PERFORMANCE OF RAINWATER HARVESTING WITH STORAGE FOR SUPPLEMENTARY IRRIGATION ON PADDY PRODUCTION IN SEMI-ARID HOMBOLO TANZANIA

BY

LUSWEMA SETHI PHILLIP

A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURAL ENGINEERING OF SOKOINE UNIVERSITY OF AGRICULTURE

1997

ABSTRACT

Rainfed lowland rice production covers 75 % of the total area (369 000 ha) currently under rice production in Tanzania. It is the most predominant rice ecosystem compared to others like Irrigated (3 %), Upland (22 %), Hydro-morphic and Inland swamp ecosystems. The system employs simple flood water management techniques of Rainwater Harvesting (RWH). RWH system has a catchment or collecting area and a cropped basin where the collected runoff is used to grow crops.

In the semi-arid areas of Tanzania (parts of Tabora, Shinyanga, Mwanza, Singida and Dodoma regions) farmers have developed a system of RWH, involving water diversion from sheet flow and ephemeral streams to valley basins for lowland rice production. Rice in this system is grown in flooded bunded basins called 'Majaruba'. The usual stand establishment is transplanting, although direct seeding onto puddled or dry fields are also practised.

The main problem with the current RWH system is that it is subjected to high uncertainities of rainfall amount and distribution. The rainfall in these rice growing areas is very unreliable characterised with frequent dryspells during the growing season. This phenomenon makes rice cultivation very risky. Often water stored in cultivated basins 'Majaruba' is inadequate to sustain the crop through 20 to 40 day dryspells. As a result, low yields or total crop failure due to 'drought' is quite common.

This study focused on evaluation of performance of surface storage for supplementary irrigation of the paddy crop to reduce the effect of long dry spells. The specific objectives were: (i) test the performance of water storage system, (ii) assess the effect of supplementary irrigation on soil moisture, stress effect at different growth stages of paddy rice and the overall paddy yield.

Results show that there was a significant difference in yield, between with and without supplementary irrigation treatments. RWH with storage and supplemental irrigation produced 3.2 tons/ha while RWH without storage produced 0.2 tons/ha and the one without RWH yielded 0.1 tons/ha.

These results show that RWH incorporating storage reservoir for supplementary irrigation of paddy could help to stabilize yields of paddy in semi-arid areas of Tanzania. Further research of RWH plus storage for supplementary irrigation on paddy production along with its economic analyisis is recommended.

DECLARATION

I LUSWEMA SETHI PHILLIP, do here by declare to the Senate of Sokoine University of Agriculture that this dissertation is my original work and that it has never been submitted for a degree in any other university.

Signature..

Date..........15th APRIL, 1997..........................

COPYRIGHT

ACKNOWLEDGEMENT

The author is deeply indebted to Dr. N. Hatibu, his Supervisor for his encouragement, guidance, valuable suggestions and help during every phase of the study.

Many thanks are conveyed to GTZ/SACCAR for awarding sponsorship to the author of this dissertation.

Further, the author gratefully acknowledge all staff of Hombolo Research Centre for allowing the study to be conducted in their premises.

Finally, the author wishes to express his deepest gratitude to his wife, Joyce Mkilania Luswema for her patience during the author's absence from home.

TABLE OF CONTENTS

LIST OF APPENDICES

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF SYMBOLS AND ABBREVIATIONS

η_s	Run-off efficiency
η_o	Run-off coefficient
R	Run-off depth (mm)
CB	Cropped basin (m^2)
p	Precipitation (mm)
CA	Catchment area (m^2)
θ_{FC}	Soil moisture at field capacity (% v/v)
θ_{PWP}	Soil moisture at permanent wilting point (% v/v)
$\lvert Z_r \rvert$	Root zone depth (mm)
I	Run-off infiltrated (mm)
ET_o	Reference crop evapotranspiration (mm/hr)
K_c	Crop coefficient
W	Temperature related weighting factor
R_n	Net radiation equivalent evaporation (mm/day)
f(u)	Wind related function (km/day)
(ea - ed)	Difference between saturation vapour pressure (ea) at mean air temperature and the actual vapour pressure (ed) of the air (mbar).
C	Adjustment factor to compensate for the effect of a day and night weather condition.

Tmax	Maximum Temperature (°C)
Tmin	Minimum Temperature (°C)
n	Actual sunshine hours
N	Maximum possible sunshine hours
α	Albedo
Ra	Extra-Terrestrial Radiation(mm/day)
Rnl	Net Longwave radiation (mm/day)
Rns	Shortwave radiation (mm/day)
Rs	Measured Solar radiation (mm/day)
f(T)	Effect of Temperature on Longwave radiation (Rnl)
f(n/N)	Effect of the Ratio Actual and Maximum Bright Sunshine Hours on Longwave (Rnl)
f(ed)	Effect of Vapour pressure on Longwave Radiation (Rnl)
Uday,night	Day and Night Wind Speed (m/s)
m.a.s.l	Altitude in metres above sea level
r	Rank
Net Irr. Req.	Net irrigation Requirement (mm)
Rhmax,min	Maximum and minimum Relative humidity (%)
P(%)	Probability of being equalled or exceeded
T1-3	Treatments 1,2 and 3
CA:CB	Catchment area to cropped basin ratio
θ_c	Critical soil moisture (% v/v)
ETo	Potential Crop Evapotranspiration (mm/day)
Er	Reservoir storage efficiency

h	Reservoir depth (m)
x	Top length/bottom width ratio of ratio of reservoir
V	Reservoir volume (m^3)
V_e	Evaporation volume from the reservoir(m^3)
V_s	Seepage volume from the reservoir (m^3)
V_i	Inflow to the reservoir during a time interval(m^3)
C1-3	Reservoir compartments 1, 2 and 3
Cu	Coefficient of uniformity
Es	Soil storage efficiency
S_{rz}	Amount of water in the root zone during irrigation (cm)
S_{fc}	Amount of water to fill the root zone to field capacity (cm).
θ_i	Soil moisture content after irrigation (% v/v)
D_{rz}	Root zone depth (cm)
s	Standard deviation
x	Average depth infiltrated(cm)

1 INTRODUCTION

Paddy rice is the second most important food crop after maize in Tanzania. The annual per capital consumption has risen from less than 15 kg in 1970s to more than 50 Kg at present. Annual rice production is about 800 000 tones up from an estimated 300 000 tones in 1980s (MoA, 1993).

Rice is mainly produced under three systems; namely: irrigated lowland, rainfed lowland and upland production systems (Table 1.1). Others of less importance includes hydro-morphic and inland swamp rice systems.

Table 1.1: Amount of rice produced under different production systems in Tanzania.

Rice ecosystem	Area (ha x 10^3)	Production (t x10^3)	Yield (t/ha)	Area (%)
Irrigated	10	28	4.0	2.7
Rainfed lowland	279	564	2.0	75.6
Rainfed upland	80	72	0.9	21.7
TOTAL	369	664	1.8	

Source: MoA (1993) Irrigation division.

Irrigated lowland rice is grown in bunded, levelled and puddled fields irrigated using river - water diversion for one or more crops per year. Rainfed lowland rice is also grown in bunded basins which accumulates water but, the system is entirely dependent on direct rainfall and run - off collection. Upland rice or dryland rice refers to the rice grown on both level and sloping fields that are not bunded, but are prepared and seeded under dry conditions. This system depends entirely on direct rainfall.

The hydro-morphic and inland swamp rice production systems are performed by very few farmers in Tanzania. In principle the roots are periodically saturated by fluctuating water table in addition to the rainfall for the case of hydro-morphic, while the inland (mangrove) swamp rice is grown in coastal swamps with tidal intrusion, dominated by mangrove vegetation.

Rain Water Harvesting for crop production consists of a catchment or collecting area and a cropped basin where the collected runoff is used to grow crops (Fig.1.1). RWH is restricted to methods which are entirely dependent on local rainfall (Reij et al. 1990).

