of the company. Daily rainfall and decade Class A Pan evaporation data were used (App. 17). The reference evapotranspiration (ETo) was derived from pan evaporation. Crop and field data used for evaluation are included in appendix 16.

3.4 Data analysis

3.4.1 Calculation of crop water and irrigation requirements

Average monthly weather data derived from 35 years of record were used to determine the average seasonal irrigation requirements (just like in preliminary planning). However, when evaluating past irrigation schedules, actual daily rainfall and decade ETo data were used.

The water requirements of sugarcane were calculated for different planting dates and for different categories of cane. The calculations were based on the standard cane growing period of 12 months and the standard planting season of June to December. The FAO CROPWAT computer program was used for the calculation of crop water requirements.

In order to estimate rainfall deficit for irrigation water requirements, a statistical analysis was made from long term rainfall records (35 years) to determine probabilities of rainfall or the amount of rainfall that is considered dependable using RAINBOW computer program (Raes et al., 1990). Results of the analysis are included in appendix 9.

For agricultural production dependable rainfall is normally understood as the rainfall which can be expected in three out of each four or in four out of each five years (Raes et al., 1988; Abdulmumin and Bastiaansen, 1991; Smith, 1992). In order to minimize the risk of reduction or complete loss of the yield of sugar cane, the probability of exceedance of 80% was used in this study in calculating net irrigation requirements.

Rainfall in wet, normal and dry years has been defined by Smith (1992) as the rainfall with a respective 20, 50 and 80% probability of exceedance. For the calculation of monthly irrigation requirements in dry, normal and wet years, the monthly rainfall at 80, 50 and 20% frequency of exceedance respectively have been used. These were determined by:

$$Pidry = Piav*Pdry/Pav \tag{4}$$

where,

Pidry = monthly dry year rainfall for month i (mm)

Piav = average monthly rainfall for month i (mm)

Pdry = annual dry year rainfall (mm)

Pav = average annual rainfall (mm)

Similar values for the wet and normal years were determined. Results of these calculations are presented in appendix 10.

Effective rainfall was in this research estimated by the evapotranspiration/precipitation ratio method (USDA SCS) as cited by Smith (1992) and the net irrigation requirement per month was calculated for an 80% dry month using the CROPWAT computer program as ETcrop minus dependable effective rainfall. No other gain of water was considered. Dependable effective rainfall for the wet, normal and dry months is shown in table 4.1.

3.4.2 Calculation of irrigation system efficiencies.

3.4.2.1 Coefficient of Uniformity (CU)

This is a statistical representation of the catch pattern and was calculated from:

$$CU = (1-D/C)*100 \qquad (5)$$

where,

D = average deviation from the average catch.

C = average catch.

3.4.2.2 Distribution Uniformity (DU).

This indicates the uniformity of water distribution throughout the field and was evaluated by measuring the depth of water caught.

$$DU = R_{1q}/R_c*100 \tag{6}$$

where,

R_{1q} = average low quarter rate caught.

R_c = average rate of water caught.

3.4.2.3 Potential Application Efficiency of Low Quarter (PELQ)

This indicates a measure of system performance attainable under reasonably good management when the desired irrigation is being applied and was determined from:

$$PELQ = R_{1q}/R_s*100 \tag{7}$$

where,

R_{1q} = average low quarter rate of water caught

R_s = average rate applied through sprinklers.

$$R_s = 3,600 * q/(S_1 * S_2) \text{ (mm/h)}. \tag{8}$$

where,

q = measured average sprinkler discharge (l/s)

S_1 = lateral spacing (m)

S_2 = sprinkler spacing (m)

An estimate of the efficiency reduction (ER) due to pressure variation throughout the system was computed from:

$$ER = 0.2 * (Pmax - Pmin)/Pr.av \quad (9)$$

where,

Pmax = maximum pressure during the tests (bar)

Pmin = minimum pressure during the tests (bar)

Pr.av = average pressure during the tests (bar)

ER = efficiency reduction

The system PELQ was calculated from:

$$\text{System PELQ} = (1 - ER) * \text{Test PELQ} \quad (10)$$

The average of low quarter catch (LQ) in all calculations was obtained by summing the lowest one quarter rates or depths in each set and averaging them. Since there were 72 catch-can data in each set, the low quarter values were obtained as the average of the lowest 18 catch can data.

3.4.2.4 Application Efficiency of Low Quarter (AELQ)

This indicates how well a system is being used and is given by:

$$AELQ = SMD/(Ar*Ta)*100 \qquad (11)$$

(for SMD < LQ) or

$$AELQ = X_1/(Ar*Ta)*100 \qquad (12)$$

(for SMD ≥ LQ)

where,

SMD = soil moisture deficit

Ar = average rate caught

Ta = set duration

X_1 = average low quarter depth caught

3.4.2.5 Calculation of Relative Water Supply (RWS)

Available estate records were used to calculate actual system utilization using Relative Water Supply (RWS) concept as follows:

$$RWS = Va/Vr \qquad (13)$$

where,

Va = actual volume of water delivered to the field per season

Vr = required volume of water to be delivered to the field per season (supply requirements).

3.4.3 Determination of basic infiltration rate of soils

The results of infiltration tests were processed using plots of the depth of water infiltrated against time on a Log-Log graph paper so as to determine the constants *a* and *b* in the *Kostiakov* equation:

$$I = a*t^{b} \tag{14}$$

$$\text{i.e } \operatorname{Log} I_t = \log a+(b*\log t) \tag{15}$$

where,

I = cumulative infiltration at time t (mm)

t = time (h)

a and b are constants

For infiltration rate the above equation was differentiated to give:

$$I^{t} = (a*b)*t^{b-1} \tag{16}$$

where,

I^t = infiltration rate at time t (mm/h)

t = time in hours

This was plotted as a curve of infiltration rate against time. The straight line portion of the curve was used to give the basic infiltration rate. A sample of basic infiltration rates and infiltration curves are shown in table 4.9 and appendix 15 respectively.

3.4.4 Determination of sugarcane yield/water use relationship

Potential crop evapotranspiration (ETcrop) for a particular season was calculated from daily Class A pan evaporation (Epan) data and the crop factors (kc) developed by ILACO as reported by Povel (1976) as follows:.

$$\text{ETcrop} = kc * \text{Epan} \tag{17}$$

where ETcrop and Epan are in mm and kc is the dimensionless crop factor.

The calculated ETcrop for each crop cutting was then used in the Thompson's production function to determine potential climatic yield. A typical example of calculating yield for a plantcane is included in appendix 14.

Actual yields obtained from various fields at Msolwa estate and those calculated using Thompson's function are presented in table 4.11.

Figure 7 shows the Thompson's (1976) linear production function and the actual Msolwa estate sugarcane yields.

Actual productivity was evaluated in terms of the average sugarcane yields realized per centimetre of water transpired. A comparison was then made with the potential productivity of Msolwa estate.

4. RESULTS AND DISCUSSION

The purpose of this study was to investigate irrigation system design and operational related factors contributing to low sugarcane production at Msolwa estate. Results of the study are discussed in eleven sections as follows:

4.1 System design

The Msolwa irrigation system was designed under the following assumptions:

- critical moisture content is attained if two thirds (63 mm) of the available moisture has been depleted;
- the peak irrigation requirement is 4.5 mm/day;
- field application efficiency from nozzle to soil surface is 75%; and
- daily irrigation time is 20 hours (day and night irrigation).

The overall design of the irrigation system is good. The layout was well planned and adequately cover the area to be irrigated. The sprinkler lines are well designed and can provide even applications of water if properly operated since pressure variations are close to the allowable limits. Sprinkler sizes and spacing are capable of adequately irrigating the area by using 10 hour settings in 14 days.

Appendix 8 shows important design data of the system.

4.2 Rainfall distribution, crop water and irrigation requirements

Data on dependable effective rainfall distribution and calculated ETo are shown in table 4.1. From the table the following is deduced:

(1) The average dependable yearly effective rainfall is 1032.3, 931.9 and 810.9 mm for wet, normal and dry years respectively.

(2) The rainfall distribution throughout the year is very uneven.

(3) The average annual (ETo) is 1390 mm.

(4) The average effective rainfall deficit is 48 mm per month for a dry year.

(5) The dry season generally runs from June to October.

Table 4.2 presents data on expected annual sugarcane water requirements for ratooncane and plantcane planted on different dates. Irrigation requirements for ratoon and plant cane for dry, normal and wet years are shown in table 4.3.

From the data presented, the following can be said:

(1) The average annual water requirements for plantcane and ratooncane are 935 and 863 mm respectively meaning that the average annual water requirement for sugarcane is 900 mm.

(2) From calculated ETcrop values, the water requirement of sugarcane ranges from 0.9 to 4.6 mm/day.

(3) The average annual irrigation requirements for plantcane and ratooncane are 277 and 231.7 mm respectively.

(4) The maximum annual irrigation requirements for plantcane and ratooncane are 364 and 316 mm respectively.

(5) The average annual irrigation requirements for sugarcane are 254 mm or 28% of the average annual water requirement.

(6) Sugarcane planted/harvested in December requires more support by irrigation than cane planted/harvested in any other month.

(7) Sugarcane can generally do without irrigation between the months of January and May (except for newly planted fields).

(8) Plantcane needs more support by irrigation than ratooncane.

Table 4.1: Calculated mean ETo and dependable effective monthly wet, normal and dry year rainfalls

Month	ETO (mm/day)	Dependable eff. rainfall (mm/month) wet year	normal year	dry year
Jan	4.2	134.5	120.8	103.7
Feb	4.3	121.1	107.0	90.6
Mar	4.1	153.5	147.4	132.6
Apr	3.5	164.5	157.9	151.4
May	3.2	111.5	97.8	82.2
June	3.1	30.9	26.0	21.0
July	3.0	18.0	15.1	12.2
Aug	3.3	10.7	9.0	7.2
Sept	3.8	19.2	16.1	12.9
Oct	4.3	42.1	35.6	28.9
Nov	4.6	98.7	85.8	71.5
Dec	4.4	127.5	113.5	96.7
TOTAL	1390.1	1032.3	931.9	810.9

Effective rainfall with USBR method

Table 4.2: Calculated annual sugarcane water requirements (mm) at Msolwa estate for different planting or harvesting dates

Planting date	Ratooncane	Plantcane
June II	895.0	972.7
July I*	892.7	969.3
July II**	887.1	962.4
August I	881.1	954.8
August II	872.7	945.0
September I	865.2	936.2
September II	856.7	927.0
October I	850.8	920.6
October II	845.0	915.0
November I	842.5	912.9
November II	840.4	911.5
December I	841.6	913.2
December II	842.6	914.9
Total	11213.0	12156.0
Average	863.0	935.0

* From 01 - 15/07 ** From 16 - 31/07

Table 4.3: Calculated annual irrigation requirements (mm) for sugarcane at Msolwa estate for different rainfall years and different planting or harvesting dates

Planting date	Rainfall Years					
	Plantcane			Ratooncane		
	Dry	Normal	Wet	Dry	Normal	Wet
June II	279.1	216.1	203.9	233.7	190.6	160.0
July I*	263.4	200.2	159.9	216.2	170.4	139.7
July II**	252.7	186.3	146.0	203.6	156.7	123.5
Aug I	244.6	177.6	136.3	197.0	147.7	117.9
Aug II	234.8	168.6	138.1	188.9	143.9	120.2
Sept I	225.9	174.4	149.9	184.2	150.2	129.3
Sept II	230.0	193.2	171.5	193.0	163.8	145.8
Oct I	255.5	221.3	199.8	212.9	185.8	167.8
Oct II	280.7	250.0	229.0	232.9	208.4	190.5
Nov I	304.7	277.2	254.8	255.7	233.6	215.7
Nov II	324.6	298.2	275.8	278.4	255.8	235.0
Dec I	345.5	318.3	291.8	299.7	274.2	253.4
Dec II	363.9	332.3	305.4	316.0	289.4	264.3
Total	3605.4	3013.7	2662.2	3011.9	2570.5	2263.1
Mean	277.3	231.8	204.8	231.7	197.7	174.1

* From 01 - 15/07

** From 16 - 31/07

4.3 System performance parameters

The system performance parameters investigated in this study were DU, CU, PELQ, AELQ, RWS and system maintenance. Since the performance of most sprinklers is related to operating pressure (James, 1988) then hydrant pressure, sprinkler nozzle pressure and pressure variation between the first and last sprinkler were also investigated.

The performance parameters of the system are shown in table 4.4. The average pressure for the hydrant and nozzle for the tested fields is 3.1 and 2.6 bar with standard deviations of 0.5 and 0.4 respectively. The highest sprinkler operating pressure is 3.2 bar while the lowest is 1.8 bar. The average hydrant pressure of 3.1 bar is less than the recommended value of 4.4 bar. Likewise, the average nozzle pressure of 2.6 bar is less than the designed pressure of 3.5 bar (Appendix 8).

The average pressure variation between the first and last sprinkler is 0.36 bar which is slightly higher than the maximum allowable value of 0.35 bar (design data).

Table 4.4: Calculated performance parameters (CU, DU, PELQ and AELQ)

Field	Av. hydrant pressure (bar)	Av. sprinkler pressure (bar)	Sprinkler pressure variation (bar)	CU (%)	DU (%)	PELQ (%)	AELQ (%)
F13	1.96	1.80	0.20	48.5	34.1	31.6	31.6
F12A	2.60	2.14	0.50	58.7	37.9	35.0	35.0
F24A	2.65	2.28	0.40	74.9	65.5	62.0	34.8
F29	3.75	3.05	0.35	81.6	71.8	63.7	67.3
F16	3.25	2.65	0.55	69.3	59.9	55.8	55.8
F64A	2.70	2.30	0.00	83.3	70.3	60.7	60.7
F45A	3.75	3.22	0.15	53.2	30.6	23.3	23.3
F61	3.05	2.40	0.60	53.4	19.9	16.9	16.9
F64B	2.50	1.86	1.00	71.0	50.0	43.2	43.2
F92	3.35	3.05	0.20	78.8	73.0	70.9	70.9
F54	3.45	2.66	0.45	74.3	58.8	57.1	57.1
F45B	2.90	2.41	0.45	79.4	68.4	67.0	67.0

Table 4.4 continued

Field	Av. hydrant pressure (bar)	Av. sprinkler pressure (bar)	Sprinkler pressure variation (bar)	CU (%)	DU (%)	PELQ (%)	AELQ (%)
F44A	2.95	2.44	0.25	74.7	65.5	62.0	62.0
F45C	3.45	3.13	0.15	87.0	80.5	78.5	75.7
F44B	3.70	2.86	0.40	85.0	78.1	76.0	76.0
F12B	3.15	2.83	0.20	79.2	69.1	66.4	63.8
F84	3.20	2.38	0.25	74.7	65.0	55.3	49.0
F24B	2.85	2.58	0.30	76.8	68.3	63.7	51.1
F72	3.45	2.70	0.55	76.0	68.2	57.9	54.9
F14	3.05	2.59	0.25	69.7	60.1	58.6	58.6
Mean	3.09	2.57	0.36	72.5	59.7	55.5	52.7
S.d.	0.45	0.38	0.21	10.7	16.2	16.5	16.6

The average DU is 59.7% with a standard deviation of 16.2. This is less than the required Du of 67% proposed by Merriam and Keller (1978). The lowest DU of 19.9% was obtained from field F61 while the highest DU of 80.5% was from field F45C.

The average CU obtained from the study is 72.5% which is less than that between 81 and 87% recommended for typical field crops having medium root depths (Merriam and Keller, 1978). It is pointed out by Tarjuelo et al. (1992) that low CU values below 80% indicate an incorrect combination of nozzle number and size, operating pressure and spacing.

The average PELQ and AELQ obtained were 55.5 and 52.7% with standard deviations of 16.5 and 16.6 respectively. Since pressure variation throughout the tested sprinkler lines was almost within the recommended value, the efficiency reduction (ER) calculated using equation 9 was also low, i.e., only 2.8%. This reduced the test PELQ of 55.5 to a system PELQ of 53.8% (Eq. 10). The calculated system PELQ of 53.8% is far less than the designed application efficiency of 75%.

Appendix 12 presents a summary of catch-can test results. The average evaporation rate and wind speed measured during the test period are 0.06 mm/h and 2.28 m/s respectively. The evaporation rate of 0.06 mm/h was very low to cause any appreciable loss of irrigation water. The highest values of evaporation loss of 0.09, 0.11, 0.13 and 0.13 mm/h coincided with the highest recorded wind speeds of 1.36, 2.48, 2.24 and 1.39 m/s respectively.