Pacey and Cullis (1986) classify RWH systems according to catchment and storage. Catchments are divided into micro-catchments with sheet runoff (Fig. 2.1 - 2.5) and macro-catchments with turbulent runoff (Fig.2.4 and 2.5).

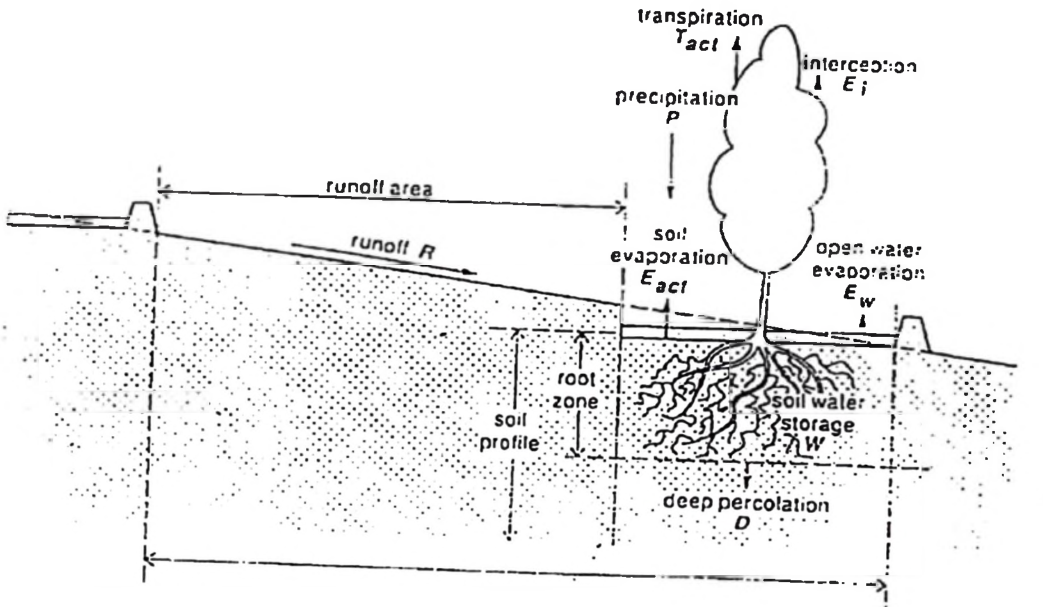


Figure1.1: Principle of Rainwater Harvesting for plant production (Source: Boers, 1994).

The semi-arid areas of Tanzania occupies about 295 000 Km^2 of the total land (886 000 Km^2) area (ERB, 1989). In the semi - arid areas of parts of Tabora, Shinyanga, Mwanza, Singida and Dodoma regions (Fig.1.2), farmers have developed a system of RWH which involve diversion of water from sheet and turbulent flow and ephemeral streams to valley basins for rice production. Rice in this system is grown in bunded basins called 'Majaruba' which collects the water. The usual stand establishment is transplanting, although direct seeding onto puddled or dry fields is also practised.

The main problem with the current RWH system is that, water is stored only in the cultivated basins and thus there is very high risk of crop damage due to dry spells. Often dry spells of up to 40 days may occur leading to total depletion of water stored in paddy fields, thus causing yield reduction or total crop failure.

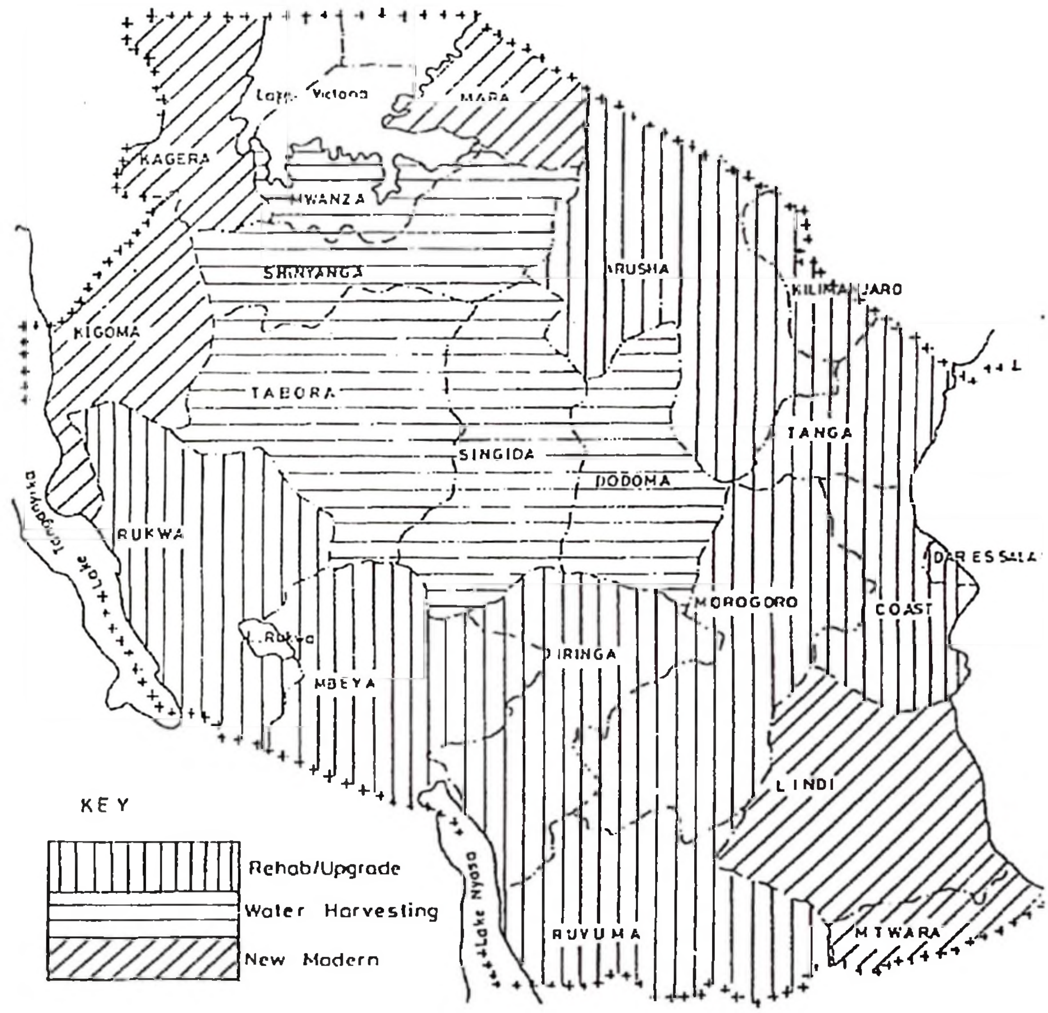


Figure 1.2: Irrigation priorities by regions (Source: MoA,1993; Irrigation division).

Therefore, there is a need to find means and interventions for reducing the effect of long dry spells on the paddy crop. The main objective of this study was to evaluate the performance of storage of the harvested water for supplementary irrigation, on paddy production under semi-arid Tanzania. Specific objectives were;

(i) test the performance of water storage system.

(ii) assess the effect of supplementary irrigation on: soil moisture - stress reduction at different growth stages of paddy rice and the overall crop yield.

2 LITERATURE REVIEW

2.1 Rice crop environment

The rice crop environment is composed of the climate, soil, and biotic surroundings. There are naturaly climatic variations in the environmental, and particulary climatic conditions in the world. These variations translate into yield and quality differences among varieties that can be grown in these areas.

Rice is not in itself very demanding as regards soil characteristics, and is grown in different parts of the world in a wide variety of soils as reported by Chatterjee and Maiti (1988). He pointed out that soil properties related to the hydraulic characteristics are the most important and that yields are usually associated with a high clay content (40-60 percent) with a high degree of humification and sufficient but not excessive drainage.

Because of the percolation losses, rice grown on permeable soils may require from two to three times as much water as rice producing the same yield when grown on typical rice soil (Adair et al.1962). The pH can range from 4.0 to 7.0 without yields being affected (Chandler, 1963). However, in the arid and semi-arid regions, rice is frequently grown on alkaline soils with a high pH. For upland rice the most favourable soils are medium to heavy loams while for lowland rice the soil varies in morphology and nutrient status and mostly arise from colluvium materials for the case of Africa. These are poorly drained, with thick humus - rich surface layer and many are clayey and often have high Iron Content. The reduction of Iron and the high content of organic matter are likely to lead to Iron toxicity in the low areas of flooding (FAO, 1982).

Pan and Djimia (1962) mentioned that rice is fairly resistant to salinity, although there are marked varietal differences. The maximum tolerance of rice seedlings to salt concentration are reported to vary from 3 to 5 mmho. Rice can be grown on saline land that is being reclaimed provided sufficient water of suitable quality is available for leaching and the excess salts can be removed by drainage.

De Datta (1981) discussed major climatic factors that have an effect on rice. These factors are rainfall, temperature, solar radiation, relative humidity and wind. Of these rainfall, temperature and solar radiation are the most important. However their importance is closely linked to the region of production: temperate or tropical. Rainfall fluctuates and solar radiation is fairly stable in the tropics (Ayoade, 1983; IRRI, 1982).

In most of the temperate rice growing areas of Asia, North America, Australia and Europe, cropping is determined primarily by temperature patterns because water is provided through irrigation (De Datta, 1981). In the tropics where temperature is adequate and fairly stable throughout the year and the crop is mostly rainfed, variability in the amount and distribution of rainfall is the most limiting factor (Ayoade, 1983; De Datta, 1981). Thus , of all the problems facing rainfed rice production 'drought' and 'flood' are the most limiting (IRRI, 1994). For example, a field that is favourable parcel one year may be submerged the next year and a parcel that is drought stressed one year may be favourable the next. Experienced rice farmers are reported to adapt their cropping practices to the drought risks by employing Rainwater Harvesting (RWH) techniques for crop production (IRRI, 1994).

2.2 Practices of RWH for plant production in the world

RWH is practised in several countries in the world such as Israel, India, Pakistan, and China in the Asian continent. In African continent it is mainly practised in North Africa and is a relatively new intervention in Sub-Sahara Africa (Reij et al. 1990).

RWH for plant production also referred as runoff agriculture constitutes four major categories (Reij et al.

1990): (a) RWH from short slopes or micro - catchment water harvesting, (b) RWH from long slopes or macro - catchment, (c) flood water harvesting within the streambed and (d) Floodwater diversion.

The RWH basin plus catchment systems from short (less than 100 m) slopes for trees or cereals varies between 0.5 - 1000 m^2 (Boers and Ben-Asher, 1982). The most well known systems are the demi-lunes (small semi-circular hoops) in West Africa and Kenya and the "Meskat" micro - catchment in Tunisia. Their slopes lies between 1 % and 7 % (Fig. 2.1 - 2.3).

RWH from long (greater than 100 m) slopes also referred to as RWH from external catchment systems, receive external runoff through earth bunds enclosing relatively large areas and impound large quantities of water (Finkel et al. 1987). Typical examples are shown in Fig. 2.4.

Floodwater Harvesting within the streambed comprises those techniques which concentrate runoff in the streambed by blocking the water flow. The valley floor is cultivated and the water is utilized on the spot (UNEP, 1983). Cross-Wadi

walls built of stones in Jordan and the silt trap in Mexico are forms of inbed floodwater harvesting (Gilbetson, 1986).

Floodwater diversion comprises those techniques that force water to leave its natural course. 'Warping' is one typical example practised in China (UNEP, 1983). Its main purpose is to fertilize the soil with nutrients contained in water and simultaneously irrigate the crops (Fig. 2.5 and 2.6)

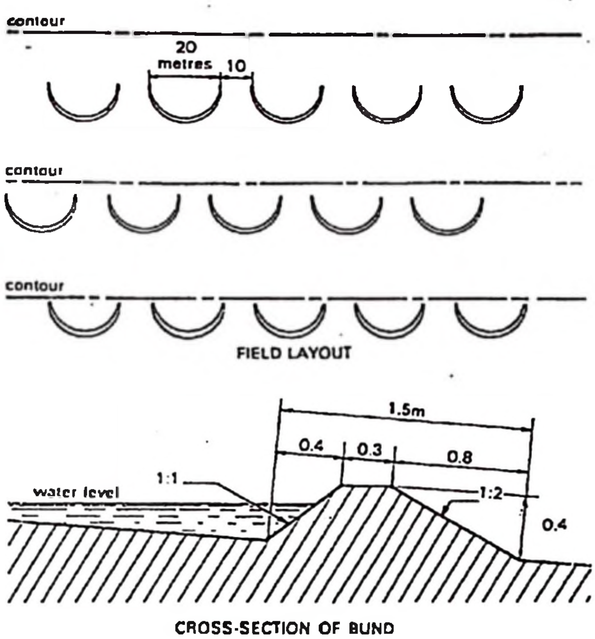


Figure 2.1: Semi-circular hoops in Turkana District, Kenya (Source: Finkel, 1984)

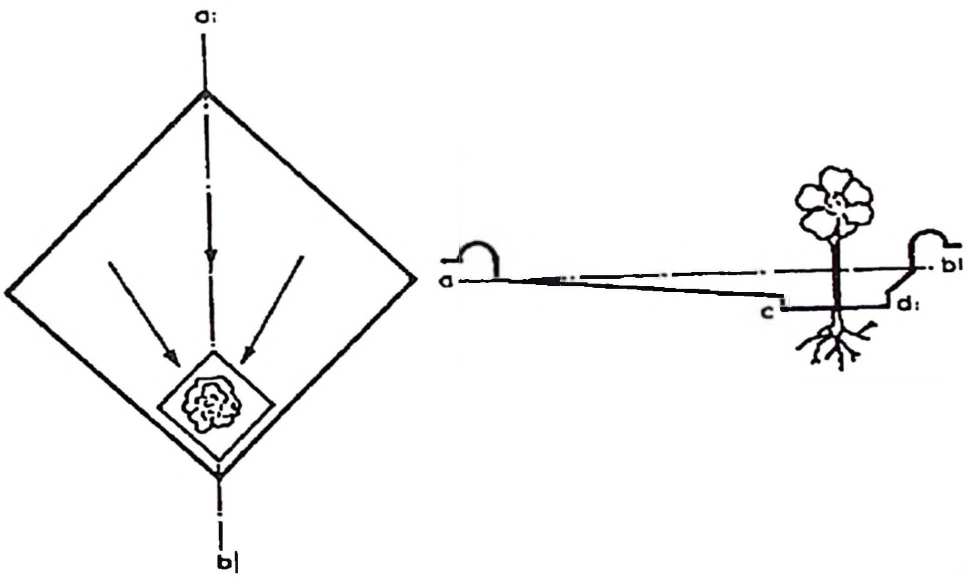
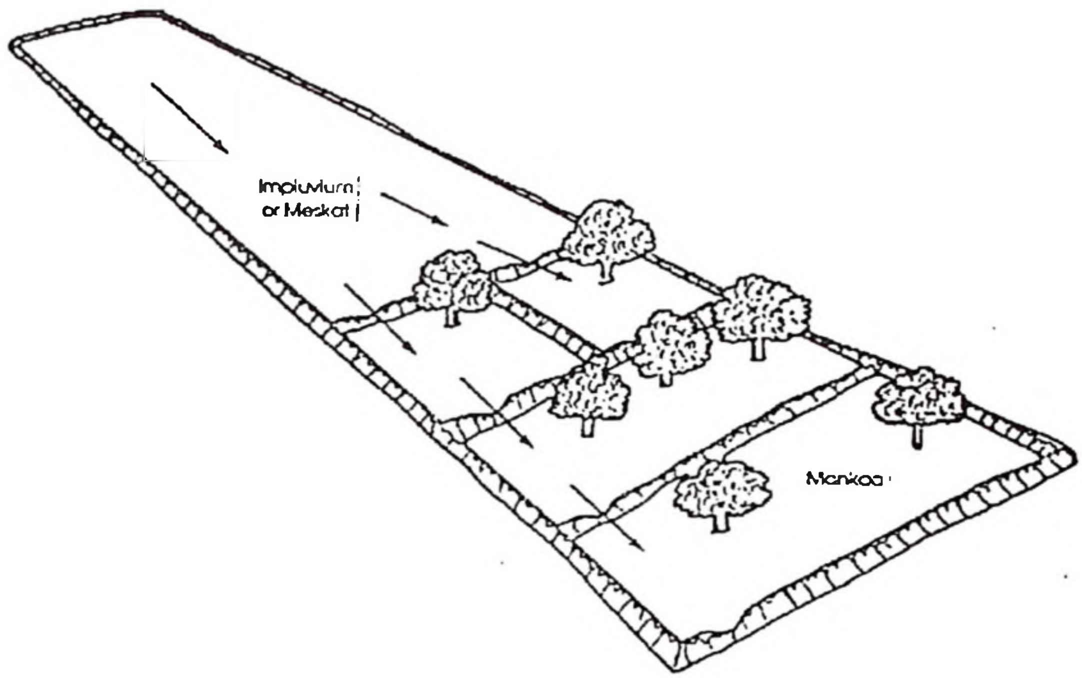