Irrigation performance figures presented in tables 4.5 and 4.6 for the whole estate reveal that the irrigation system is only capable of supplying 27.4% of irrigation requirements. However, this small amount is erratically supplied as evidenced from evaluation of irrigation system efficiencies. This could therefore be one reason that is contributing to the decline of sugarcane yields at Msolwa estate.

4.3.1 Factors influencing performance

Wind was one of the factors which disrupted the distribution pattern of irrigation water. The wind speed was high between 10 and 2 o'clock therefore coinciding with the test duration. The effect of wind speed is manifested in the low values of DU and PELQ obtained from fields F 45A, F 61 and F 12A as compared to other fields with lower or the same average sprinkler operating pressure. Although the average sprinkler operating pressure for field F 45A was 3.2 bar (the highest ever recorded during the entire evaluation period), high wind speed blowing parallel to the sprinkler line lowered the DU to the lowest value of 19.9%. The same can be said for the other two fields.

Table 4.5: Irrigation performance (hours)*

Season	Irrigation hours ** Target	Achieved	%
1990/91	477 968	137 897	28.85
1991/92	595 136	178 328	29.96
1992/93	625 920	136 320	21.78
1993/94	546 064	139 582	25.56
1994/95	275 472	97 696	35.46
Total	2 520 560	689 823.0	
Mean	504 112	137 964.6	27.4

** Irrigation hours (Hi) per field per day were calculated from:

Hi = (Lateral positions per set) * (number of sets per day) * (set duration).

Total irrigation hours per season were obtained by multiplying the above result by the number of days each field was under irrigation and summing up for all fields in the estate.

Table 4.6: Total volume of water (m^3) delivered to all fields in the estate (3140 ha)

Season	Target	Achieved	RWS (%)
1990/91	27 781 059.1	8 015 023.4	28.85
1991/92	28 413 462.2	8 513 879.0	29.96
1992/93	30 388 031.2	6 618 252.2	21.78
1993/94	25 922 387.5	6 626 144.0	25.56
1994/95	13 077 023.8	4 637 759.6	35.46
Total	125 581 963.8	34 411 058.2	
Mean	25 116 392.8	6 882 211.6	27.4

The hydrant and sprinkler operating pressures were very much below the recommended and designed values, thereby lowering almost all the efficiency parameters measured. Where the sprinkler operating pressure was high, DU and PELQ values were also high. The highest DU of 80% was attained in field F 45C with the second highest sprinkler operating pressure (3.1 bar).

The low operating pressures were mainly due to; (a) operating many irrigation lines at a time which exceeded the capacity of the pumps in operation; (b) excessive leakage of water from the sprinkler lines (water was leaking from the connecting bend connecting sprinkler lines to the hydrants, punctured holes in the lateral pipes, quick closure coupling water seals and sprinkler heads); and (c) operating sprinkler lines with more than 10 sprinklers each due to non uniform size and irregular shape of some of the fields (all fields are required to be rectangular shaped).

The efficiency values for the entire irrigation system could be less than the calculated values from the test area because about 20% of the sprinklers in the sprinkler lines were not rotating due to, among other things, sprinkler nozzle clogging, worn springs and low sprinkler operating pressure.

The irrigation duration for the first five hour set in the morning in all the ratooncane fields was less than five hours (Appendix 12) because of the late start of the pumping stations. The irrigation duration values in the table were calculated between when water started to come out of the sprinklers' nozzle and when the pumps were stopped (at 1300h). Taking into account the time required for the pressure to stabilize and time spent attending to the leaking points, the effective duration of the first five-hour set was only four hours. This, coupled with the high soil moisture deficit in ratooncane fields and low operating pressure resulted in all of the tested ratooncane fields except one to be underirrigated in the lowest one quarter.

However, a tendency of over irrigating the lowest one quarter was noticed in some of the plantcane fields tested. The reasons for this are two-fold. First the fields were irrigated without checking soil moisture deficit which was very low. The second reason was that the fields were irrigated using a five hours set instead of a three hours set as recommended due to the age of the cane.

The problems mentioned above are however not all known to the head of section and his immediate assistants because the reports sent to the section's head office contain only what was supposed to be done and not what actually took place in the fields. But due to poor supervision (as a result of lack of reliable transport for the head of section, section supervisor and the foreman) the culprits go scot-free.

The low value of RWS could be due to among other things, the dwindling number of sprinkler lines and interruption of the irrigation operation. Out of the required 205 irrigation lines only 88 are now still in operation. During the conduction of the study which coincided with the peak irrigation season (December - January) the researcher witnessed two major power cuts lasting for a total of over one month due to non-payment of electricity charges to TANESCO and a defective transformer which was struck by lightning.

Moreover, there is now an increasing rate of the underground main system pipe bursts (400 and 500 mm pipes) forcing suspension of irrigation activities to some fields. Most of the burst pipes undergo the so called 'Wet grinding' before succumbing to the high pressure in the system due to old age (estate records).

Although the system has been designed to operate for 20 hours per day, night irrigation is no longer being practised due to lack of lighting equipment and theft of irrigation pipes and sprinklers thereby lowering the relative water supply.

It is therefore not surprising to note that the total irrigation hours and hence the volume of water delivered to the fields account for only 27.4% of the total requirement and unless something is done urgently to rectify the situation, Msolwa irrigation system is soon going to collapse.

4.4 Irrigation water quality

The average characteristics of the five water samples collected are presented in table 4.7. All water samples had pH values ranging between 7.5 and 8. These values are within the normal range in irrigation water (6.5 to 8.4) (Westcot, 1979; Ayers and Westcot, 1985). The levels of electrical conductivity of less than 0.75 mmhos/cm indicate that the water used for irrigation can not cause salinity problems (Westcot, 1979; EUROCONSULT, 1989). However the very low levels of electrical conductivity (< 0.2 mmhos/cm) could create soil permeability problems (Westcot, 1979).

Fortunately though, the level of sodium in irrigation water is rather low. It ranges from 0.14 to 0.98 me/l across the five storage reservoirs with a mean of 0.8 me/l. The low levels of sodium in the irrigation water and the low soil sodium content (Appendix 13) imply that the irrigation water can safely be used without causing severe soil permeability problems.

Barnes (1964) reported that chlorides and sulphates are the principal constituents which should be carefully and regularly checked in irrigation water. The accumulation of salts, especially chlorides, in the soil could adversely affect the yield and composition of the cane and lower mill recoveries. The levels of chlorides and sulphates in the water samples were all within the usual range in irrigation water (Ayers and Westcot, 1985). Chloride content of the samples ranged from 0.2 to 0.4 me/l with a mean of 0.36 me/l which is less than the maximum safe value of 16.9 me/l for sugarcane irrigation water (Barnes, 1964).

Calcium, magnesium, potassium and sodium adsorption ratio (SAR) levels are all within the usual range in irrigation water (Table 3.2) which is also acceptable for sugarcane growing.

The results also show that water sample from reservoir IV which receives its water from Msolwa river showed the lowest values for all constituents determined except the pH as compared to other storage reservoirs that receive their water from the Great Ruaha river. The differences could be due to the distances travelled by the two rivers before passing the estate. While Msolwa river rises from the nearby Gologolo mountains, the Great Ruaha river comes all the way from Dodoma, through Iringa Region until it passes the estate thereby carrying a large amount of dissolved constituents than Msolwa river.

From these results it is obvious that the quality of water from both, the Great Ruaha and Msolwa rivers is good and the water is suitable for sugarcane irrigation.

4.5 Maintenance of drainage canals and irrigation equipments

Maintenance of open supply system consists of grass cutting and desilting of the canals and storage reservoirs. Desilting of the drainage canals is done both manually and mechanically using excavators and a dragline.

Table 4.8 presents the performance of drainage canals cleaning operations. From the table it is seen that the maintenance of drainage canals and in-field drains is very poor. Precision land grading is not carried out at Msolwa estate and although parallel drains are constructed at 30 m interval, the researcher observed, during the conduction of the study that both the intensity and the maintenance of cross drains is minimal with the result that water accumulated in depressions throughout most of the fields.

Regular cleaning of the ditches which is essential to destroy the growth of weeds and aquatic plants that seriously slow down the flow of water and encourage rapid siltation is not done as required. As a result of this many fields in the Msolwa and Simbalambende areas where there are heavy clay soils have drainage problems.

The researcher noticed the effects of poor drainage when it rained on the morning of 17/3/1996. Fields F48, 49, 50, 51, 52, 53, 57, 59, 60, 61, 62, 63, 64, 71, 72, 73, 74, 75 and 84 in the Ruaha area and M2, M02, M5, M05, M8, M23 and M24 in Msolwa area were all found to be inundated with water knee-high, six hours after it stopped raining. As a result of poor drainage the cane plants in some of the fields in Msolwa area appeared yellowish-green in colour and the growth was stunted. Dead cane was also observed in some spots within field M24 where water accumulated.

Poor maintenance and non-replacement of flow control and measuring structures and irrigation equipments has resulted in the system operating poorly and below its capacity. All Romijn weirs that have been installed to measure and control the water flow into the storage reservoirs are now capable of only controlling the flow. Measurement of flow is impossible because the centimetre scales attached to the frames and the litre scales attached to the movable parts have all been vandalised.

Measurement of the flow at the sill which is a broad crested weir constructed as a measuring structure in the main canal is not possible. This is because a gauge placed in the stilling basin, next to the sill can not be used to directly read discharge due to the silting up of the stilling basin. As such the amount of water available for irrigation of sugarcane after extracting the water for factory uses is never known. As a consequence of this, irrigation of sugarcane is sometimes stopped after only a few hours of irrigation due to low water levels in the storage reservoirs brought about by low flows into the reservoirs during irrigation. This is especially common for reservoirs number III and V.

Moreover, out of the required 205 irrigation lines, only 88 (about 43%) lines are currently available. Worse still, these 88 irrigation lines consist of many leaking lateral pipes (due to old age and damage) and sprinklers with worn out nozzles.

Out of the total 48 nozzle pressure gauges that were required and available for testing the pressure at the nozzles, none is now working. Of the 24 pressure gauges provided for checking the pressure in the sprinkler line, only one is still in good working condition. As for the pressure pumping stations, flow measuring instruments for registration of water quantity supplied by each pump are all out of order. Automatic operation of the sprinkler lines is no longer possible because instruments provided for that purpose are all defective.

Table 4.7: Analytical results of irrigation water quality evaluation

Parameter	Water source (reservoirs)					
	I	II	III	IV	V	Mean
ECw (mmhos/cm)	0.17	0.18	0.21	0.04	0.19	0.16
SAR	1.83	1.85	1.91	0.52	1.89	1.60
pH	8.0	7.5	7.5	7.8	7.5	7.7
Ca (me/l)	0.31	0.35	0.33	0.08	0.33	0.28
Mg (me/l)	0.19	0.2	0.21	0.07	0.21	0.17
Na (me/l)	0.91	0.97	0.99	0.14	0.98	0.80
K (me/l)	0.16	0.11	0.12	0.02	0.12	0.11
Cl (me/l)	0.4	0.4	0.4	0.2	0.4	0.36
SO_4 (me/l)	0.003	0.003	0.003	0.00	0.003	0.003

Table 4.8: Performance of drainage operations (m)

Year	Mechanical canal cleaning	Grass cutting on canals	Manual canal cleaning
1991/92			
Target	72873	97500	-
Achieved by Apr. 1992*	50466	77916	-
1992/93			
Target	72873	-	97500
Achieved by Feb. 1993	6210	-	28164
1993/94			
Target	72873	-	97500
Achieved by Jan. 1994	5970	-	45356
1994/95			
Target	72873	-	97500
Achieved by Jan. 1995	9520	-	52937

* The drainage season ends in April of each year

4.6 Soil physical properties

A summary of the physical properties of soils is presented in tables 4.9 and 4.10. The bulk density of the soils sampled ranged from 1.2 to 1.7 g/cm^3 with a mean of 1.4 g/cm^3. The highest value of 1.7 g/cm^3 was found in field F 12 at a depth of 30 cm from the surface.

For sugarcane growth, bulk density values less than 1.4 g/cm^3 are recommended (Trouse and Humbert, 1961). Critical values for sugarcane growth are between 1.4 and 1.6 (Juang, (1972) as cited by Kunda, 1996). The average bulk density value obtained (1.4 g/cm^3) is at the borderline of the recommended value. Higher bulk density values limit plant growth, aeration and impede water movement which in turn result in reduced yields. It is therefore important to carry out subsoiling in soils which show signs of compaction. Cultivation, harrowing, chiselling and harvesting operations should be carried out only when soil moisture conditions are ideal.

Available soil water capacity was generally low ranging from an average of 8% by volume for field M 4 to 19% by volume for field M 15. All the soils show an increase in bulk density and a decrease in soil available water capacity with depth. Low top soil bulk density values and high top soil available capacity values are due to the large quantity of organic matter which has the property of holding additional moisture. Even the sandier soils show moderate available water capacities.

Table 4.9 shows that the lowest basic infiltration rate of the soils sampled was 6 mm/h (field M 4 - clay soil) while the highest value was 30 mm/h (field F 34 - sandy clay soil). These results are in close agreement with the basic infiltration rates obtained by ILACO (1970).

Since the sprinkler application rate of 8.4 mm/h is less than the basic infiltration rate of the soils in the estate with the exception of the heavy clay soils, the recommended application rate of the sprinklers poses no danger of producing run off. The fine textured clay soils found in much of the Msolwa area have basic infiltration rates which are more favourable for surface irrigation methods. However, hard facts on soil physics, on topography and on soil profile in relation to the allowance for land forming or levelling have proved long ago that only about 7.5% (483 out of 6603 acres) of the cane lands at Msolwa estate meet the requirements for gravity irrigation (HVA International, 1977). The location of this cane land is divided into three small units (fields M2, M02, M3, M05, M6, F75, F76, F77, F81 and F82). This area is too small to be considered for a separate treatment. So the only solution to the problem will be to reduce the application rate to match with the water intake capacity of the soils. This can be done by either increasing the sprinkler spacing or lateral spacing accompanied by an increase in duration of irrigation so as to supply the required amount of water per irrigation.

These results indicate that the soils of Msolwa estate still have favourable physical properties for sugarcane production. Moreover, the ground water table which is 2 m below the surface and the soil depth of more than 1 m deep (ILACO, 1970) are all within the suitable limits for sugarcane production (section 2.1.3).

4.7 Comparison of chemical properties of soil samples from fields showing lowest and highest five years average yields

Results of some chemical analysis of composite auger soil samples from sugarcane fields for fertility comparison are presented in appendix 13. Results show that fields with the highest five years average yields and those with the lowest five years average yields from the same section have almost the same soil chemical properties.

This indicates that differences in yields among fields in the same section are not due to differences in fertility or chemical properties and composition of the soil. Since it is known that soils of the Msolwa sugar estate have generally suitable physical and chemical properties and fertility status for sugarcane production (ILACO, 1970; Kunda, 1996) it is therefore apparent that the soils of the study area are not limiting to sugarcane production.

Table 4.9: Basic infiltration rates of some soil types found at Msolwa estate

Field	Soil type	Basic inf. rate (mm/h)
F 11	Sandy loam	24
F 12	Sandy clay loam	18
F 34	Sandy clay	30
M 4	Clay	6
M 15	Sandy clay loam	27

Table 4.10: Physical characteristics of the representative soil types

Field	Sampling depth (cm)	Textural class	FC % vol	PWP % vol	Sa % vol	BD g/cm^3
F11	10		43.7	26.9	16.8	1.2
	20	SANDY	41.4	36.3	5.1	1.3
	30	LOAM	37.9	34.6	3.3	1.6
F12	10	SANDY	40.2	13.4	26.8	1.4
	20	CLAY	45.1	29.1	16.0	1.6
	30	LOAM	28.6	17.9	10.7	1.7
F34	10		42.7	30.1	12.6	1.5
	20	SANDY	43.7	36.4	7.3	1.5
	30	CLAY	43.0	36.8	6.2	1.5
M4	10		39.9	30.6	9.3	1.4
	20	CLAY	42.3	34.6	7.7	1.4
	30		39.2	32.3	6.9	1.5
M15	10	SANDY	44.7	25.7	19.0	1.3
	20	CLAY	33.3	20.2	13.1	1.3
	30	LOAM	34.9	28.3	6.6	1.4

4.8 Sugarcane yield/water use relationship

Data on actual and calculated sugarcane yields for different seasons and various moisture regimes at Msolwa estate are presented in table 4.11. The table shows that the fields under consideration received an average of 1491.78 mm of water per season against the required average sugarcane water requirement of 1223.2 mm. However, in all occasions actual yields are far less than the calculated climatic potential yields of the estate. The average actual sugarcane yield is 81.96 tc/ha as compared to the average calculated yield of 116.12 tc/ha. This is due to the fact that 90% of the total water supply came from rainfall which as it has already been pointed out is erratically and unevenly distributed.