Figure 2.2: Plan and cross-sectional of a micro-catchment (Source: Evenari, 1968).



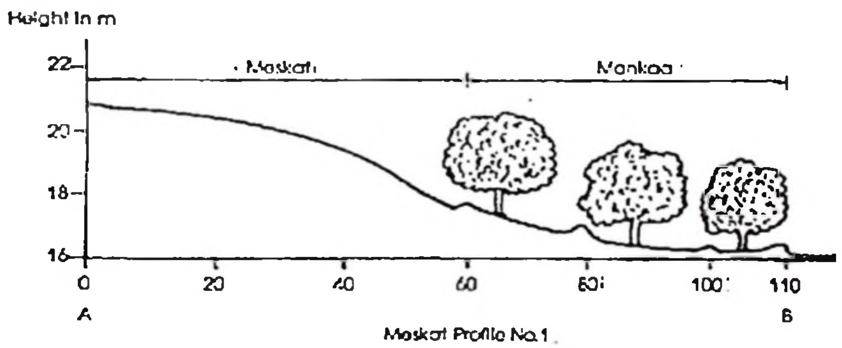


Figure 2.3: 'Meskat' micro-catchment system in Tunisia (Source: El Amani, 1983).

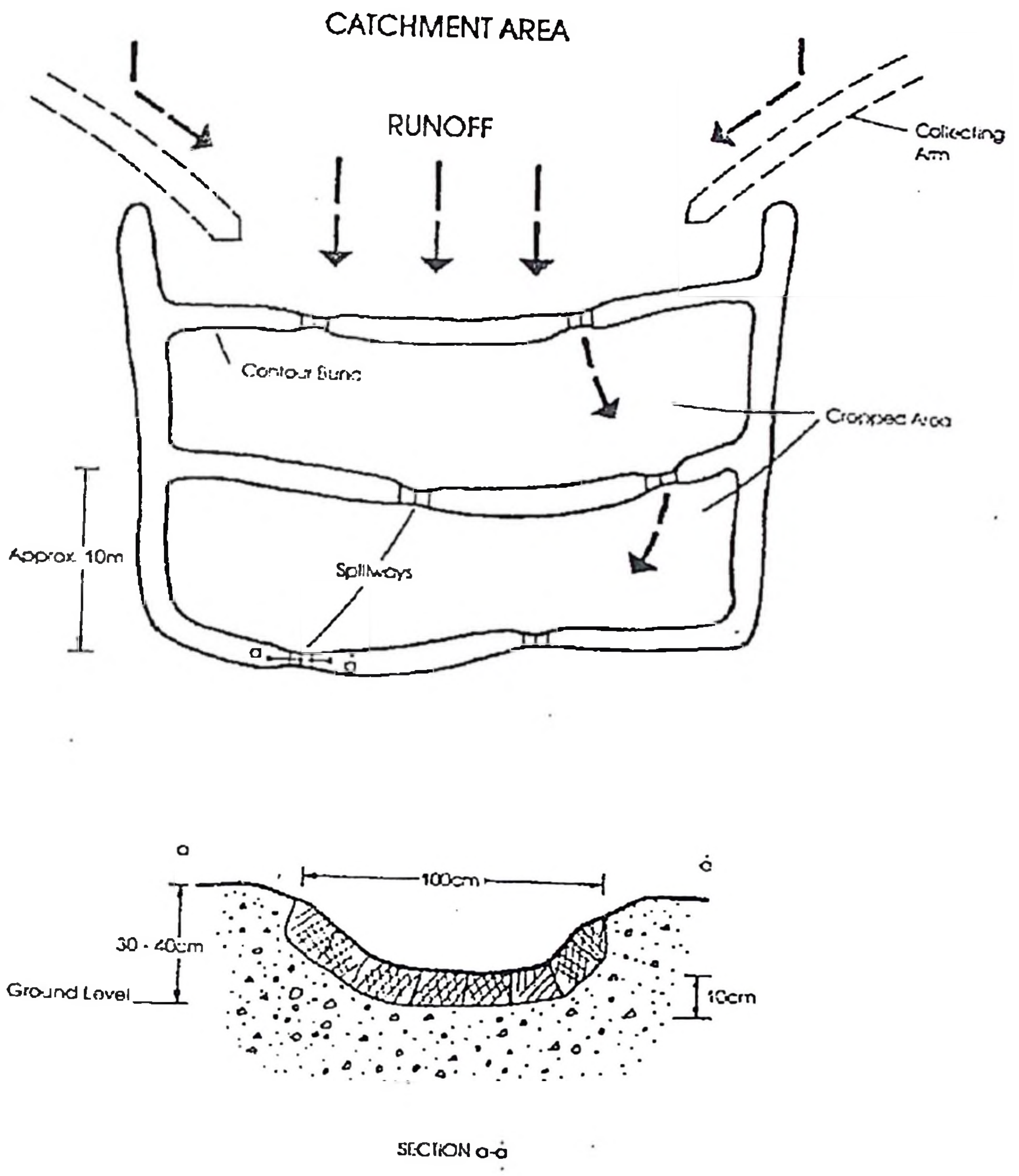


Figure 2.4:External catchment (macro-catchment) system as used in the Baringo District, Kenya (Source: Crichley, 1987).

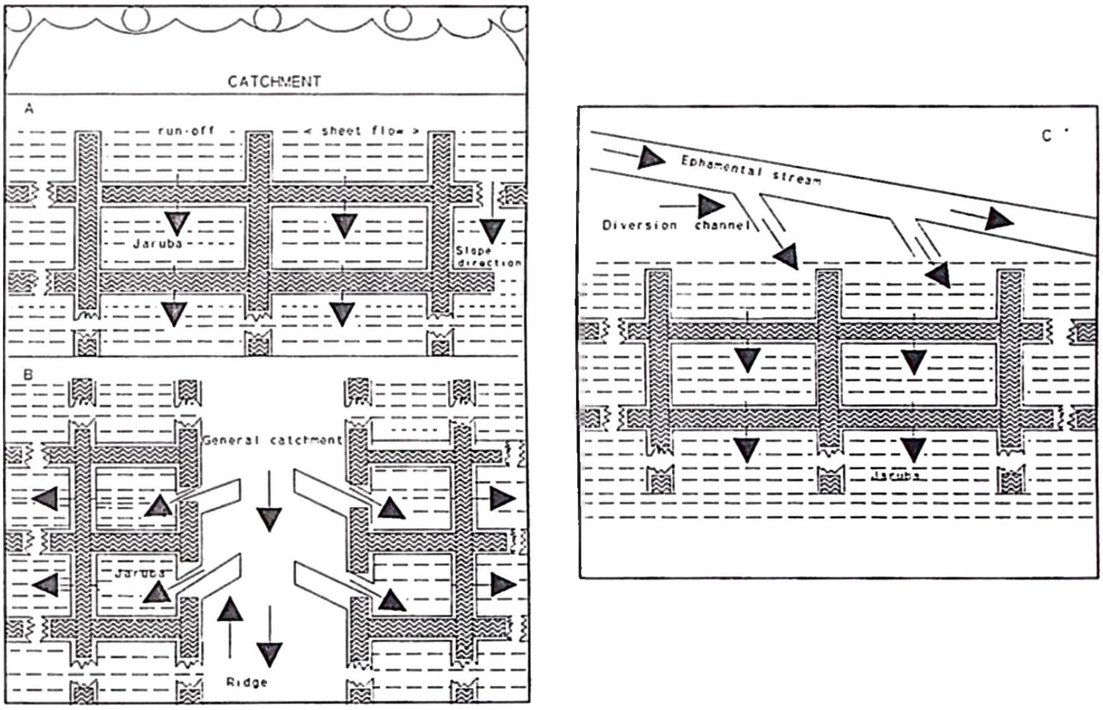


Figure 2.5: RWH for paddy production as used in Shinyanga Tanzania (Source: Mwakalila, 1992).

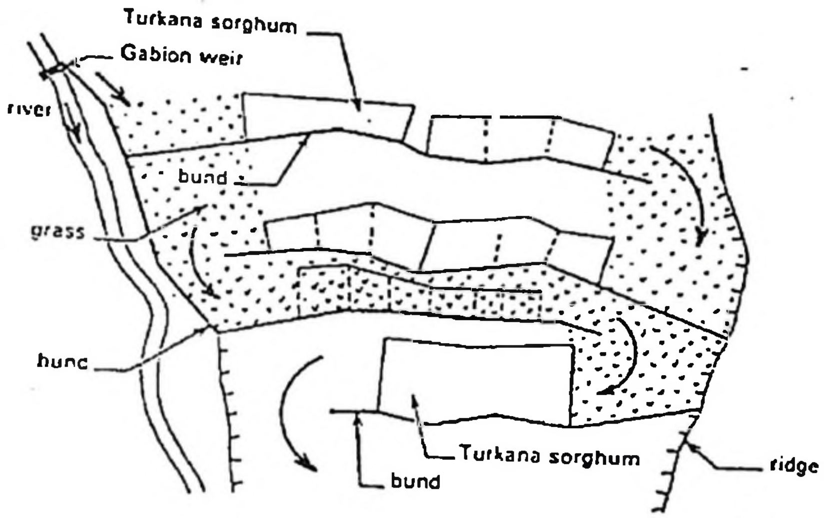


Figure 2.6: Flow diversion system in combination with water spreading in the Turkana District, Kenya (Source: Fallon, 1963).

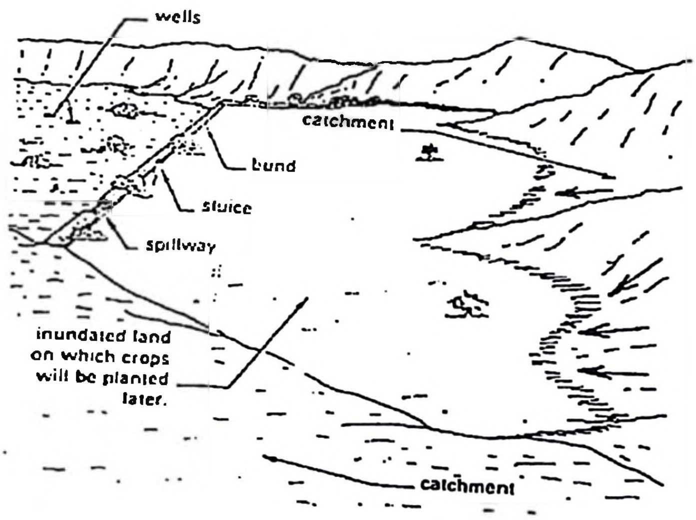


Figure 2.7: Cultivated reservoirs, ideal setting of a 'khadin' (Source: Kolarkar, 1983).

Pacey and Cullis (1986) reported on cultivated reservoirs which stores water above the ground level for longer period (several months) behind mostly large bunds. They collect runoff from streams or from long slopes. The typical physiographic setting includes a rocky catchment with sand soils and very fertile soils on which runoff is stored behind an earthen bund. They further reported the use of embankments in Sudan, East of Nile on gently sloping clay plains so as to capture the water (Fig. 2.7). Further, Evenari et al. (1971) reported that runoff has been concentrated on lands to grow crops in arid and semi-arid areas in some parts of the World for centuries, but surface storage in the form of small reservoir in conjunction with runoff concentration on lands has not been extensively used.

2.3 Surface storage for RWH agrisystem

Lakes, ponds, streams, pervious soil mass and the water bearing rock formations are the best examples of natural water storage. Absence of these natural water bodies in semi-arid regions pre-supposes construction of some artificial storage works. Cluff (1979) mentioned that water storage in relatively flat terrain may be relatively expensive but cost effective if used for supplemental irrigation when the soil is the primary means of water storage.

The selection of reservoir capacity can have a significant impact on farming system served by the reservoir. Reservoirs which are too small will frequently be unable to hold sufficient water for the irrigation season, and this can result in unsatisfactory yields. Conversely, reservoirs which are too large result in unnecessary high construction and maintenance costs. Oversizing of reservoirs can also decrease returns to farmers if land must be taken out of crop production to provide a site for the reservoir.

James (1988) noted that some common methods for sizing reservoirs are not well suited for use in an economic framework. This is because such methods generally are not site specific and are based on average values of rainfall, runoff, evaporation and irrigation demand. The use of this type of data does not allow one to account for crop and management responses to random fluctuations in daily weather variables even though irrigated crops are managed on a daily , rather than monthly basis. He proposed an assessment of the performance of various capacities as the first step in identifying the best reservoir capacities for specific crop/soil/weather situation using a mathematical model.

The efficiency with which water is stored in these reservoir is mainly reduced by evaporation and seepage losses and is expressed by the following mathematical expression (James, 1988);

$$Er = 100\left(1 - \frac{(Vs + Ve)}{Vi}\right) \quad (1)$$

Where:

Er = Reservoir storage efficiency in percent(%);

Ve = Evaporation volume from the reservoir(m^3);

Vs = Seepage volume from the reservoir(m^3);

Vi = Inflow to the reservoir during a time interval(m^3).

The loss of water by evaporation is a very serious problem in both arid and semi-arid regions. It increases as the temperature increases at a low humidity (Sahasrabudhe, 1984). Evaporation is accelerated by wind, the rise in temperature and fall in humidity. The water evaporated is directly proportional to the exposed surface area.

Cluff (1979) reported various methods of controlling evaporation: they include; (a) surface area reduction for example, selecting proper reservoir sites, constructing reservoirs with a minimum ratio of area to storage volume, diking shallow areas and compartmentalizing reservoirs, (b) reflective methods for instance, floating reflective beads and dyes, (c)surface films of oil and long-chain fatty alcohols and (d) use of mechanical covers for example roofs, floating rafts, pots and wind breakers.