The average irrigation water supplied was 212.9 mm or 10% of the average seasonal crop water requirement (Table 4.11). This is less than the required level of irrigation which was calculated to be 28% of total sugarcane water requirement (section 4.2). This means that for the seasons and fields under consideration only 35% of the irrigation requirement was met. This figure agrees closely with the earlier observation that for the past five seasons (1990/91 - 1994/95) the Msolwa estate irrigation system was only capable of supplying 27.4% of the total irrigation water requirement (section 4.2).

The results indicate that all fields which received more water from irrigation (in the same season, from the same section and of the same cane category) recorded higher yields than fields which either received less or no irrigation water at all. This is clearly seen when looking at actual yields from fields F20B and F5; F45 and F7A; F87, F0128B, F128 and F28; F50C and F74; F37 and F64B; M1 and M5; and F96 and F97. The Msolwa estate yield data when compared to the calculated yields using Thompson's (1976) production function seem to be too low. This is because of the failure of the irrigation system to fully meet the sugarcane water requirements.

Msolwa estate achieved yields which approached the average calculated potential yield (116.12 tc/ha/annum) in 1971/72 - 1973/74 seasons (Appendix 1) when the irrigation system was in good working condition and was being operated according to design recommendations.

The Msolwa yield data when compared to the Thompson's (1976) production function (Fig. 7) seem also to fall below the linear relationship. Regression analysis of the actual yield data with ETcrop gave a correlation coefficient of 0.4 showing that there is almost no linear correlation between the actual Kilombero yields and the amount of water transpired. The reason for this behaviour is again the failure to meet moisture requirements of the crop.

The above results show that at Msolwa estate 1 cm of water transpired produces 0.67 tc/ha per annum. This is far less than the production potential of the area which was calculated to be 1 tc/ha for every centimetre of water transpired (BAIL, 1977).

Table 4.11: Actual and calculated sugarcane yields for different seasons and various moisture regimes

Section	Field	Planting date	Cutting date	Harvesting season	Cane category	Rainfall (mm)	Irrigation (mm)	Water Supplied (mm)	ETcrop (mm)	Actual yield (tc/ha)	Calculated yield (tc/ha)
I	F 20B	8/7/90	8/7/91	1991/92	R1	1218.6	0.0	1218.60	1237.2	75.30	117.49
	F 5	12/8/90	12/8/91	1991/92	R1	1244.3	177.6	1421.90	1253.9	90.40	119.10
	F 45	20/8/90	20/8/91	1991/92	PC	1239.5	410.0	1649.50	1320.6	100.00	125.56
	F 7A	30/9/90	30/9/91	1991/92	PC	1243.2	387.0	1630.20	1237.3	81.00	117.49
	F 34 A	19/7/91	19/7/92	1992/93	R1	1408.8	461.0	1869.80	1240.2	82.10	117.78
	F 24B	3/8/91	3/8/92	1992/93	R1	1408.2	0.0	1408.20	1213.3	79.10	115.17
	F 14	1/11/91	1/11/92	1992/93	PC	1384.4	0.0	1384.40	1141.2	96.00	108.18
	F 1	26/10/92	26/10/93	1993/94	R1	1266.4	151.5	1417.90	1019.0	69.40	96.34
II	F 87	20/6/90	20/6/91	1991/92	R1	1209.5	283.2	1492.70	1253.7	71.30	119.09
	F 0128B	8/7/90	8/7/91	1991/92	R1	1218.6	0.0	1218.60	1237.2	61.50	117.49
	F 128	12/10/90	12/10/91	1991/92	R1	1239.0	39.0	1278.00	1137.6	70.70	107.83
	F 28	1/11/90	1/11/91	1991/92	R1	1234.3	369.1	1603.40	1112.5	85.20	105.40
	F 72	2/7/91	2/7/92	1992/93	R1	1432.5	0.0	1432.50	1226.1	81.30	116.41
	F 30B	14/7/91	14/7/92	1992/93	R1	1457.0	508.7	1965.70	1242.4	98.80	117.99
	F 27	31/7/91	31/7/92	1992/93	PC	1408.2	398.7	1806.90	1247.2	101.30	118.45
	F 17B	31/8/93	31/8/94	1994/95	R1	1094.4	0.0	1094.40	1238.4	78.70	117.60
III	F 50C	8/7/90	8/7/91	1991/92	R1	1218.6	499.5	1718.10	1237.2	76.90	117.49
	F 74	10/7/90	10/7/91	1991/92	R1	1218.6	296.4	1515.00	1267.3	73.40	120.40
	F 37	30/7/90	30/7/91	1991/92	PC	1093.5	644.0	1737.50	1288.4	104.00	122.44
	F 64B	22/10/90	22/10/91	1991/92	PC	1239.7	0.0	1239.70	1197.1	80.80	113.60
IV	M 1	10/8/90	10/8/91	1991/92	R1	1241.1	218.1	1459.20	1253.9	80.40	119.10
	M 5	29/10/90	29/10/91	1991/92	R1	1235.8	15.3	1251.10	1111.5	59.70	105.30
	M 19	29/6/90	29/6/91	1991/92	PC	1217.2	350.6	1567.80	1296.5	93.80	123.23
	M 13	24/8/90	24/8/91	1991/92	PC	1239.5	315.7	1555.20	1263.6	78.70	120.05
	M 17	4/9/90	4/9/91	1991/92	PC	1239.1	293.0	1532.10	1269.7	78.30	120.63
	M 9	2/9/91	2/9/92	1992/93	R1	1402.5	161.1	1563.60	1174.6	69.20	111.41
V	F 97	2/7/90	2/7/91	1991/92	PC	1217.7	249.5	1467.20	1297.7	92.50	123.35
	F 96	4/7/90	4/7/91	1991/92	PC	1217.7	277.7	1495.40	1299.3	96.50	123.50
	F 54A	23/7/91	23/7/92	1992/93	R1	1408.8	301.8	1710.60	1210.6	76.90	114.91
	F 101	28/7/91	28/7/92	1992/93	R1	1408.5	216.9	1625.40	1200.4	70.90	113.92
	F 124	19/9/93	19/9/94	1994/95	R1	1093.1	0.0	1093.10	1236.8	56.54	117.44
VI	P A 3A	10/9/91	10/9/92	1992/93	R1	1402.5	0.0	1402.50	1168.7	93.30	110.84
	P A 4B	18/9/91	18/9/92	1992/93	PC	1402.6	0.0	1402.60	1233.8	100.70	117.16
	Total					42203.4	7025.4	49228.80	40364.6	2704.64	3832.13
	Mean					1278.9	212.9	1491.80	1223.2	82.0	116.1
	s.d.									12.49	6.05

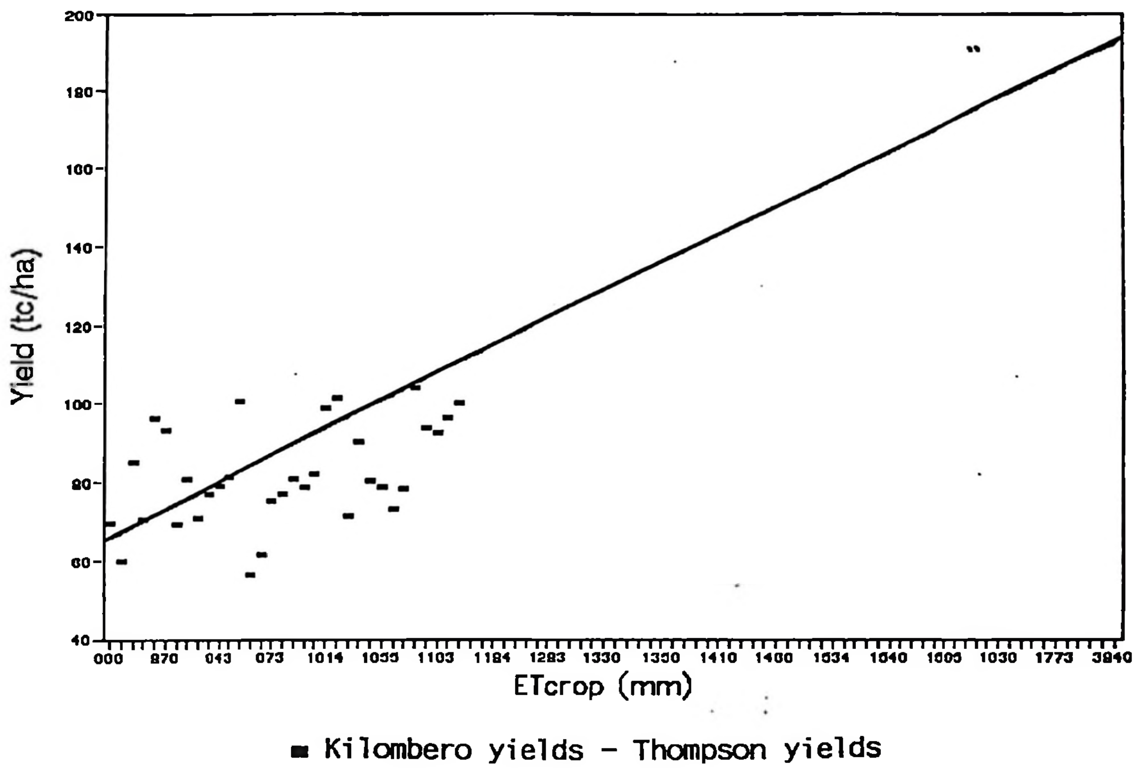

Figure 7 Thompson's linear production function and actual Msolwa estate sugarcane yields

4.9 Comparing designed/recommended performance parameters with measured ones

The "Students" t-distribution (Spiegel, 1981) was used to determine if there is any significant difference between measured and designed or recommended system technical performance parameters.

It was found that at both 0.01 and 0.05 levels of significance CU, PELQ and sprinkler nozzle pressure were significantly different from designed and recommended values thus confirming the earlier discussion.

The z-distribution (Spiegel, 1981) was used to see if there is any difference between the average sugarcane yield calculated using Thompson's (1976) production function and actual average yield obtained at Msolwa estate. It was found that there is significant difference between the means of actual and calculated yields at levels of significance of 0.05 and 0.01.

4.10 Evaluation of 1993/94 irrigation schedules

Results of the evaluation are presented in table 4.12 and figures 8a to 8e. The table shows that ETa was less than ETcrop for all 10 fields evaluated. The average ETcrop is 1315 mm as compared to average ETa of 1104 mm. The actual crop evapotranspiration is low because of the failure of the system to fully meet the irrigation requirements of sugarcane. Whereas the average irrigation depth applied was 435 mm, the average irrigation requirement was 568 mm (Table 4.12).

Comparison of the means using "Student's" t-distribution reveals that at 5% level of significance both ETa and Irrigation depth are significantly different from ETcrop and net irrigation requirements respectively thus confirming the above discussion.

Since the supply of water does not meet the demand, corrective measures should be taken to improve the performance of the system or an optimal distribution of the available water basing on the present condition of the system should be calculated and adhered to.

The unreliability of rainfall to fully meet the crop water requirement of sugarcane at Msolwa estate is evident from the low values of rainfall efficiencies for the evaluated fields. The average rainfall efficiency is only 60%. This low value is due to the erratic distribution of rainfall whereby much of it is concentrated in the months of March to May.

The graphical displays of root zone depletion indicate that all 10 fields evaluated experienced either under-irrigation or over-irrigation during much of the growing period of sugarcane. Under-irrigation resulted in moisture stress and hence in yield reduction ($Ya/Ym < 100\%$). The low actual yields obtained from the evaluated fields (Table 4.12) are testimony to this. Excess water supply was evident during the rain season resulting in drainage and water logging problems. Graphical displays for some of the evaluated fields are shown in figures 8a to 8e.

Table 4.13 and figures 9a and 9b show the response of root zone in case of rainfed conditions for fields F041 (clay) and F45 (sandy loam). The graphical displays show that moisture content in the root zone would have been less than the critical moisture content during a substantial part of the growing period, serve for about 3 months coinciding with the rain season. Furthermore table 4.13 shows that whereas Etcrop was 1287.6 and 1175.7 mm, ETa would have been 788 and 732.9 mm for fields F041 and F45 respectively. This could have resulted in higher sugarcane yield losses if the crop at all managed to survive due to excessive moisture stress.

4.11 Irrigation scheduling of sugarcane at Msolwa estate

At the time of writing this dissertation it was not possible to set out optimal irrigation schedules as per prevailing conditions because of lack of information on harvesting program and cane composition for the 1996/97 season. This information is important because the forecast of the season's water requirements and hence irrigation requirements depend in fact on the composition and on the planned sequence of harvesting and uprooting.

However this task can easily be done by the irrigation section personnel. The dependable rainfall can be represented by 80% dry year conditions. At the start of the dry season the cane's age and harvesting scheme are known at the irrigation section. Age related crop factors have been developed at the Agronomy Department of Kilombero Sugar Company. Therefore crop water requirements and hence irrigation requirements can easily be calculated and the irrigation schedules for the season prepared.

Irrigation scheduling must be backed up with practical checks in the field, and basic criteria such as total available moisture, soil depth, and evaporation deficits must be adjusted according to crop responses in the field concerned.

Table 4.12: Water balance, root zone depletion, yield response and application efficiency for evaluated fields.

Field	ETo (mm)	ETcrop (mm)	ETa (mm)	R/fall (mm)	Inet (mm)	Irr D (mm)
F041	1953.3	1392.2	1196.1	1108.7	594.2	424.0
F99	1922.0	1494.9	1199.1	1204.6	774.8	455.0
M3	1953.5	1400.6	1158.3	1108.7	594.9	415.0
M32	1919.5	1357.1	975.0	1143.0	591.4	303.0
F13	1827.3	1257.2	1118.0	1182.6	499.3	369.0
F34	1945.4	1243.7	1005.3	1109.3	591.4	350.0
F44	1938.5	1244.1	1156.8	1143.0	531.5	601.0
F45	1754.1	1230.8	958.0	1108.7	453.4	626.0
F54	1955.5	1269.8	1208.9	1108.7	521.4	499.0
F84	1956.0	1255.5	1061.5	1108.7	530.1	310.0
Total		13145.9	11037.0		5682.4	4352.0
Mean		1314.6	1103.7		568.2	435.2
S.d.		90.0	96.5		87.0	112.4

Table 4.12 continued

Field	TAM (mm)	RAM (mm)	Deficit to FC (mm)	% RAM depleted	Yield (tc/ha)	Rain eff. (%)	Irr. eff. (%)	R/off (mm)
F041	127.4	105.3	172.0	110	54.9	64.2	100.0	343.3
F99	77.6	60.4	21.9	23	109.5	65.7	100.0	177.3
M3	127.4	105.4	169.0	109	79.1	62.0	100.0	354.8
M32	77.6	64.7	98.5	104	64.0	57.5	94.6	155.1
F13	90.5	76.4	101.4	107	67.4	60.6	100.0	139.4
F34	90.5	74.9	101.6	108	52.9	58.0	93.9	170.4
F44	90.5	76.5	65.5	69	49.1	56.4	85.8	159.7
F45	89.3	75.1	105.0	111	51.2	49.7	59.2	172.1
F54	148.7	123.8	170.6	110	51.1	59.2	100.0	357.0
F84	148.7	124.1	171.3	110	43.9	62.4	100.0	345.6
Total						595.7		
Mean						59.6		

Table 4.13: Water balance, rainfall efficiency and root zone depletion for rainfed conditions.