Seepage control have been invariably documented. The use of chemical treatments such as: sodium salts, bentonite clay, soil cement which is a mixture of portland cement, soil and water. Also methods like; concrete linings, synthetic membrane linings and asphalt linings have been reported (Cluff, 1980).

2.3.1 Reservoir water balance

Sahasrabuthe (1984) reported a one dimensional water balance equation used to estimate the elevation of water in the reservoir. The equation used is mathematically expressed as;

$$ELV(i) = ELV(i-1) + RAIN(1) + FIL(1) - EVAP(1) - SEEP(1) - GIRR(1)$$

where;

ELV = Reservoir water elevation (mm);

RAIN = Daily rainfall(taken as all rainfall falling on or within the inside levee slopes)(mm);

FILL = Amount of water added to the reservoir through runoff (mm);

EVAP = Evaporation from the reservoir (mm);

SEEP = Sum of vertical and lateral seepage losses from the reservoir (mm), and

GIRR = Gross daily irrigation (mm).

The subscript denotes the day on which the computation is made.

Methods used for estimation of potential evaporation from the soil surface are also used to estimate potential evaporation from the reservoir surface. He further reported that, seepage losses through the base of the reservoir are estimated using Darcy's law under the assumption of unit hydraulic gradient i.e. seepage velocity is taken as equal to the saturated hydraulic conductivity of the reservoir material.

2.3.2 Operating rule

The value of the soil moisture deficit during the growing season is considered the determining factor on deciding when to irrigate. Each time during the growing season that the soil moisture deficit exceeds a threshold value it is assumed that the field will be irrigated. The only exception is that no irrigation is applied on the days receiving rainfall.

2.4 Design considerations of RWH

2.4.1 Runoff inducement and collection

The success or failure of RWH depends to a great extent on the quantity of water that can be harvested from an area under given climatic conditions. The threshold retention of a catchment is the quantity of precipitation required to initiate runoff. This quantity depends on surface storage, rainfall intensity, and its infiltration capacity, while the runoff efficiency 'η_s' has been expressed as annual averages to account for variability due to storm size (Fink et al. 1979).

Mathematically:

$$\eta_s = \frac{R \times CB}{P \times CA} \tag{3}$$

Where:

η_s = Run - off efficiency (%);

R = Run - off depth (mm);

CB = Cropped basin (m^2);

P = Precipitation (mm);

CA = Catchment area (m^2).

The ratio of catchment area to cropped basin is the second important catchment design parameter (Finkel, 1986).

Mathematically:

$$\frac{CA}{CB} = \frac{ET_{crop} - R_D}{R_D \times \eta_s \times \eta_o} \qquad 4$$

Where:

CA = Catchment area (m2);

CB = Cropped basin area (m2);

ET_{crop} = Crop water requirement (mm);

R_D = Design rainfall (mm);

η_s = Run-off efficiency (%);

η_o = Run-off coefficient.

This equation is also used for computing the amount of water for collection from the catchment given ET_{crop} and R_D. This ratio can be reduced, thus making catchments more efficient by removing plant growth from the catchment, treating them with sodium salt, and compacting them and also shaping catchment to conform with the natural slope of the land (Finkel, 1986).

2.4.2 Rice crop water requirement

Doorenbos and Prutt (1984), defined crop water requirement as the depth of water needed to meet the water lost through evapotranspiration of a disease free crop, growing in large field under non restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment. He pointed out that, water requirement of paddy rice for evapotranspiration are between 450 and 700 mm depending on climate and length of the total growing period.

Mathematically, crop water requirement is expressed as (Doorenbos and Prutt, 1984);

$$ET_{crop} = K_c ET_o \qquad 5$$

Where:

ETcrop = Crop water requirement (mm/day);

ETo = Reference crop evapotranspiration (mm/day);

K_c = Crop co-efficient.

For paddy rice the K_c values are as shown in Table 2.1 while the potential evapotranspiration according to Penman (1963) cited by Doorenbos and Prutt (1977) is expressed mathematically as;

$$ET_o = C[(W.R_n)+(1-W).f(u).(e_a-e_d)] \qquad 6$$

Where:

ETo = Reference crop evapotranspiration (mm/day);

W = Temperature related weighing factor;

Rn = Net radiation equivalent evapotranspiration(mm/Day);

f(u) = Wind related function (Km/day);

$(e_a - e_d)$ = Difference between saturation vapour pressure(e_a) at mean air temperature and the actual vapour pressure (e_d) of the air (mbar);

C = Adjustment factor to compensate for the effect of a day and night weather condition.

The climatical data input to Equation 6 are as shown in Table 2.2, at an assumed albedo of 0.25. The sample calculation is shown in Appendix 5.

Table 2.1: Kc values as a function of growth stages.

Crop stage	Kc value
First and second month	1.1 - 1.15
Mid-season	1.1 - 1.3
Last month	0.95 - 1.05

Source: Doorenbos and Kassam (1979)

De Datta (1981) reported that, rice plants requires a large amount of water after transplanting. The amount of water required in the field depends on the water depth maintained, water management practices, soil types and evaporative demand. He mentioned that the crop water requirement of lowland rice is usually 10 mm/day, including seepage and percolation.

Grist (1965) reported rice seasonal water requirement of 1500 to 1800 mm in California, while Hodges (1957) in Texas reported 800 to 1200 mm. Also, Adair and Engler (1955) in Egypt reported a water requirement of about 1500 to 1700 mm all under controlled irrigation. They pointed out that a period of 10 to 12 days before tillering and the period of flowering and fertilization are the most critical periods of the rice plant. Chatterjee and Maiti(1988) generalized that the crop water requirement depending on climate and soils are between 1000 to 1500 mm for a six months crop.

Das (1983) reported a seasonal crop water requirement of 1100 to 1600 mm for irrigated rice in India, referring to water requirement values under efficient water management practices. He splited the rice crop water requirement into two broad components, namely evapotranspiration and seepage and percolation losses in the field. However, he cautioned that for different varieties it varies with duration and their response to submergence/saturation. On the other hand the rice crop water requirement at Kapunga, Usangu village irrigation scheme in Tanzania is 1100 mm (Mlay,J.A. Personal communication, 1993).

The ET_{crop} for rice computed using Equation 5, potential evapotranspiration (ETo) from Equation 6 employing weather data is shown in Table 2.2.

2.4.3 Water management in paddy fields

De Datta (1981) reported that, after the paddy has germinated and has become established after transplanting, water is kept in the fields until a month before harvesting. This is important for the following two reasons: (a) to meet the water demand of the paddy plant and to obtain the highest possible yield, and (b) to suppress the weeds.

The time when the paddy plant is most sensitive to a water stress is during flowering and the second half of the vegetative growth stage. Paddy yields decline when the soil moisture content decreases to 70 - 80 % of the saturation point. At 50 % saturation, the yield expectancy drops to 50 % - 70 % and at 30 % saturation no yield is expected. At 20 % saturation the paddy plants die due to draught stress. Paddy roots can grow to a depth of 1 m depending on the soil and variety. The fibrous root system gradually increases from transplanting up to heading stage. At maturity most of the roots are dead. The most important characteristic of these roots is that they survive under low oxygen content in the soil. During and immediately after transplanting the depth of water allowed in the basin should be 10 cm. This can be decreased further to 3-4 cm during the tillering stage. After tillering, water depth can be increased again to 10 cm during the heading and flooring stages. During ripening periods the fields should be gradually drained up to harvesting. Paddy can tolerate complete submergence for one day or two only, but any will die under prolonged submergence.

2.4.4 Water losses in paddy fields

Das(1983) mentioned that the most important losses in paddy fields are evapotranspiration(ETo) and seepage and percolation loss. He pointed out that evapotranspirational losses under non limiting water supply conditions of ponded rice fields is essentially a function of net radiation incident in the area. The net radiation received in a unit area is utilized in evaporating water from the land crop surface. If moisture is limiting in the area, the balance amount of energy is used up in heating the soil and heating the air near ground surface. The heated air may flow to the adjoining crop field well supplied with water and may result in excessive ETo losses. This phenomenon is called the oasis effect. To minimize the influence of advective energy or oasis effects it is recommended that rice should be grown in large and compact areas instead of scattered and solitary fields with the patches of bare fields or of upland crops (Das, 1983).