Field	Rainfall (mm)	Irrigation (mm)	ETcrop (mm)	ETa (mm)	Rain eff.(%)
F041	1108.7	0.0	1287.5	788.0	65.6
F45	1177.2	0.0	1175.7	732.9	62.9

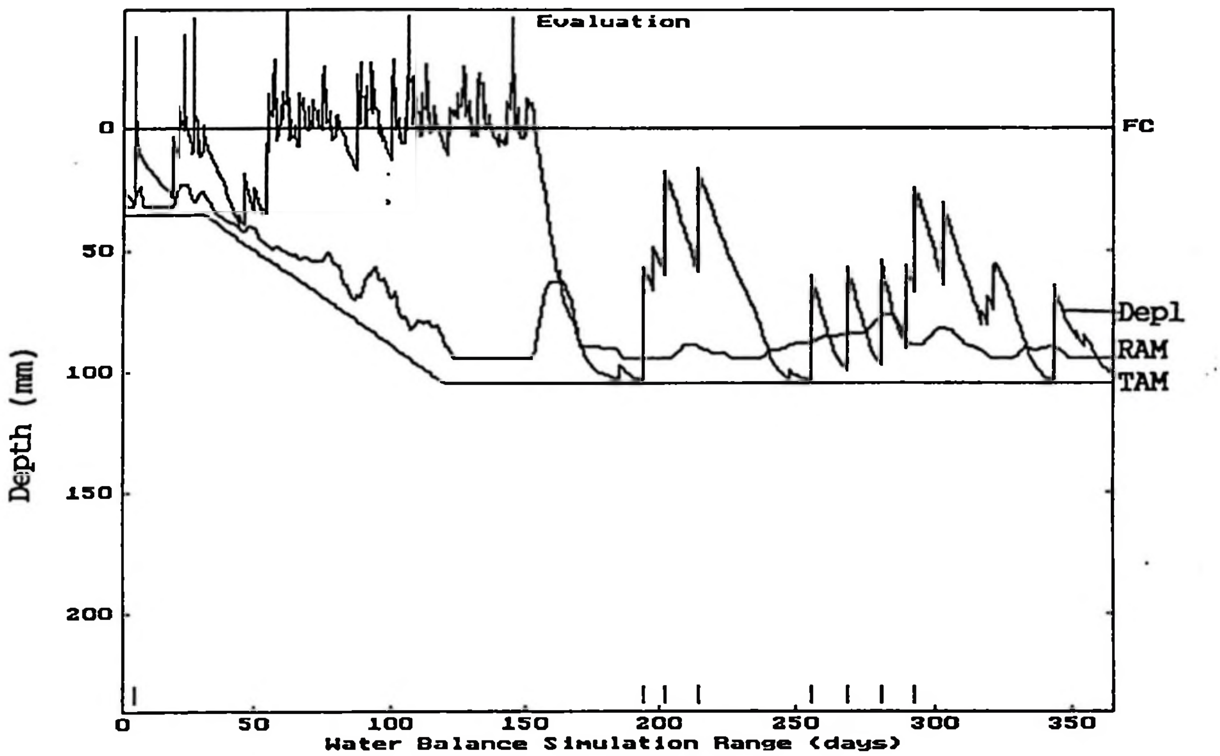

Figure 8a: Root zone depletion graph for field F13

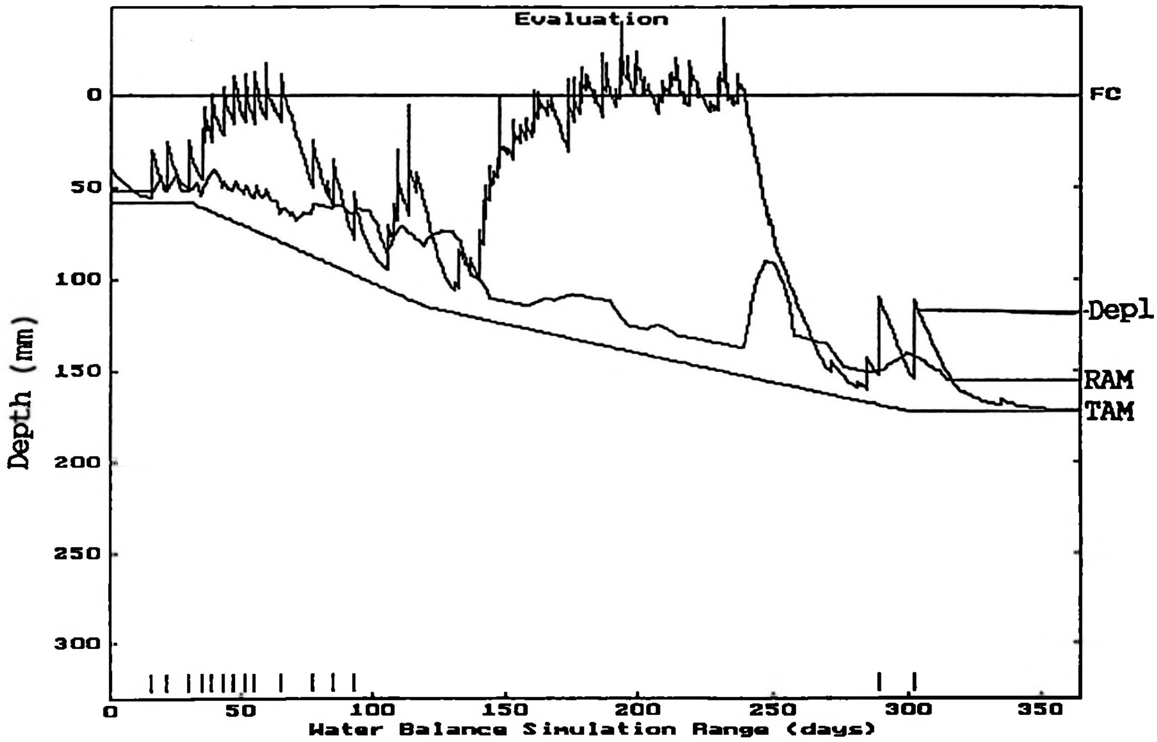

Figure 8b: Root zone depletion graph for field F041

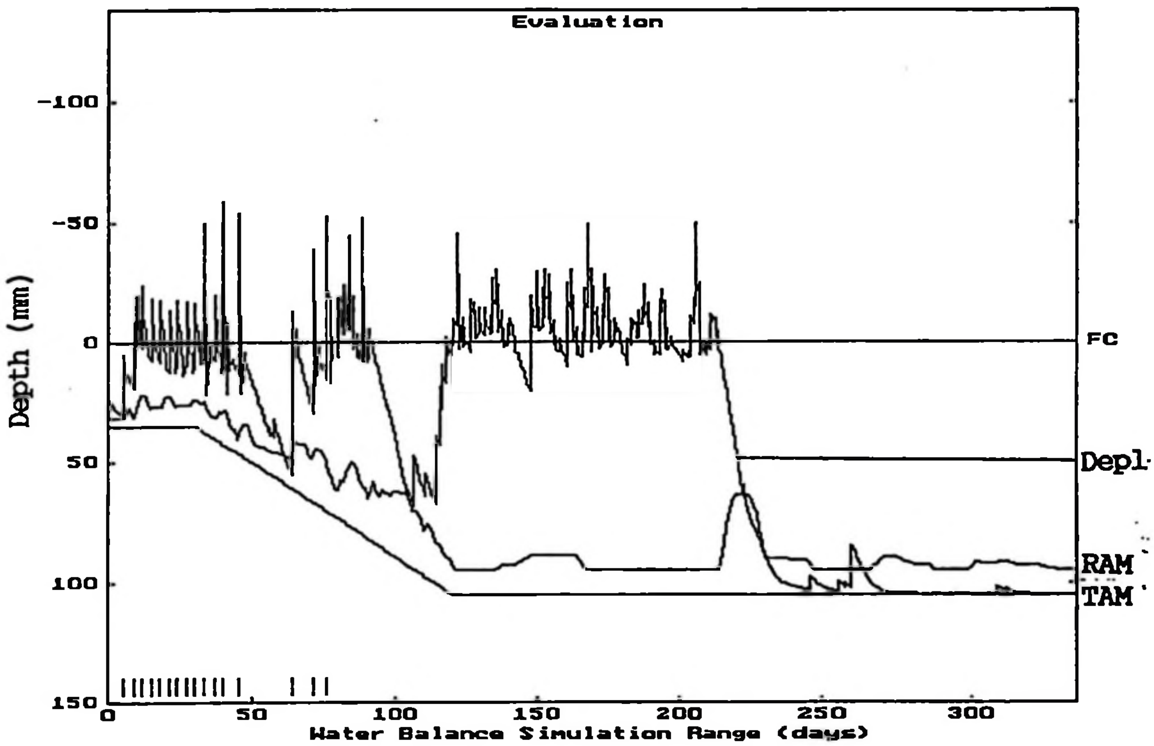

Figure 8c: Root zone depletion graph for field F45

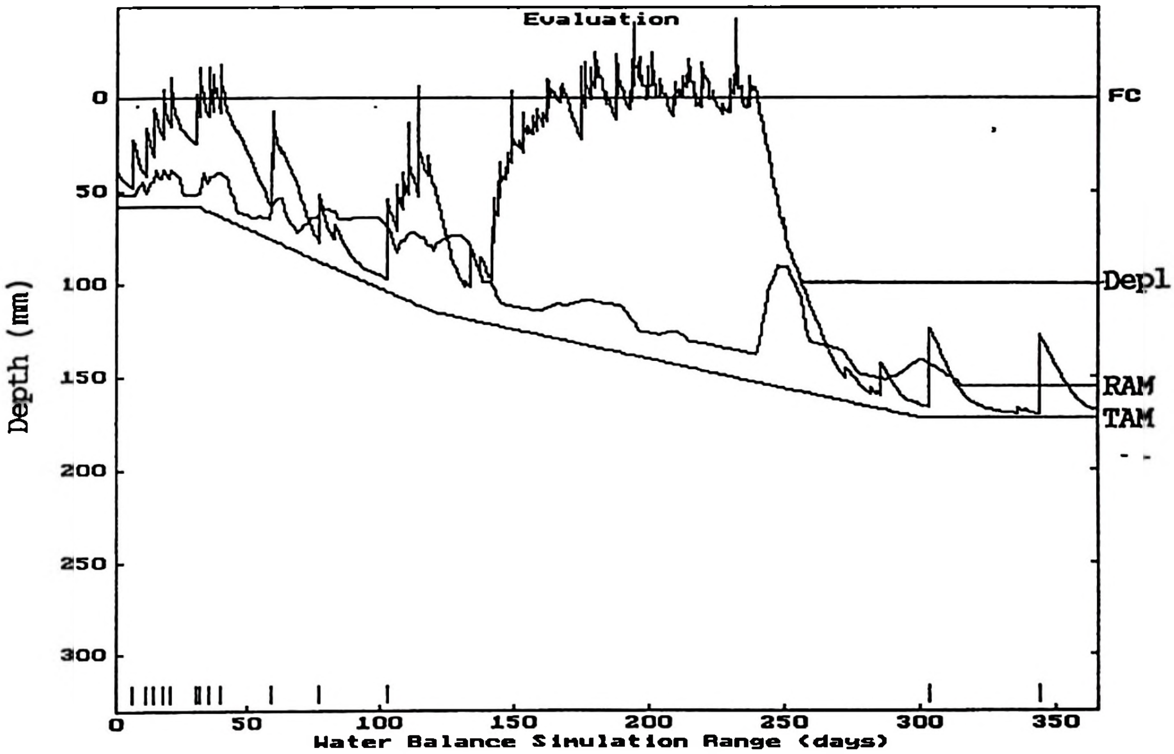

Figure 8d: Root zone depletion graph for field M3

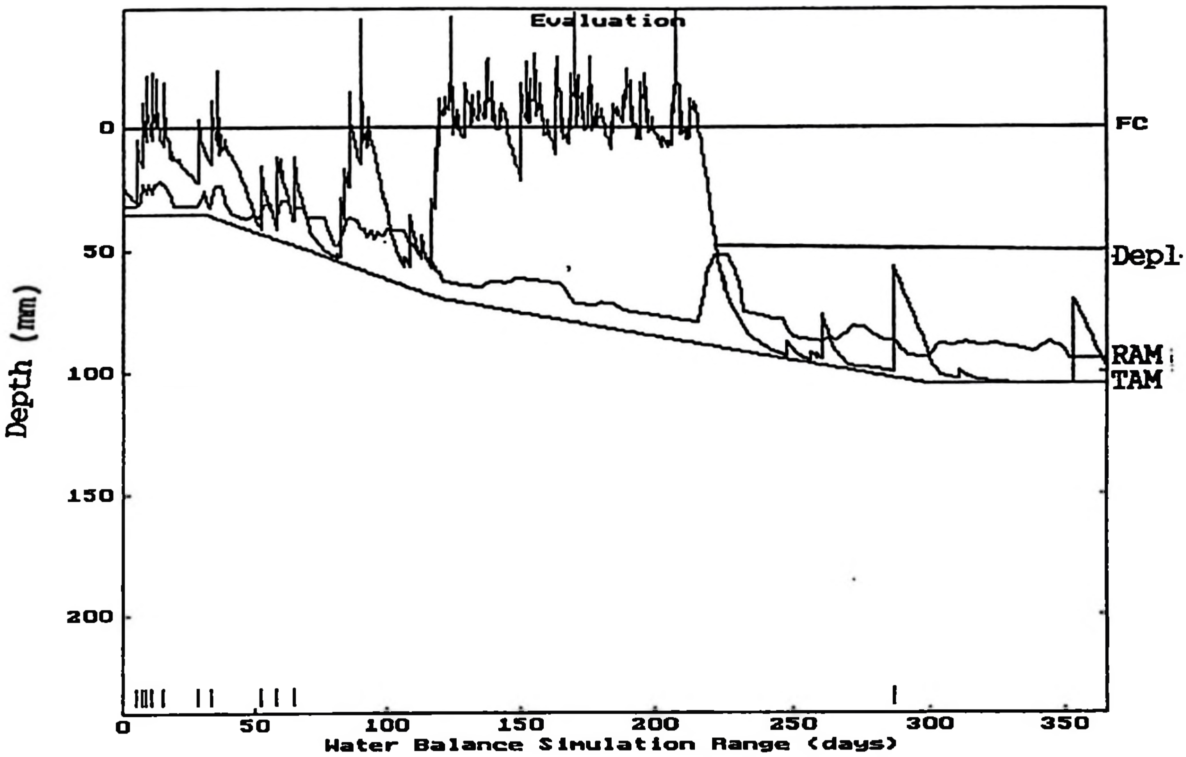

Figure 8e: Root zone depletion graph for field M32

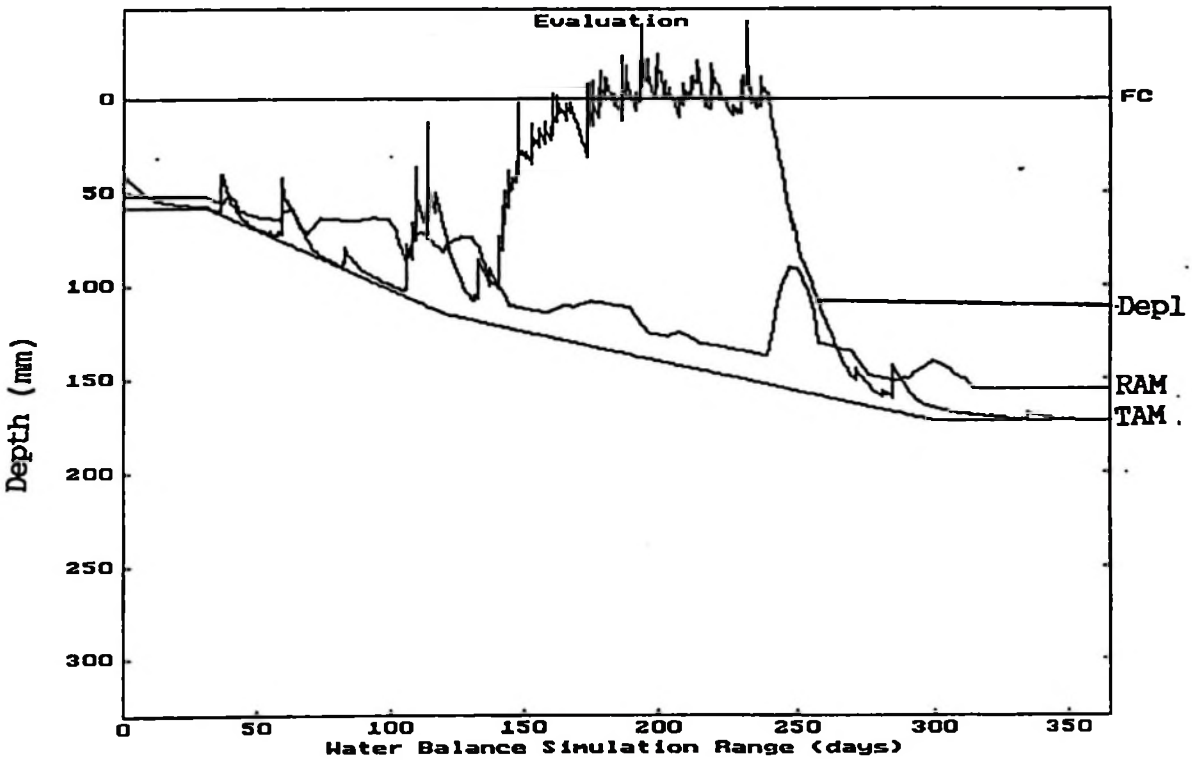

Figure 9a: Root zone depletion graph for field F45 (no irrigation)