Seepage and percolation losses are two important aspects accounting higher losses in paddy fields. Seepage is the lateral movement of the water from the field, while percolation is the downward movement of the water from the field. It varies directly with the magnitude of hydraulic gradient and hydraulic conductivity obeying the Darcy's law (1856) cited by Childs (1969).

Mathematically;

$$Qs = -K(\theta)\frac{\partial H}{\partial s} \quad (7)$$

Where;

Qs = Volume of water moving through the soil in the s-direction per unit area per unit time;

$\partial H/\partial s$ = Hydraulic gradient in the same direction;

$K(\theta)$ = Hydraulic conductivity which depends on both properties of the fluid and the porous medium;

H = Hydraulic head which is the sum of the pressure head 'h' and the elevation head 'z'. The negative sign indicates flow is in the direction of decreasing 'H'.

Das (1983) reported that, hydraulic conductivity of the soil can be minimized by selecting suitable soils for rice and by adopting suitable water management practices including scheduling, that is when to irrigate (timing) and how much to apply (quantity). However, he recommended that the most practical way of reducing hydraulic conductivity of the soil in rice growing areas is to try for a good and thorough puddling before planting.

2.4.5 Characteristics and varieties of paddy grown in Tanzania.

Rao (1983) pointed out that rice plant is more susceptible to moisture at seedling and flowering stages than at any other stages and varieties differ in their ability to withstand drought at different growth stages. However, he listed the most important characteristics for an ideal plant type for low rainfall areas. These characteristics are as follows: (a) early duration (85 to 100 days), (b) deep root system with maximum spread of roots at deeper zones, (c) early vigour with moderate tillering (6-8 tillers) and synchronous flowering, (d) medium height of not exceeding 100 cm, with erect and less number of leaves and thick stem, (e) good expression of the panicle at the bottom density (400 panicles per m^2), (f) panicle weight type with higher grain number per panicle and moderate seed dormancy, (g) low requirement of Iron and manganese, (h) resistant to diseases like 'Helminthosporium', and (g) drought tolerance.

In view of the above characteristics there is generally not much varietal diversity in traditionally grown rice, in all the rice ecosystems in Tanzania. Varieties are, however, markedly diversified in Pangani and Kalinawe plains (Tanga region) and coastal region. Cultivars most belong to *Oryza sativa* and to subgroup indica variety. Local upland rice varieties are a typical sample of indica types exhibiting tall plant stature, broad and droopy leaves with long grains. 'Supa India' is the variety most widely cultivated in lowland areas throughout the country (Dibwe, 1984). The variety bears several local names, such as, Supa Kilombero in Kilombero and Kyela plains, and Tuliani in Maswa district in Shinyanga region. The variety is tall (130 cm) with great tendency to lodge before ripening particularly during grain filling. Other rice varieties (replaced by Supa India in some areas) are Kihogo, Sindano, Faya and Gwindimba. These have pleasant aroma but with low grain yielding potential (Dibwe, 1984). Others are: Afaa Mwanza 1/159 and 0/749, IR 54, TxD 85, Dakawa 83, Jaribu 200 Vs Zambia/Mwanza, and Katrin. These are improved varieties currently being popularised to smallholder farmers in Tanzania.

2.4.6 Net irrigation requirement

Net irrigation requirement is the amount of water for harvesting. It represents the deficit for rainfall to meet the ET_{crop}. It is higher for the months of December, March and April (Table 2.3). This is due to the fact that adequate water is needed for puddling and nursery establishment and thereafter plants needs more water during reproductive stage towards the end of March and the whole of April. At maturity most of the roots are dead and no water is required. Thus a total water of 419 mm need to be harvested from rainfall for supplementary irrigation and 519 mm had to be met by rainfall.

2.4.7 Dependable rainfall

Due to high uncertainties in rainfall distribution in semi-arid areas, probabilities of rainfall, or the amount of rainfall that is considered dependable is therefore used rather than the absolute means of totals. Average annually rainfall is ranked in descending order (Table 2.4), the highest value first and the lowest value last by attaching a serial rank number (r) to each value (p) with (r) equal to (1) for the highest value (P1), and (r) equal to (n) for the lowest value (Pn) and the frequency of exceedance as probability calculated as reported by Doorenbos and Prutt (1984).

Mathematically;

$$P(\%) = \frac{r - 0.44}{n + 0.12} \tag{8}$$

Where:

P(%) = Probability of being equalled or exceeded.

The dependable rainfall was taken as rainfall which can be expected in 3 out of 4 years. The value of rainfall corresponding to the 75 % probability is extrapolated from Table 2.4 and is found to be 519 mm. This value of rainfall is the design rainfall in Equation 4.

Table 2.4: Ranked rainfall (mm) over 20 years with probability (%)

Year	Total	Rank	Prob. (%)
1976/77	326	20	97
1985/86	443	19	97
1974/75	470	18	92
1975/76	484	17	86
1983/84	514	16	81
1987/88	518	15	76
1981/82	525	14	71
1984/85	545	13	66
1992/93	553	12	60
1977/78	568	11	55
1982/83	570	10	50
1979/80	571	9	45
1991/92	588	8	40
1990/91	593	7	34
1993/94	616	6	29
1980/81	663	5	24
1986/87	746	4	19
1988/89	821	3	14
1978/79	843	2	8
1989/90	882	1	3
MEAN	592		

2.5 Rainwater Harvesting for rice production in Tanzania

RWH in Tanzania is mainly practised in the North-West part comprising Shinyanga, Tabora, Singida, Mwanza and Dodoma (Fig. 1.2).

Mwakalila (1992) reported that, the system of RWH is mainly used for paddy production in which rainwater is collected from the diversion of water from ephemeral streams and stored in bunded fields called "Majaruba" which are rectangular in shape (Fig.2.5). The bunds are built with simple provisions for entry and outlet of water. The bunds height vary from 25 to 100 cm.

KATC(1995) reported that, the distribution of rainfall in rice growing areas of Kilimanjaro and those shown in Table 2.5 is very unreliable and frequent occurrence of dry spells in these areas make rice cultivation very risky. Some farmers are reported to adapt the following measures: (a) establishing low plant densities in the rice fields (less competition for water during severe dry spells), (b)growing of drought tolerant varieties of Indica type; (c)flexibility in transplanting time and the water depth regulation in their "Majaruba".

As long as the water is in these basins it is heavily used for rice cultivation. However, due to evapotranspiration rates and field losses resulting from prolonged dry spells, only a relatively small amount of rainfall is beneficially consumed by the crop and these "Majaruba" soon dry up leading to low or total crop failure.