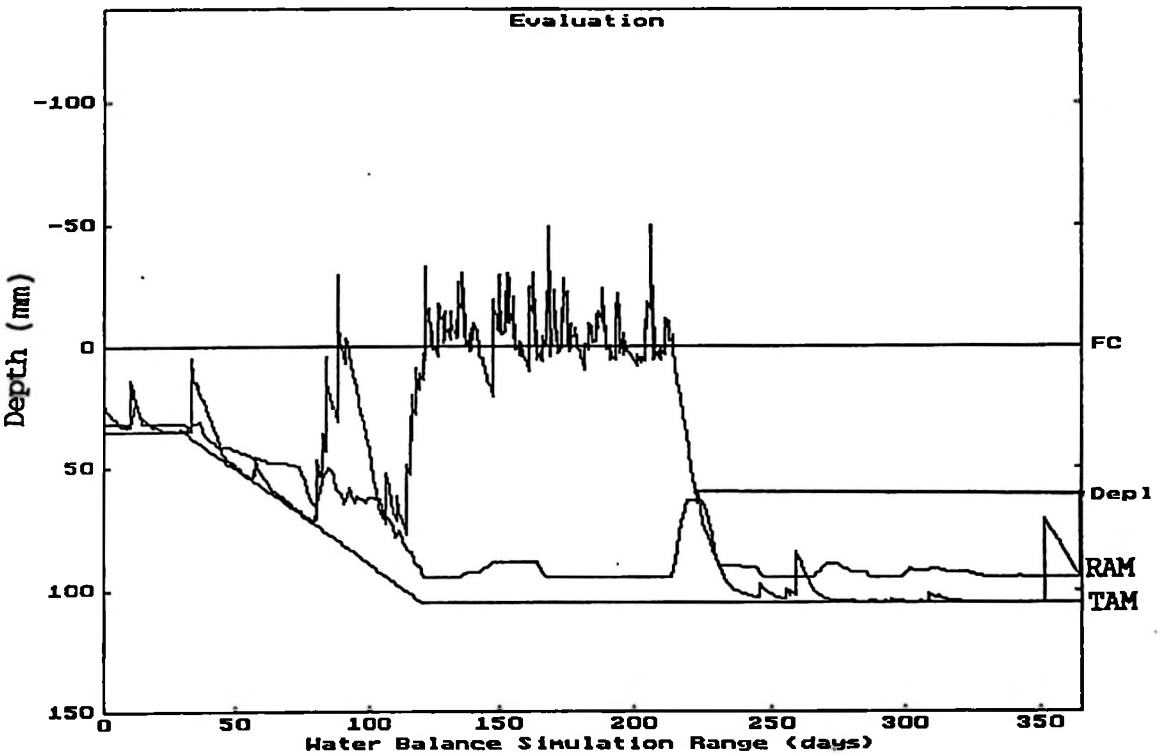

Figure 9b: Root zone depletion graph for field F041 (no irrigation)

5. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be drawn from the study.

5.1 Conclusions

(1) The Msolwa irrigation system designed for a compensation rate of 4.5 mm/day with a possibility built-in to increase the compensation rate to 5 mm/day is capable of meeting the maximum consumptive use of sugarcane of 4.6 mm/day even in complete absence of rainfall. However, this is only possible if the system is operated according to design recommendations.

(2) The average net irrigation requirement of 28% of the water requirement of sugarcane and the erratic and irregular monthly distribution of rainfall at Msolwa estate makes supplementary irrigation necessary to guarantee continuous commercial sugarcane production. Due to the fact that water consumption and cane yields are linearly related, provision of adequate amounts of irrigation water could increase yield levels considerably as compared to yields obtainable under rainfed conditions provided that other growth factors are not limiting.

(3) The standard irrigation cycle time of 14 days appears to be too long for the sandy areas which causes a depression in growth rates and serious wilting due to the low soil moisture holding capacity of these soils.

(4) The CU, DU, PELQ and AELQ values obtained from the study are all below the designed and recommended ones. These low efficiency values are due to poor condition of the system, low sprinkler nozzle operating pressure and shorter irrigation duration. Lower sprinkler operating pressure is as a result of operating too many irrigation lines at a time as compared to the capacity of pumps in operation, leakages in the sprinkler lines and having more than the recommended number of sprinklers (10) in a line. The poor state of the irrigation system is due to lack of proper maintenance and non-replacement of worn out parts.

(5) Water logging problems experienced during the rainy season on heavy clay soils are indicative of a high degree of neglect of drainage activities over a large area of the estate.

(6) The current level of sugarcane production is far below the climatic yield potential of the area which is estimated at 109 tonnes cane per hectare per annum. However, irrigation water quality, physical and chemical

properties of soils and climatological conditions of the study area are all favourable for sugarcane production. As such Msolwa estate is capable of achieving potential climatic yields if proper sugarcane agronomic practices are followed and crop water requirements are met.

5.2 Recommendations

(1) Proper attention should be given to the system's operation and maintenance activities in order to increase irrigation efficiencies. This should include increasing irrigation lines to 205, replacement of worn out parts and repair of damaged structures.

(2) It is recommended that adequate transport facilities should be provided to the supervisors and the foremen to enable close supervision of irrigation activities and to ensure that the system is operated efficiently and according to design recommendations.

(3) In order to avoid shorter durations of the first sets in the morning, it is recommended that irrigation pumps should be started at 0700h in the morning instead of 0800h as is the case now.

(4) It is recommended that the drainage system should be rehabilitated to allow efficient removal of surface water.

(5) It is recommended that irrigation scheduling should be done using available modern softwares such as Irrigation Scheduling Information System (IRSIS) that take into account different soil and plant factors.

(6) It is recommended that concerted efforts should be made to identify areas of wastage and loss of irrigation water and to correct them effectively.

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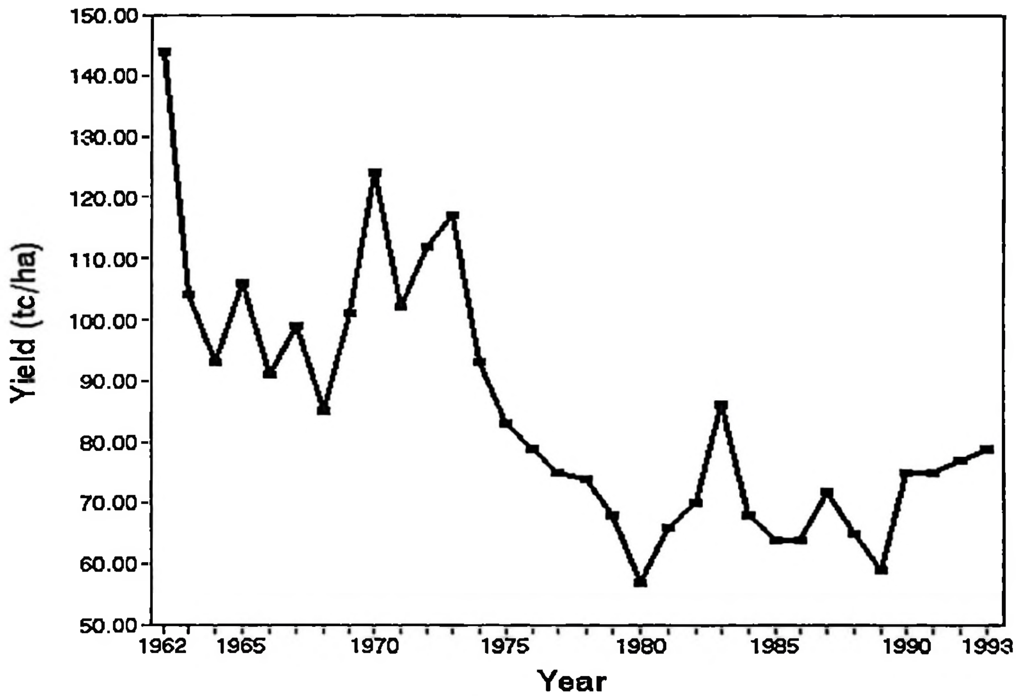
APPENDICES



Appendix 1a: Kilombero Sugar Estates - historical cane production (1962 - 1993)

Appendix 1b: Kilombero Sugar Company historical cane production for period 1962 - 1993

	Msolwa		Ruembe		Total	
Year	tc/h	Sugar (t)	tc/h	Sugar (t)	tc/h	Sugar (t)
1962	144	11109			144	11109
1963	104	12894			104	12894
1964	93	19602			93	19602
1965	106	25234			106	25234
1966	91	26538			91	26538
1967	99	31300			99	31300
1968	85	29075			85	29075
1969	101	36118			101	36118
1970	124	39193			124	39193
1971	102	37543			102	37543
1972	112	35625			112	35625
1973	117	38973			117	38973
1974	93	35378			93	35378
1975	83	34318			83	34318
1976*	81	35238	77	11549	79	46787
1977	79	20821	70	23111	75	43932
1978	70	33145	77	23940	74	66085
1979	67	25328	69	26620	68	51948
1980	51	19504	63	28566	57	48070
1981	59	20093	73	30000	66	50093
1982	67	14712	74	25394	70	40106
1983	83	24040	89	31100	86	55140
1984	71	21210	66	25018	68	46228
1985	67	20892	61	24615	64	45507
1986	63	18676	66	22510	64	41186
1987	70	20948	72	24270	72	45218
1988	67	20737	63	21832	65	42569
1989	57	15710	62	23494	59	39204
1990	62	18376	70	24361	75	53674
1991	73	22501	78	31173	75	53674
1992	77	23529	77	24380	77	57909
1993	79	19554	79	24615	79	44169

* Ruembe Factory started sugar production in 1976

Appendix 2: Average monthly rainfall (mm) at Msolwa estate

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
1961	148.0	136.7	63.0	322.0	123.3	62.5	64.7	8.7	47.0	191.7	260.7	457.5	1885.8
1962	248.0	159.8	282.8	325.3	66.5	6.6	5.8	60.1	12.3	34.0	19.4	119.8	1340.4
1963	177.3	160.0	515.0	342.3	44.8	61.8	5.7	1.3	0.8	22.3	386.9	144.7	1862.9
1964	157.0	178.3	361.6	366.0	44.3	6.3	2.2	15.4	2.2	19.7	6.9	63.9	1223.8
1965	227.6	157.3	371.3	345.3	71.1	1.0	8.0	27.8	34.0	46.2	75.7	167.0	1532.3
1966	107.9	138.3	203.0	296.9	120.4	20.4	1.1	3.3	9.7	37.4	78.7	66.1	1083.2
1967	63.0	143.6	206.0	314.4	235.1	52.4	55.9	13.4	70.6	52.0	199.1	466.8	1872.3
1968	171.9	120.3	291.2	651.8	135.0	67.9	0.0	0.8	10.0	8.2	158.2	120.5	1735.8
1969	94.1	122.1	165.0	265.3	95.6	15.2	6.9	4.6	1.3	12.2	87.6	15.1	885.0
1970	438.7	230.3	250.0	215.3	20.9	5.6	6.8	4.9	42.0	9.7	0.0	139.0	1363.2
1971	116.0	82.1	229.0	388.0	116.0	23.0	37.0	0.0	5.7	26.0	41.0	102.0	1165.8
1972	107.0	243.1	325.0	344.0	243.5	0.1	8.0	5.0	115.0	24.4	303.0	140.5	1858.6
1973	196.6	170.2	142.1	403.6	116.8	18.0	2.1	0.0	2.4	0.0	68.0	48.3	1168.1
1974	183.4	98.6	92.4	534.9	116.5	76.0	52.2	0.4	18.1	74.1	49.1	35.1	1330.8
1975	149.4	83.5	150.5	317.6	184.3	36.2	10.8	4.5	23.7	13.2	17.2	171.4	1162.3
1976	179.1	102.1	220.3	229.6	76.8	38.3	4.5	20.5	0.6	4.7	3.1	71.5	951.1
1977	182.1	151.0	197.4	281.5	134.9	1.1	14.3	12.2	49.2	89.6	159.8	163.6	1436.7
1978	166.2	34.2	254.8	196.2	28.3	19.1	0.7	3.2	0.8	5.6	246.8	336.2	1292.1
1979	206.7	360.1	351.7	509.4	136.2	36.6	15.5	15.8	10.2	24.7	37.1	294.4	1998.4
1980	253.6	96.3	152.3	309.5	177.7	0.0	1.4	2.0	0.0	12.8	76.6	90.6	1172.8
1981	165.9	82.8	186.5	383.7	122.3	36.4	0.0	3.4	1.9	32.0	9.6	149.7	1174.2
1982	155.6	53.8	213.6	239.3	137.8	31.2	34.7	1.0	61.4	207.7	204.4	290.9	1631.4
1983	129.0	85.3	248.2	202.1	153.6	31.4	18.7	12.9	5.5	0.3	17.4	151.8	1056.2
1984	130.9	282.7	227.7	399.7	82.2	44.5	11.6	5.2	6.0	83.1	123.8	228.3	1625.7
1985	35.3	127.2	220.6	252.5	85.1	9.7	23.6	15.7	0.0	3.3	130.4	46.8	950.2
1986	159.0	63.7	144.7	298.9	92.4	2.7	1.1	5.5	0.2	50.3	122.1	180.6	1121.2
1987	221.2	95.0	168.8	272.7	156.7	0.0	52.9	12.7	0.9	6.8	127.0	62.8	1177.5
1988	113.4	97.7	304.8	218.3	84.2	53.8	0.2	12.1	8.7	16.3	63.7	197.4	1170.6
1989	234.4	96.9	250.7	490.2	224.4	32.6	10.7	6.4	2.7	29.8	91.2	218.9	1688.9
1990	94.0	147.5	254.7	178.1	112.3	20.2	3.9	5.0	8.5	14.6	142.6	87.6	1069.0
1991	153.7	29.0	218.5	402.7	142.9	8.7	24.6	5.9	12.4	5.7	39.9	150.9	1194.9
1992	41.5	196.0	208.2	499.0	155.0	95.4	0.4	0.2	0.0	0.0	155.5	105.6	1456.8
1993	190.6	106.0	201.3	240.8	208.4	24.3	32.3	0.4	1.2	26.0	42.6	12.8	1086.7
1994	167.4	243.6	239.8	218.1	107.4	6.1	23.6	5.8	0.0	95.3	44.5	73.3	1224.9
1995	164.4	122.5	421.2	272.9	94.3	8.2	0.0	22.2	13.1	48.0	0.0	45.2	1212.0
Total	5729.9	4797.6	8333.7	11527.9	4247.0	953.3	541.9	318.3	578.1	1327.7	3589.6	5216.6	47161.6
Mean	163.7	137.1	238.1	329.4	121.3	27.2	15.5	9.1	16.5	37.9	102.6	149.0	1347.5
s.d.	70.4	69.2	89.4	106.8	54.2	24.3	18.0	11.1	25.0	47.2	92.0	108.9	301.0
CV	0.4	0.5	0.4	0.3	0.4	0.9	1.2	1.2	1.5	1.2	0.9	0.7	0.2

Appendix 3: Average monthly Class A Pan evaporation (mm) at Msolwa estate

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
1962	-	155.0	182.5	141.0	148.0	141.0	118.5	121.5	171.0	187.0	231.0	222.0	1818.5
1963	180.5	167.5	151.5	126.0	148.0	142.0	128.5	151.0	167.0	201.0	150.0	188.5	1901.5
1964	171.5	204.5	163.5	131.0	132.0	149.0	150.5	143.5	185.5	205.5	239.0	239.0	2114.5
1965	185.0	166.0	176.0	120.0	136.5	139.0	139.0	151.5	152.5	180.5	198.0	180.5	1924.5
1966	232.0	179.0	167.5	122.0	126.5	120.0	159.0	169.0	191.5	216.5	222.0	227.0	2132.0
1967	232.0	193.0	186.5	123.0	103.5	113.5	122.5	147.5	147.0	186.0	178.5	145.0	1878.0
1968	156.5	170.5	147.0	110.0	123.5	116.0	138.0	152.0	166.3	207.5	172.5	219.0	1878.8
1969	228.0	146.5	178.0	143.0	137.5	129.5	144.5	129.0	187.0	231.0	191.0	231.0	2076.0
1970	117.5	119.5	140.5	110.5	147.0	133.0	123.5	138.0	146.0	186.0	241.5	200.0	1803.0
1971	158.0	141.5	144.5	112.5	126.5	138.5	111.5	136.5	140.0	177.0	226.0	196.0	1808.5
1972	176.0	128.5	126.0	104.0	103.0	120.0	120.0	139.0	143.0	153.0	152.5	180.0	1645.0
1973	140.0	129.0	168.0	106.0	119.5	130.0	134.0	134.0	168.5	214.0	195.5	204.5	1843.0
1974	186.0	193.5	179.5	104.0	115.8	107.8	102.4	140.8	157.1	181.1	214.4	222.2	1904.6
1975	169.3	196.0	136.8	126.0	114.7	102.7	126.2	132.2	145.3	170.8	229.0	179.7	1828.7
1976	179.8	161.5	142.3	116.6	131.8	110.3	129.5	131.2	149.3	194.2	230.6	202.2	1879.3
1977	137.0	137.7	147.7	67.4	109.2	131.5	130.0	123.0	145.6	153.7	140.6	149.7	1573.1
1978	125.0	144.9	146.1	132.6	126.9	112.6	136.2	143.2	164.3	196.3	179.2	-	1607.3
1979	145.1	110.9	145.1	90.0	102.5	133.4	134.9	117.7	161.2	195.5	219.2	147.6	1703.1
1980	116.8	173.9	153.8	120.4	123.9	143.0	129.0	152.7	163.5	214.1	193.6	180.9	1865.6
1981	190.0	157.2	177.2	109.6	126.1	133.0	137.5	144.0	171.0	184.2	236.0	178.6	1944.4
1982	222.2	172.0	181.1	128.8	114.1	116.6	133.4	153.1	154.0	153.3	162.4	167.7	1858.7
1983	181.0	163.6	143.9	118.8	166.9	105.6	123.9	133.8	171.2	197.6	240.0	195.5	1941.8
1984	132.2	153.5	157.9	89.1	123.9	114.7	111.9	123.1	177.5	185.5	150.4	169.7	1689.4
1985	199.5	110.7	158.2	106.0	122.8	137.1	135.2	156.2	165.5	188.5	173.4	199.4	1852.5
1986	131.4	178.6	141.0	110.2	94.4	141.6	142.2	148.9	158.5	216.3	191.4	163.3	1817.8
1987	155.1	157.7	152.0	131.3	126.5	139.0	124.8	137.6	166.5	184.4	198.5	213.3	1886.7
1988	185.0	181.9	137.4	113.1	124.9	111.8	127.9	140.9	172.4	201.2	185.2	162.2	1843.9
1989	94.4	161.9	144.8	77.5	102.7	108.4	118.1	122.6	152.0	178.5	198.8	140.2	1599.9
1990	161.1	127.6	125.6	125.9	119.5	123.8	133.9	139.9	142.6	185.9	177.9	205.2	1768.9
1991	167.5	178.3	164.9	130.2	115.6	131.3	130.6	144.9	162.1	191.7	204.1	161.6	1882.8
1992	207.3	139.9	162.8	95.6	108.4	104.1	122.7	154.3	176.3	217.5	183.1	183.3	1855.3
1993	147.3	150.5	150.6	107.6	118.8	130.1	123.8	131.4	165.8	211.3	205.2	271.9	1914.3
1994	193.0	103.6	140.7	105.1	166.4	121.5	132.9	130.6	169.5	160.2	181.6	186.3	1791.4
1995	171.9	147.3	179.9	159.0	115.1	129.6	131.0	139.7	147.0	194.7	238.0	240.7	1993.9
Total	5574.9	5303.2	5300.8	3913.8	4222.4	4261.0	4407.5	4754.3	5503.5	6501.5	6730.1	6353.7	62826.7
Mean	168.9	156.0	155.9	115.1	124.2	125.3	129.6	139.8	161.9	191.2	197.9	192.5	1858.5
s.d.	33.9	33.9	25.2	16.7	18.2	16.6	12.9	10.9	11.5	13.3	19.0	33.9	128.7
CV	0.2	0.2	0.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1

Appendix 4: Mean monthly climatological data at Msolwa estate (34 - year mean data)

Month	Max temp. (C)	Min temp. (C)	Mean temp. (C)	Max RH (%)	Min RH (%)	Mean RH (%)	Epan (mm)	Sunshine hours per day (h)	Wind speed (km/day)	Rainfall (mm)	Moisture deficit (mm)
January	33.4	21.8	27.6	94.0	52.0	73.0	169.0	6.2	74.6	163.6	5.4
February	33.3	21.9	27.6	94.0	51.0	72.5	156.0	6.4	73.0	137.1	18.9
March	32.7	21.9	27.3	95.0	53.0	74.0	156.0	6.1	65.3	238.1	-82.1
April	30.8	22.3	26.6	96.0	57.0	76.5	115.0	5.1	70.0	329.4	-214.4
May	29.6	20.2	24.9	95.0	55.0	75.0	124.0	5.4	70.7	121.3	2.7
June	28.8	17.0	22.9	94.0	52.0	73.0	123.0	6.2	75.3	27.2	95.8
July	28.6	16.3	22.5	93.0	47.0	70.0	130.0	5.8	75.0	15.5	114.5
August	29.7	17.3	23.5	91.0	49.0	70.0	140.0	5.8	68.0	9.1	130.9
September	31.5	18.4	25.0	90.0	45.0	67.5	162.0	6.1	72.8	16.5	145.5
October	33.3	20.4	26.9	89.0	46.0	67.5	191.0	6.7	76.9	37.9	153.1
November	33.3	21.6	27.5	89.0	47.0	68.0	198.0	7.5	78.7	102.6	95.4
December	33.2	22.0	27.6	92.0	50.0	71.0	193.0	7.1	77.6	149.0	44.0
Total	378.2	241.1	309.7	1112.0	604.0	858.0	1857.0	74.4	877.9	1347.3	509.7
Mean	31.5	20.1	25.8	92.7	50.3	71.5	154.8	6.2	73.2	112.3	42.5

Appendix 5: Sugarcane growth factors at Msolwa estate

Age (months)	plantcane	seedcane	late ratoon*	early ratoon
0 - 0.5	0.3	0.3	0.3	0.3
1	0.3	0.4	0.4	0.4
1.5	0.4	0.5	0.5	0.5
2	0.5	0.6	0.6	0.6
2.5	0.6	0.7	0.7	0.6
3	0.7	0.8	0.8	0.7
3.5	0.8	0.8	0.9	0.8
4	0.8	0.9	1.0	0.8
4.5	0.9	0.9	1.0	0.9
5	0.9	1.0	1.0	0.9
5.5	1.0	1.0	1.0	1.0
6	1.0	1.0	0.8	1.0
6.5	1.0	1.0	0.7	1.0
7	1.0	1.0	0.6	1.0
7.5	1.0	-	0.6	1.0
8	0.8	-	0.5	0.8
8.5	0.7	-	0.5	0.6
9	0.6	-	0.4	0.4
9.5	0.6	-	0.3	0.3
10	0.5	-	0.3	0.3
10.5	0.5	-	0.3	0.3
11 - 12.5	0.4	-	0.3	0.3
> 12.5	0.3	-	0.3	0.3

* from 15 October onwards

Appendix 6: Water use and sugarcane yields (tons cane/hectare) in Hawaii, South Africa, Mauritius and Australia

Data source	ETcrop (mm)	Yield (tc/ha)	Data source	ETcrop (mm)	Yield (tc/ha)
Hawaii	2640.0	279.0	Pongola	1177.0	126.0
	3020.0	313.0		1481.0	141.0
	3250.0	326.0		1627.0	146.0
	3840.0	342.0		1590.0	160.0
Cornubia	1671.0	155.0		1330.0	131.0
	1595.0	133.0		1381.0	137.0
	1488.0	131.0		1534.0	136.0
	1377.0	118.0		1711.0	153.0
	1021.0	86.0		1082.0	91.0
	1770.0	156.0		1184.0	93.0
	1636.0	148.0		1286.0	106.0
	1466.0	140.0		1438.0	124.0
	1349.0	132.0		893.0	96.0
	1024.0	101.0		943.0	115.0
	1050.0	93.0		993.0	121.0
	1002.0	83.0		1243.0	148.0
	975.0	91.0		1014.0	103.0
	972.0	75.0		1164.0	134.0
	901.0	76.0		1264.0	140.0
Ottawa	1514.0	151.0		1364.0	149.0
	1410.0	132.0		1773.0	134.0
	1242.0	108.0		1540.0	121.0
	1095.0	106.0		1340.0	130.0
	790.0	63.0		1290.0	122.0
	1438.0	144.0		1348.0	143.0
	1346.0	136.0		1619.0	181.0
	1163.0	116.0		1287.0	148.0
	762.0	58.0		1402.0	124.0
	1796.0	184.0		1540.0	135.0
	1595.0	168.0		1540.0	128.0
	1359.0	166.0		1540.0	137.0
	1118.0	149.0		1540.0	131.0
	937.0	77.0		973.0	96.0
	1167.0	102.0		1177.0	129.0
	1039.0	84.0		1458.0	142.0
	931.0	78.0		1590.0	141.0
	879.0	72.0		973.0	87.0
	725.0	61.0	Shakaskraal	1201.0	116.0
	1623.0	165.0		1011.0	97.0
	1494.0	151.0		660.0	57.0
	1326.0	148.0	Mauritius	1613.0	137.0
	1283.0	142.0		1421.0	146.0
	963.0	83.0		1673.0	139.0
	964.0	82.0	Australia	1560.0	136.0
	838.0	81.0		1080.0	103.0
	1055.0	85.0			

Appendix 7: Practised Irrigation schedules at Msolwa estate for plantcane, seedcane and ratooncane

Irrigation	Days after planting	Application duration (h)	Application rate (mm/day)
Plant cane			
1st	0	3	2.7
2nd	7	3	2.7
3rd	14	3	2.7
4th	21	3	2.7
5th	28	3	2.7
6th	35	5	3.3
7th	45	5	3.3
8th	55	5	3.3
9th	65	5	3.3
10th	75	5	3.3
11th	85	10	4.5
Ratoon cane			
1st	0	10	3.0
2nd	21	5	3.3
3rd	31	5	3.3
4th	41	5	3.3
5th	51	10	4.5
Nurseries			
1st	0	3	2.7
2nd	7	3	2.7
3rd	14	3	2.7
4th	21	3	2.7
5th	28	3	2.7
6th	35	5	3.3
7th	45	5	3.3
8th	55	5	3.3
9th	65	5	3.3
10th	75	5	3.3
11th	85	10	4.5

Appendix 8: Design data of Msolwa estate irrigation system

Size of irrigation area

Total area to be irrigated (gross)	3140 ha
Division of areas	
pump station i	510 ha
pump station ii	500 ha
pump station iii	720 ha
pump station iv	630 ha
pump station v	780 ha
Crops grown:	sugarcane
Critical soil moisture content	1/3 of the total available moisture in the 1st 0.75 m of the soil profile
Water application per cycle	84.6 mm gross
Precipitation cycle	14 days
Daily irrigation time	2 * 10 = 20 hours
Water source	Great Ruaha and Msolwa rivers

Sprinkler irrigation system

Sprinklers

Number of nozzles	2
Diameter of nozzles	7.0/4.5
Pressure at nozzle	3.5 bar
Water consumption	4.88 m^3/h
Spray range (radius)	20 m
Sprinkler spacing	24 m by 24 m

Appendix 8 continued

Density of irrigation	8.45 mm/h
Percentage of overlapping	83.5%
Application efficiency	75%

Riser pipes for sprinklers

Diameter	30 mm
Overall length (from ground to nozzle)	1.4 m; 3.4 m

Sprinkler lines

Length of line	234 m
No. of sprinklers per line	10
Water consumption per line	48.8 m^3/h
Pressure to be set at the hydrant	4.4 bar

No. of sprinkler lines in operation
per pump station

PPS	I	32
	II	32
	III	46
	IV	46
	V	49

Total no. of sprinkler lines	205
Distance between hydrants	72 m

Pressure losses in a sprinkler line not to exceed 0.35 bar

Appendix 9a: Rainbow print out file - Rainfall probability at Msolwa estate

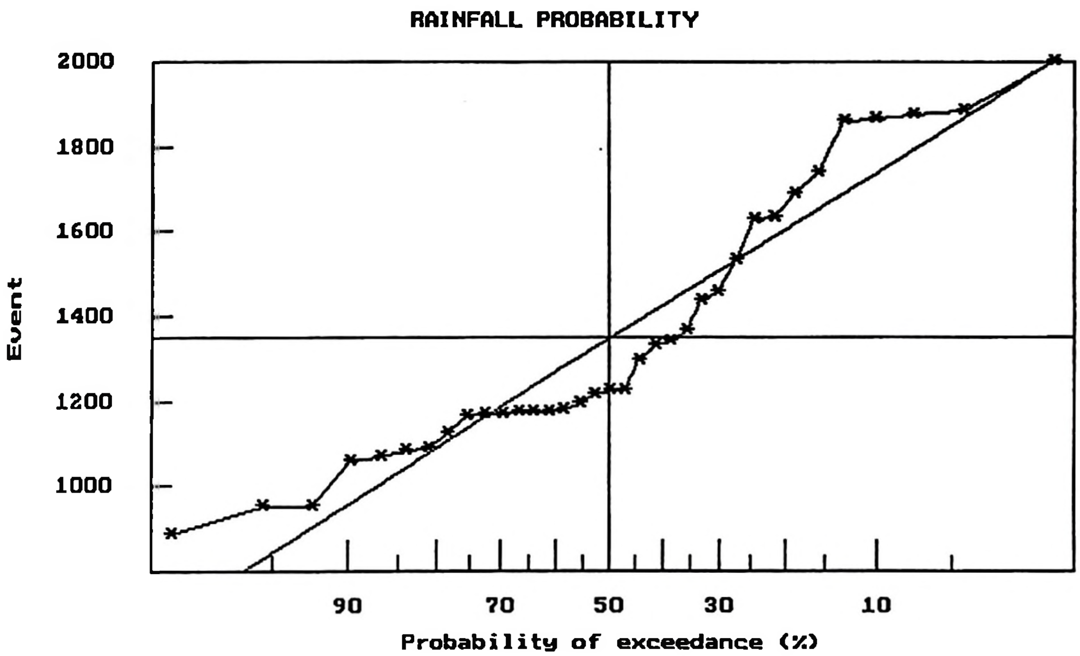
Observation range : from 1961 to 1995

Year	Rainfall (mm)
1961	1886.0
1962	1340.0
1963	1863.0
1964	1224.0
1965	1532.0
1966	1083.0
1967	1872.0
1968	1736.0
1969	885.0
1970	1363.0
1971	1166.0
1972	1859.0
1973	1168.0
1974	1331.0
1975	1162.0
1976	951.0
1977	1437.0
1978	1292.0
1979	1998.0
1980	1173.0
1981	1174.0
1982	1631.0
1983	1056.0
1984	1626.0
1985	950.0
1986	1123.0
1987	1178.0
1988	1171.0
1989	1689.0
1990	1069.0
1991	1195.0
1992	1455.0
1993	1087.0
1994	1225.0
1995	1212.0

Total : 35 observations

Appendix 9a continued

Probability of Exceedance (%)	Probability of Non-Exceedance (%)	Magnitude Event (mm)
5	95	1868.5
10	90	1753.4
15	85	1675.7
20	80	1614.0
25	75	1561.0
30	70	1513.4
35	65	1469.4
40	60	1427.6
45	55	1387.2
50	50	1347.5
55	45	1307.8
60	40	1267.4
65	35	1225.6
70	30	1181.5
75	25	1134.0
80	20	1081.0
85	15	1019.3
90	10	941.6
95	5	826.5



Appendix 9b: Rainfall probability graph for Msolwa estate

Appendix 10: Dependable mean monthly wet, normal and dry year rainfalls (mm) at Msolwa estate

Month	Average	Wet year	Normal year	Dry year
January	163.6	196.0	163.6	131.2
February	137.1	164.2	137.1	110.0
March	238.1	285.2	238.1	191.0
April	329.4	394.5	329.4	264.3
May	121.3	145.3	121.3	97.3
June	27.2	32.6	27.2	21.8
July	15.5	18.6	15.5	12.4
August	9.1	10.9	9.1	7.3
September	16.5	19.8	16.5	13.2
October	37.9	45.4	37.9	30.4
November	102.6	122.9	102.6	82.3
December	149.0	178.5	149.0	119.5
YEAR	1347.3	1613.8	1347.3	1080.8

Appendix 11: Data sheet for sprinkler lateral evaluation

1. Location	section	------
	block	------
	date	------
2. Crop	r/zone depth	------
	MAD	------
3. Soil	texture	------
	available Moisture	-----
	SMD	------
4. Sprinkler:	make	---------
	model	---------
	nozzles	---------

5. Sprinkler spacing (m) ------ by ------

6. Irrigation duration (h) ---------

7. Rated sprinkler discharge (l/s) ---------

8. Rated sprinkler pressure (bar) ---------

9. Rated application rate (mm/h) ---------

10. Lateral	diameter (m)	---------
	slope (%)	---------
	riser height (m)	---------

11. Actual sprinkler pressure and discharge rates:

		Sprinkler no. on test lateral				
		1	4	5	6	end
Initial pressure	(bar)	---	---	---	---	---
Final pressure	(bar)	---	---	---	---	---
Catch volume	(l)	---	---	---	---	---
Catch time	(s)	---	---	---	---	---
Discharge	(l/s)	---	---	---	---	---

12. Wind run (m)		
	initial	--------
	final	--------

13. Wind speed (m/s) --------

Appendix 11 continued

14. Container grid spacing (m) ------ by ------

15. Evaporation container
    initial -------
    final -------
    loss -------

16. Sprinkler pressure (bar)
    maximum
    minimum -------
    average -------

17. Test
    start -------
    stop -------
    duration -------

18. Comments ---

Appendix 12: Msolwa estate sprinkler irrigation performance evaluation results

Field	Av. hydrant pressure (bar)	Av. spr. pressure (bar)	Spr. pressure variation (bar)	Av. spr. discharge (l/s)	Application rate (mm/h)	Irrigation duration (h)	Test duration (h)	Av. depth applied during irrigation (mm)	Av. depth applied during testing (mm)
F 13	1.96	1.80	0.20	0.74	4.63	4.50	2.17	20.81	10.04
F 12A	2.60	2.14	0.50	1.12	7.00	3.00	2.50	21.00	17.50
F 24A	2.65	2.28	0.40	1.20	7.50	4.50	3.58	33.75	26.85
F29	3.75	3.05	0.35	1.50	9.38	4.50	4.03	42.19	37.78
F16	3.25	2.65	0.55	1.34	8.38	4.75	4.18	39.78	35.01
F64A	2.70	2.30	0.00	1.27	7.94	4.50	3.75	35.72	29.77
F45A	3.75	3.22	0.15	1.51	9.44	4.30	3.80	40.58	35.86
F61	3.05	2.40	0.60	1.28	8.00	4.75	4.13	38.00	33.04
F64B	2.50	1.86	1.00	0.76	4.75	4.50	3.78	21.38	17.96
F92	3.35	3.05	0.20	1.50	9.38	3.00	2.25	28.13	21.09
F54	3.45	2.66	0.45	1.41	8.81	4.50	3.92	39.66	34.55
F45B	2.90	2.41	0.45	1.29	8.06	4.80	4.30	38.70	34.67
F44A	2.95	2.44	0.25	1.31	8.19	3.25	2.87	26.61	23.50
F45C	3.45	3.13	0.15	1.51	9.44	5.00	4.40	47.19	41.53
F44B	3.70	2.86	0.40	1.48	9.25	3.90	3.80	36.08	35.15
F12B	3.15	2.83	0.20	1.46	9.13	3.00	2.50	27.38	22.81
F84	3.20	2.38	0.25	1.32	8.25	3.00	2.60	24.75	21.45
F24B	2.85	2.58	0.30	1.26	7.88	4.75	3.67	37.41	28.90
F72	3.45	2.70	0.55	1.41	8.81	4.75	4.25	41.86	37.45
F14	3.05	2.59	0.25	1.28	8.00	4.75	4.60	38.00	36.80
Total	61.71	51.33	7.20	25.95	162.19				
Mean	3.09	2.57	0.36	1.30	8.11				
s.d.	0.45	0.38	0.21	0.21	1.33				
CV	0.15	0.15	0.59	0.16	0.16				

Appendix 12 continued.

Field	Av. depth caught (mm)	Av. catch rate (mm)	Av. Low quarter depth caught (mm)	Av. low quarter catch rate (mm/h)	Av. wind speed (m/s)	Av. evaporation loss (mm/h)	CU (%)	DU (%)	PELQ (%)
F13	9.28	4.28	3.17	1.46	1.10	0.05	48.5	34.1	31.6
F12A	16.16	6.46	6.11	2.45	2.08	0.05	58.7	37.9	35.0
F24A	25.41	7.10	16.65	4.65	1.25	0.04	74.9	65.5	62.0
F29	35.42	8.79	25.43	6.31	1.16	0.04	81.6	71.8	67.3
F16	32.62	7.80	19.51	4.67	1.24	0.04	69.3	59.9	55.8
F64A	25.72	6.86	18.10	4.82	1.06	0.08	83.3	70.3	60.7
F45A	27.30	7.20	8.33	2.20	2.24	0.13	53.2	30.6	23.3
F61	28.06	6.80	5.59	1.35	2.48	0.11	53.4	19.9	16.9
F64B	15.36	4.10	7.76	2.05	1.39	0.13	71.0	50.0	43.2
F92	20.51	9.11	14.98	6.65	1.06	0.07	78.8	73.0	70.9
F54	33.53	8.55	19.71	5.03	1.36	0.09	74.3	58.8	57.1
F45B	33.96	7.90	23.21	5.40	0.66	0.08	79.4	68.4	67.0
F44A	22.28	7.76	14.58	5.08	0.91	0.03	74.7	65.5	62.0
F45C	40.49	9.20	32.61	7.41	1.03	0.05	87.0	80.5	78.5
F44B	33.91	9.00	26.47	7.03	1.07	0.04	85.0	78.1	76.0
F12B	21.93	8.77	15.15	6.06	1.13	0.03	79.2	69.1	66.4
F84	18.25	7.02	11.85	4.56	1.31	0.07	74.7	65.0	55.3
F24B	27.00	7.35	18.42	5.02	0.86	0.05	76.8	68.3	63.7
F72	34.40	7.48	23.50	5.10	1.22	0.05	76.0	68.2	57.9
F14	33.17	7.80	19.92	4.69	0.98	0.04	69.7	60.1	58.6
Total					25.59	1.27	1449.54	1194.83	1109.18
Mean					1.28	0.06	72.48	59.74	55.46
s.d.					0.45	0.03	10.66	16.24	16.51
CV					0.35	0.48	0.15	0.27	0.30

Appendix 12 continued.

Field	Soil textural class	Bulk density (g/cc)	FC (% vol)	Initial soil moisture (% wt.)	Initial soil moisture (% vol)	Root zone depth (m)	Soil moisture deficit (mm)	Av. low quarter depth caught during irrigation (mm)	AELQ (%)
F 13	SCL	1.47	39.1	6.5	9.5	0.25	74.0	6.6	31.6
F 12A	SCL	1.47	39.1	22.2	32.6	0.25	16.3	7.4	35.0
F 24A	SCL	1.47	39.1	23.4	34.4	0.25	11.8	20.9	34.8
F29	SC	1.43	40.5	16.7	23.9	0.25	41.5	28.4	67.3
F16	SCL	1.47	39.1	5.4	7.9	0.25	78.1	22.2	55.8
F64A	C	1.50	43.1	20.9	31.3	0.75	88.7	21.7	60.7
F45A	SL	1.37	41.0	8.2	11.2	0.25	74.6	9.5	23.3
F61	C	1.50	43.1	14.5	21.7	0.25	53.6	6.4	16.9
F64B	C	1.50	43.1	22.7	34.0	0.25	22.8	9.2	43.2
F92	SC	1.43	40.5	24.9	35.5	0.25	12.4	20.0	70.9
F54	C	1.50	43.1	17.1	25.7	0.25	43.6	22.6	57.1
F45B	SL	1.37	41.0	10.0	13.7	0.25	68.3	25.9	67.0
F44A	SL	1.37	41.0	9.3	12.7	0.25	70.8	16.5	62.0
F45C	SL	1.37	41.0	19.5	26.7	0.25	35.7	37.1	75.7
F44B	SL	1.37	41.0	19.8	27.1	0.25	34.7	27.4	76.0
F12B	SCL	1.47	39.1	23.0	33.8	0.33	17.5	18.2	63.8
F84	C	1.50	43.1	25.5	38.3	0.25	12.1	13.7	49.0
F24B	SCL	1.47	39.1	23.5	34.5	0.42	19.1	23.8	51.1
F72	C	1.50	43.1	22.6	33.9	0.25	23.0	24.2	54.9
F14	SCL	1.47	39.1	6.5	9.5	0.25	74.0	22.3	58.6
Total									1054.72
Mean									52.74
s.d.									16.58
CV									0.31

Appendix 13: Comparison of chemical properties of soil samples from different fields at Msolwa estate.

Source (Section)		pH	Organic carbon (%)	Total Nitrogen (%)	ECe (mmhos/cm)	SAR	Parameter P (mg/kg)	CEC	K (me/100g)	Na (me/100g)	Ca (me/100g)	Mg (me/100g)
I	High yield fields	5.2	0.93	0.10	0.09	0.16	2.76	2.75	0.17	0.13	4.54	1.81
	Low yield fields	5.5	0.96	0.10	0.07	0.19	9.90	3.67	0.15	0.16	4.42	2.45
II	High yield fields	5.3	0.43	0.08	0.09	0.14	0.00	6.89	0.13	0.11	4.75	1.65
	Low yield fields	5.4	1.47	0.05	0.05	0.19	6.72	4.13	0.13	0.12	2.60	1.04
III	High yield fields	5.8	1.28	0.07	0.05	0.43	9.06	6.89	0.10	0.35	5.26	1.40
	Low yield fields	5.6	1.00	0.08	0.07	0.34	4.83	6.89	0.14	0.23	3.39	1.38
IV	High yield fields	5.3	0.84	0.11	0.07	0.18	11.06	3.21	0.09	0.15	3.63	3.14
	Low yield fields	5.4	1.28	0.10	0.03	0.12	5.81	8.72	0.09	0.10	4.12	3.09
V	High yield fields	5.6	1.15	0.07	0.05	0.18	1.75	7.80	0.08	0.14	3.64	2.37
	Low yield fields	5.6	0.89	0.09	0.04	0.35	3.78	6.89	0.09	0.27	4.38	1.81
VI		5.2	2.02	0.16	0.07	0.10	0.30	3.21	0.12	0.05	1.57	0.76
Total		59.9	12.25	0.98	0.68	2.37	55.97	61.05	1.28	1.80	42.30	20.89
Mean		5.4	1.11	0.09	0.06	0.22	5.09	5.55	0.12	0.16	3.85	1.90

Appendix 14: Calculation of sugarcane yield using Thompson's production function

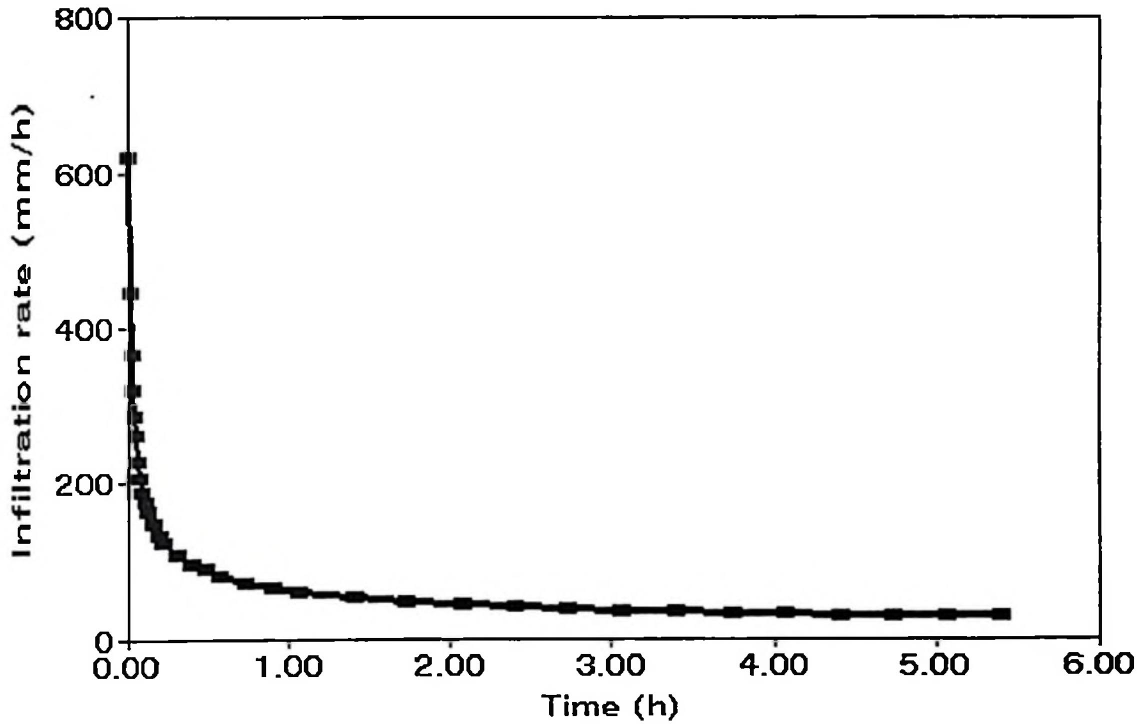
Field: F27

Cane category: Plantcane (PC)

Harvesting season: 1992/93

Month	Epan (mm)	Kc	ETcrop (mm)
August	144.9	0.3	43.5
September	162.1	0.5	81.1
October	191.7	0.7	134.2
November	204.1	0.8	163.3
December	161.6	0.9	145.4
January	207.3	1.0	207.3
February	139.9	1.0	139.9
March	162.8	0.8	130.2
April	95.6	0.6	57.4
May	108.4	0.5	54.2
June	104.1	0.4	41.6
July	122.7	0.4	49.1
Total			1247.2

$$\text{Yield} = 9.69 * (\text{ETcrop}/100) - 2.4$$
$$= 9.69 * (12.47) - 2.4$$
$$\text{Yield} = 118.45 \text{ tc/ha}$$



Appendix 15: Typical infiltration curve for field F34

Appendix 16a: Soil data used in evaluation of past irrigation seasons

Clay - Kilombero

Wilting Point : 21 Vol %
Field Capacity : 44 Vol %
(Total Available Water : 230 mm)
Basic Infiltration Rate : 120 mm/day
SCS Curve Number (CN) : 89

Sandy clay - Kilombero

Wilting Point : 22 Vol %
Field Capacity : 34 Vol %
(Total Available Water : 120 mm)
Basic Infiltration Rate : 180 mm/day
SCS Curve Number (CN) : 85

Sandy loam - Kilombero

Wilting Point : 6 Vol %
Field Capacity : 20 Vol %
(Total Available Water : 140 mm)
Basic Infiltration Rate : 420 mm/day
SCS Curve Number (CN) : 78

Sandy clay loam - Kilombero

Wilting Point : 18 Vol %
Field Capacity : 32 Vol %
(Total Available Water : 140 mm)
Basic Infiltration Rate : 240 mm/day
SCS Curve Number (CN) : 78

Appendix 16b: Crop data used in the determination of crop water and irrigation requirements and evaluation of past irrigations

Day	Growth Stage	kc	Sensit. Stage	ky	Root Depth (m)	p Factor
			Plantcane - Kilombero			
1	1	0.30	1	0.75	0.25	0.67
31	2	0.31	2		0.25	0.67
121	3	0.83	3	0.50	0.50	0.67
301	4	0.83	4	0.10	0.75	0.67
365	4	0.43	4	0.10	0.75	0.67
			Ratooncane - Kilombero			
1	1	0.33	1	0.75	0.25	0.67
31	2	0.34	2		0.25	0.67
121	3	0.76	3	0.50	0.75	0.67
301	4	0.75	4	0.10	0.75	0.67
365	4	0.30	4	0.10	0.75	0.67

Appendix 17a: Reference Evapotranspiration (ETo) data used in evaluation of past irrigation seasons

Decade Values Ranging From 1/01/1993 To 3/12/1994

			1993			
Dec/mon	1/01	2/01	3/01	1/02	2/02	3/02
ETo (mm/day)	7.0	3.6	3.7	5.9	5.0	5.1
Dec/mon	1/03	2/03	3/03	1/04	2/04	3/04
ETo (mm/day)	5.1	3.2	6.2	4.8	3.0	3.0
Dec/mon	1/05	2/05	3/05	1/06	2/06	3/06
ETo (mm/day)	3.0	5.1	3.4	4.9	3.2	5.0
Dec/mon	1/07	2/07	3/07	1/08	2/08	3/08
ETo (mm/day)	4.2	3.3	4.4	3.3	4.9	4.5
Dec/mon	1/09	2/09	3/09	1/10	2/10	3/10
ETo (mm/day)	4.0	6.0	6.6	6.9	7.4	6.3
Dec/mon	1/11	2/11	3/11	1/12	2/12	3/12
ETo (mm/day)	6.9	7.5	6.2	8.5	8.4	9.3
			1994			
Dec/mon	1/01	2/01	3/01	1/02	2/02	3/02
ETo (mm/day)	5.4	5.0	8.0	4.7	2.8	3.6
Dec/mon	1/03	2/03	3/03	1/04	2/04	3/04
ETo (mm/day)	4.2	4.7	4.7	3.3	3.9	3.4
Dec/mon	1/05	2/05	3/05	1/06	2/06	3/06
ETo (mm/day)	2.8	3.3	9.6	4.6	4.5	3.1
Dec/mon	1/07	2/07	3/07	1/08	2/08	3/08
ETo (mm/day)	3.8	4.7	4.2	3.3	4.4	4.8
Dec/mon	1/09	2/09	3/09	1/10	2/10	3/10
ETo (mm/day)	5.2	5.4	6.4	4.7	5.7	5.1
Dec/mon	1/11	2/11	3/11	1/12	2/12	3/12
ETo (mm/day)	4.4	6.4	7.4	5.4	5.8	6.7

Appendix 17b: Rainfall data used in evaluation of past irrigation seasons
Daily value ranging from 01/01/1993 to 31/12/1994

Date	Rainfall (mm)	Date	Rainfall (mm)
Jan 1993		Feb 1993	
01	0.0	01	0.0
02	0.0	02	0.0
03	0.0	03	0.0
04	0.0	04	0.0
05	0.0	05	0.0
06	0.0	06	0.0
07	4.9	07	6.7
08	8.3	08	0.0
09	0.0	09	28.3
10	0.0	10	13.5
11	1.0	11	0.0
12	0.0	12	0.7
13	14.0	13	3.4
14	0.1	14	10.6
15	9.8	15	0.0
16	3.5	16	0.0
17	0.0	17	0.0
18	1.6	18	5.4
19	0.0	19	0.0
20	4.1	20	0.0
21	11.3	21	0.0
22	2.1	22	4.4
23	0.0	23	2.7
24	0.0	24	5.0
25	11.7	25	0.0
26	51.6	26	5.3
27	10.7	27	15.4
28	18.9	28	5.2
29	18.5		
30	14.7		
31	3.4		

Appendix 17b continued

Date	Rainfall (mm)	Date	Rainfall (mm)
Mar 1993		Apr 1993	
01	0.1	01	0.0
02	2.1	02	0.0
03	4.2	03	6.4
04	0.0	04	7.8
05	0.0	05	9.2
06	0.0	06	6.4
07	0.0	07	15.1
08	0.0	08	1.3
09	0.0	09	9.7
10	2.4	10	1.0
11	0.0	11	4.7
12	7.3	12	5.8
13	3.9	13	3.8
14	1.9	14	5.4
15	8.9	15	13.9
16	77.2	16	15.2
17	26.7	17	6.8
18	18.2	18	17.8
19	5.7	19	2.7
20	0.7	20	13.9
21	7.2	21	13.7
22	0.1	22	29.2
23	21.2	23	17.3
24	6.9	24	8.3
25	0.0	25	3.4
26	0.0	26	4.5
27	0.0	27	6.8
28	0.0	28	1.4
29	0.1	29	8.4
30	0.1	30	0.1
31	6.8		

Appendix 17b continued

Date	Rainfall (mm)	Date	Rainfall (mm)
May 1993		June 1993	
01	40.7	01	0.0
02	19.3	02	0.0
03	10.0	03	0.0
04	18.8	04	0.0
05	8.5	05	0.0
06	0.0	06	0.0
07	1.8	07	0.0
08	26.6	08	0.0
09	5.4	09	0.0
10	13.4	10	0.0
11	0.0	11	0.0
12	0.0	12	0.0
13	0.0	13	9.6
14	0.0	14	0.2
15	0.0	15	7.9
16	0.0	16	10.7
17	0.0	17	0.1
18	0.0	18	0.2
19	0.0	19	0.0
20	1.1	20	0.0
21	21.1	21	0.0
22	4.8	22	0.0
23	10.7	23	0.0
24	4.4	24	0.0
25	0.0	25	0.0
26	17.8	26	0.0
27	0.0	27	0.0
28	0.0	28	1.1
29	0.0	29	0.0
30	0.4	30	0.0
31	5.3		

Appendix 17b continued

Date	Rainfall (mm)	Date	Rainfall (mm)
July 1993		Aug 1993	
01	0.0	01	0.0
02	0.0	02	0.0
03	0.0	03	0.2
04	0.0	04	0.5
05	0.0	05	0.1
06	0.0	06	0.0
07	0.0	07	0.0
08	1.1	08	0.0
09	0.0	09	0.0
10	0.1	10	0.0
11	0.0	11	0.0
12	0.0	12	0.0
13	0.7	13	0.0
14	0.0	14	0.0
15	0.0	15	0.0
16	0.5	16	0.0
17	0.2	17	0.0
18	18.4	18	0.0
19	9.7	19	0.0
20	0.0	20	0.0
21	0.0	21	0.0
22	0.0	22	0.0
23	0.0	23	1.7
24	0.0	24	0.0
25	0.0	25	0.0
26	0.0	26	0.0
27	0.0	27	0.0
28	0.0	28	0.0
29	0.0	29	0.0
30	1.8	30	0.0
31	0.0	31	0.0

Appendix 17b continued

Date	Rainfall (mm)	Date	Rainfall (mm)
Sept 1993		Oct 1993	
01	0.0	01	0.0
02	1.2	02	0.0
03	0.1	03	0.0
04	0.0	04	0.0
05	0.0	05	0.0
06	0.0	06	0.0
07	0.0	07	0.0
08	0.0	08	0.0
09	0.0	09	0.0
10	0.0	10	0.0
11	0.0	11	0.0
12	0.0	12	0.0
13	0.0	13	0.0
14	0.0	14	0.0
15	0.0	15	0.0
16	0.0	16	0.0
17	0.0	17	0.0
18	0.0	18	0.0
19	0.0	19	0.0
20	0.0	20	0.0
21	0.0	21	0.0
22	0.0	22	0.0
23	0.0	23	0.0
24	0.0	24	0.0
25	0.0	25	0.0
26	0.0	26	0.0
27	0.0	27	0.0
28	0.0	28	1.4
29	0.0	29	19.2
30	0.0	30	5.3
		31	0.2

Appendix 17b continued

Date	Rainfall (mm)	Date	Rainfall (mm)
Nov 1993		Dec 1993	
01	0.0	01	0.0
02	0.0	02	0.0
03	0.0	03	0.0
04	0.0	04	0.0
05	0.0	05	0.0
06	0.0	06	0.0
07	1.0	07	0.0
08	0.0	08	0.0
09	0.0	09	0.0
10	0.0	10	0.0
11	0.0	11	0.0
12	0.0	12	0.0
13	0.0	13	0.1
14	0.0	14	3.3
15	0.0	15	7.9
16	0.0	16	0.0
17	1.2	17	0.0
18	0.0	18	0.0
19	0.0	19	0.0
20	3.0	20	0.0
21	30.1	21	0.0
22	0.0	22	0.0
23	1.7	23	0.0
24	2.8	24	0.0
25	1.2	25	0.0
26	1.6	26	0.0
27	0.0	27	0.0
28	0.0	28	0.0
29	0.0	29	0.0
30	0.0	30	0.0
		31	0.0

Appendix 17b continued

Date	Rainfall (mm)	Date	Rainfall (mm)
Jan 1994		Feb 1994	
01	0.0	01	4.3
02	0.0	02	0.0
03	0.0	03	21.1
04	0.0	04	0.1
05	0.2	05	0.3
06	1.9	06	0.0
07	24.7	07	9.8
08	4.3	08	0.0
09	20.1	09	0.0
10	5.8	10	2.5
11	38.9	11	28.4
12	1.3	12	24.4
13	2.0	13	18.3
14	0.0	14	19.1
15	59.5	15	3.1
16	1.0	16	6.8
17	0.0	17	10.7
18	10.8	18	38.4
19	0.1	19	2.4
20	0.1	20	0.2
21	0.0	21	3.7
22	0.0	22	0.0
23	0.0	23	21.9
24	1.6	24	4.2
25	1.6	25	1.9
26	0.0	26	9.8
27	0.0	27	0.0
28	0.0	28	11.6
29	0.0		
30	0.0		
31	0.1		

Appendix 17b continued

Date	Rainfall (mm)	Date	Rainfall (mm)
Mar 1994		Apr 1994	
01	0.4	01	0.0
02	6.7	02	0.0
03	22.5	03	9.9
04	14.6	04	22.0
05	4.8	05	34.7
06	2.0	06	3.7
07	1.7	07	12.5
08	8.7	08	0.6
09	6.6	09	0.6
10	0.0	10	16.4
11	0.0	11	18.3
12	0.0	12	1.9
13	0.0	13	0.0
14	0.0	14	9.5
15	0.0	15	3.5
16	39.3	16	0.0
17	0.0	17	0.0
18	23.7	18	0.0
19	0.1	19	10.7
20	16.6	20	11.3
21	19.0	21	3.3
22	9.4	22	1.8
23	5.9	23	10.7
24	0.0	24	7.0
25	1.5	25	12.4
26	5.8	26	2.6
27	0.1	27	0.0
28	0.0	28	0.0
29	34.6	29	2.8
30	16.0	30	23.4
31	0.0		

Appendix 17b continued

Date	Rainfall (mm)	Date	Rainfall (mm)
May 1994		June 1994	
01	10.0	01	0.0
02	0.1	02	0.0
03	0.6	03	0.0
04	3.0	04	0.0
05	0.5	05	0.0
06	0.0	06	0.0
07	0.0	07	0.0
08	4.6	08	0.0
09	0.4	09	0.0
10	2.9	10	0.0
11	17.4	11	0.0
12	10.5	12	0.0
13	35.0	13	0.0
14	0.0	14	0.0
15	0.0	15	0.0
16	0.0	16	0.0
17	4.6	17	0.0
18	15.4	18	0.0
19	2.9	19	0.0
20	1.8	20	0.0
21	0.9	21	0.5
22	0.0	22	5.6
23	0.5	23	0.0
24	0.0	24	0.0
25	0.0	25	0.0
26	0.0	26	0.0
27	0.0	27	0.0
28	0.0	28	0.0
29	0.0	29	0.0
30	5.3	30	0.0
31	0.0		

Appendix 17b continued

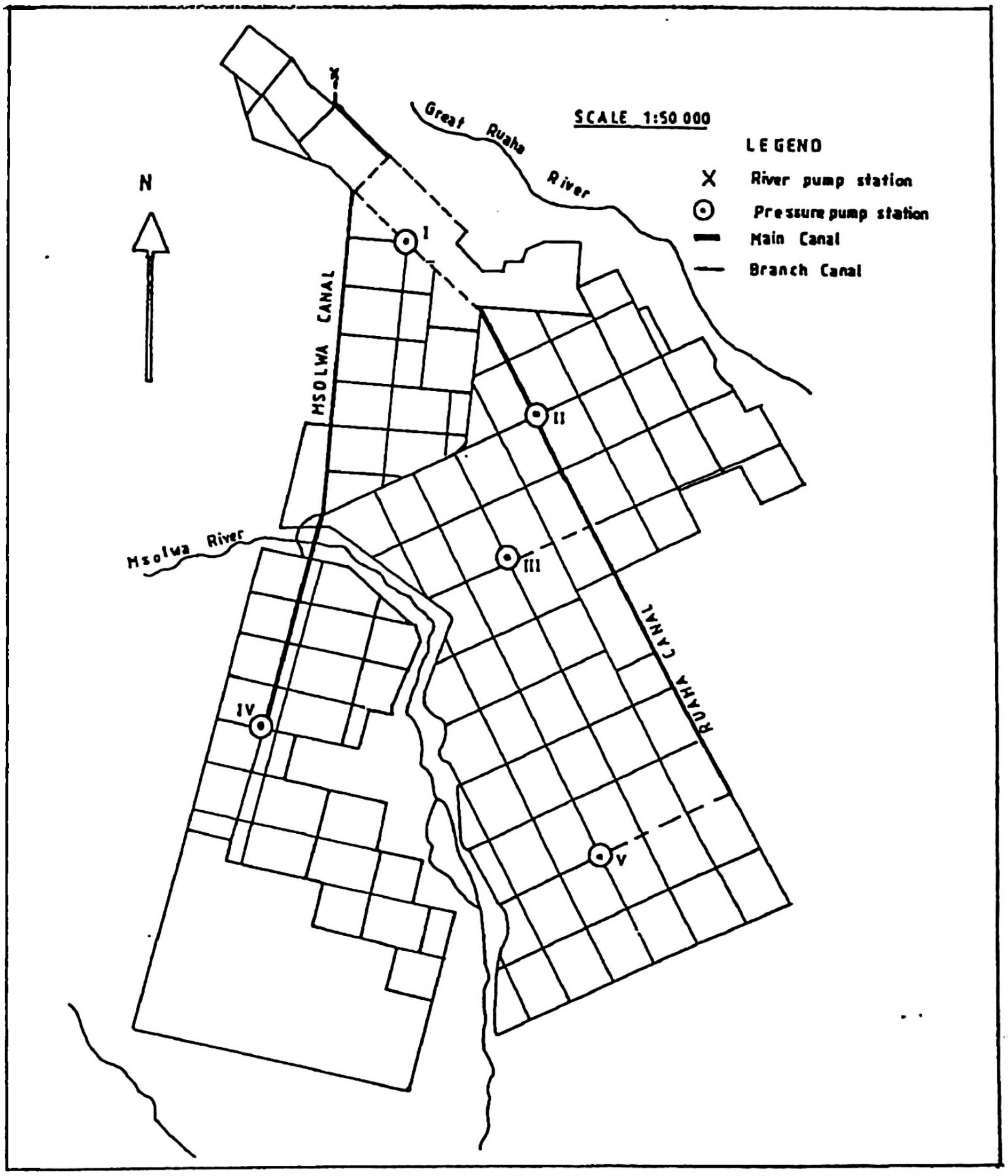
Date	Rainfall (mm)	Date	Rainfall (mm)
July 1994		Aug 1994	
01	3.6	01	0.0
02	0.0	02	0.2
03	1.9	03	0.2
04	0.0	04	0.0
05	17.8	05	0.0
06	0.3	06	0.0
07	0.0	07	0.0
08	0.0	08	0.2
09	0.0	09	0.0
10	0.0	10	0.9
11	0.0	11	0.0
12	0.0	12	0.0
13	0.0	13	0.0
14	0.0	14	0.0
15	0.0	15	0.0
16	0.0	16	0.0
17	0.0	17	0.0
18	0.0	18	0.0
19	0.0	19	0.0
20	0.0	20	0.1
21	0.0	21	0.2
22	0.0	22	0.0
23	0.0	23	0.0
24	0.0	24	3.5
25	0.0	25	0.0
26	0.0	26	0.0
27	0.0	27	0.7
28	0.0	28	0.0
29	0.0	29	0.0
30	0.0	30	0.0
31	0.0	31	0.0

Appendix 17b continued

Date	Rainfall (mm)	Date	Rainfall (mm)
Sept 1994		Oct 1994	
01	0.0	01	0.0
02	0.0	02	0.0
03	0.0	03	0.0
04	0.0	04	0.0
05	0.0	05	34.2
06	0.0	06	0.1
07	0.0	07	0.0
08	0.0	08	0.0
09	0.0	09	0.0
10	0.0	10	0.0
11	0.0	11	0.0
12	0.0	12	0.0
13	0.0	13	0.0
14	0.0	14	0.0
15	0.0	15	0.0
16	0.0	16	0.0
17	0.0	17	0.0
18	0.0	18	34.2
19	0.0	19	0.0
20	0.0	20	0.0
21	0.0	21	0.0
22	0.0	22	0.0
23	0.0	23	0.0
24	0.0	24	0.0
25	0.0	25	0.0
26	0.0	26	0.0
27	0.0	27	0.0
28	0.0	28	0.0
29	0.0	29	0.0
30	0.0	30	0.0
		31	0.0

Appendix 17b continued

Date	Rainfall (mm)	Date	Rainfall (mm)
Nov 1994		Dec 1994	
01	5.0	01	0.0
02	0.0	02	0.0
03	11.6	03	0.0
04	0.0	04	0.0
05	18.4	05	2.2
06	3.6	06	0.0
07	0.0	07	0.1
08	0.0	08	5.2
09	0.0	09	0.0
10	0.0	10	0.0
11	0.0	11	0.0
12	0.0	12	0.0
13	0.0	13	0.0
14	0.0	14	0.0
15	0.0	15	0.0
16	0.0	16	0.0
17	0.0	17	0.0
18	0.0	18	0.0
19	0.0	19	0.0
20	0.0	20	0.0
21	0.0	21	0.0
22	0.0	22	0.0
23	0.0	23	0.0
24	0.0	24	0.0
25	0.0	25	0.0
26	0.0	26	0.0
27	0.0	27	0.0
28	38.7	28	0.0
29	0.6	29	0.0
30	0.0	30	0.0
		31	0.0



Appendix 18: Layout of main irrigation system