Table 2.5: **Typical rainfed and irrigated paddy yields in Tanzania by location**

LOCATION	YIELD (Tons/ha)	COMMENTS
RAINFED		**Source: Marketing Development Bureau (MDB)**
Coast Region	1.0	
Lindi Region	1.2	
Ruvuma Region	1.8	
Mwanza/Region	1.0	Hand cultivation
Mwanza/ Region	1.1	Ox cultivation
Mwanza/Region	1.5	Improved ox cultivation
TRADITONALLY IRRIGATED		**Source: ID Survey**
Bahi (Dodoma)	1.0	RWH with high risk of failure
Usangu Plains (Mbeya)	2.0	River diversion
IMPROVED TRADITIONAL		**Source: ID Survey**
Bahi (Dodoma)	4.0	River diversion,improved land development
NEW SMALLHOLDER SCHEMES		**Source: ID Survey**
Majengo (Usangu)	3.5	Mechanised cultivation, high inputs.
Mombo (Tanga)	2.0	Low inputs, but 3 crops every 2 years possible.
Lower Moshi	6.0	Very high inputs, modern varieties.
Kitivo (Tanga)	5.5	High inputs, modern varieties
Mwamapuli (Tabora)	5.5	High inputs, modern varieties
IRRIGATED STATE FARMS		
Ruvu Mbarari Madibira		All theoretically use high input packages, mechanised operations, modern varieties. All are single cropped and currently operating at a loss

Source: MoA, 1993 Irrigation division

2.6 Rainfall and agriculture in Tanzania

Ngana (1993) reported that, Tanzania history clearly shows that famine as well as localized food shortages are no strange events and that since independence Tanzania has experienced at least eleven years of drought. The reduced agricultural production is to a large extent attributed to "drought" which is a function of low and erratic rainfall and most crops are subject to water stress at different stages. He further conducted a study in semi-arid areas to analyse the historical rainfall pattern of Dodoma, Farkwa, Manyoni, Singida, Nzega, Lubaga and Maswa stations. The study indicated that January or February are the months with minimal rainfall. Rainfall amounts ranges between 400 and 800 mm per annum.

Early planting, intercropping, the use of draught resistant crops and staggered planting are used by farmers as measures to minimize the adverse effects of water stress during the growing season (Evans, 1955; Ngana, 1993). A major characteristics of rainfall in most semi-arid parts of Tanzania is it's seasonal concentration during a short period of the year which in effect limits the length of the growing season (Mhita, 1981). Consequently, agricultural production has and still remains a risky business.

In semi-arid Hombolo in Dodoma, the rainfall amount and frequency is highly variable between 326 mm and 882 mm (Table 2.4). One important characteristics in relation to RWH is the duration of dry spells. The longest dry spell (days) varies between 10 to 27 days at 30 % risk (Hatibu et al.,1993). Among alternatives suggested by Kingamkono (1994) as possible measures to sustainable crop production are: (a) supplemental irrigation, (b) water conservation or RWH measures. Therefore it is proposed that, in order to ensure a crop in 7 out of 10 years a RWH system for supplementary irrigation need the capability to cover 27 days (Hatibu et al. 1993).

2.7 supplementary irrigation for rice production

Krishnamoworthy (1979) reported that rainfed rice can best be grown in areas receiving not less than 200 mm of rainfall per month for a minimum period of three months. Unfortunately, the rainfall pattern where rice is normally grown in Tanzania is highly erratic in its distribution and the total amount . In view of the risky of dryspell, crop water requirement and the rice supply demand gap in semi-arid areas, RWH technology in which the rainfall runoff is collected and stored in reservoir compartments in addition to paddy basins was tried at Hombolo to test the following:(a) water availability to paddy rice, (b) even out dry spells, (c) bring more land into cultivation and

(d) yields increase per unit area.

The water stored in these reservoirs is used for supplementing the natural rainfall at a critical time to rainfed rice cultivation. Krantz (1979) found that the addition of as little as 5 cm of water more than doubled the production from several crops, including corn in India.

3 MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Geographical and climatic features

(a) Location

Hombolo research station is part of Hombolo Bwawani village within Dodoma municipality and lies on latitude 5° 45′ S and longitude 35° 57′ E at an altitude of about 1037 m a.s.l. (Fig.3.1).

Hombolo Bwawani village has flat to undulating plains with occasional inselbergs and seasonal streams. The topography of this village is dominated by the Hombolo reservoir across the Kinyasungwe river. The reservoir extends for about 9 km upstream, has a mean depth of about 2.5 m and covers an area less than 7.6 square kilometres. An irrigation project has been constructed and will draw water from this reservoir once it starts operation.

The native vegetation consists of scattered baobab (*Andasonia digitate*) trees and acacia (*Hyporrhenia spp.*) bushes with grassland.

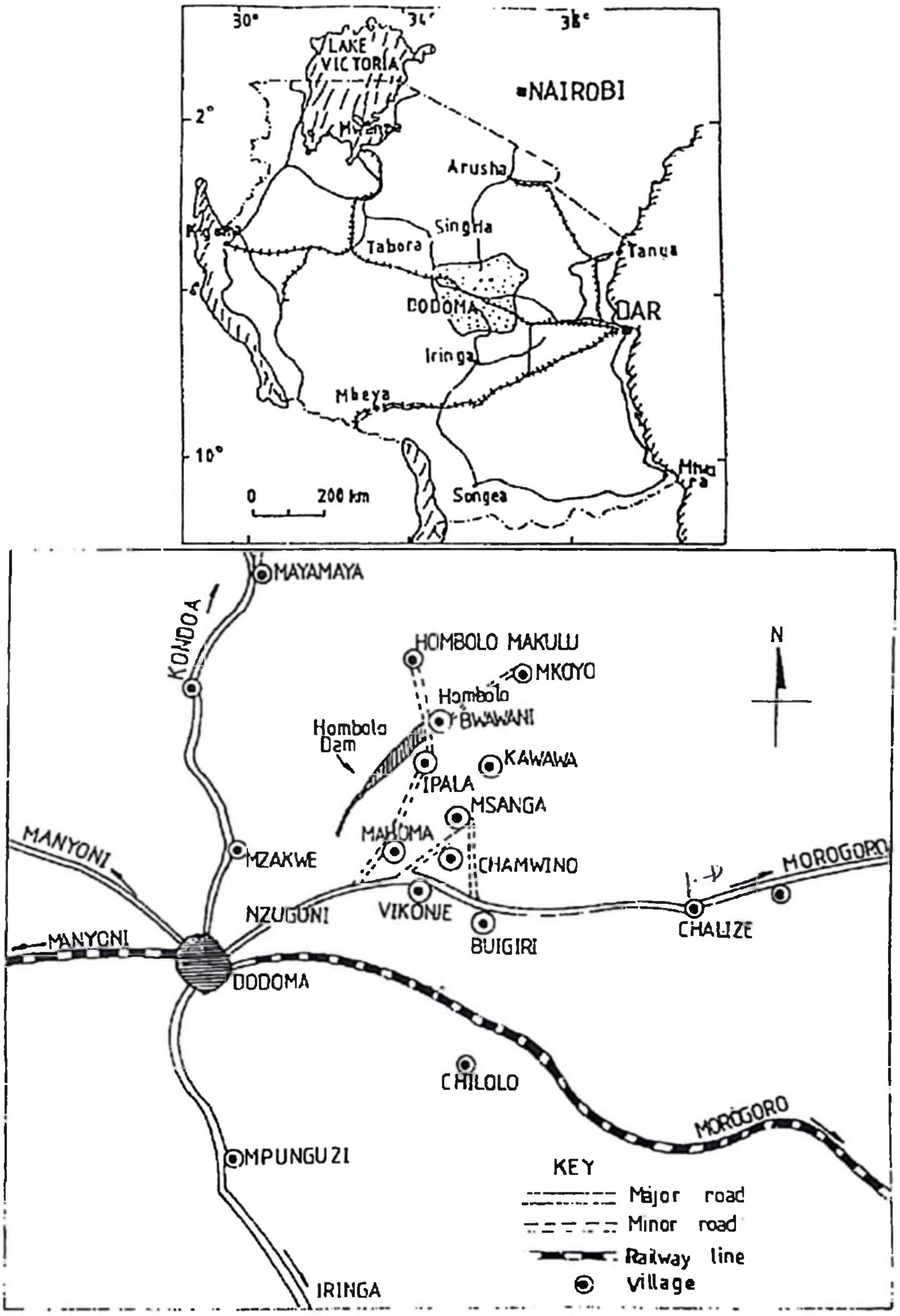


Figure 3.1: Location map of the study area (Source: Hatibu et al., 1995).

(b) Soil physical properties

The soils were examined with special emphasis on the characteristics which determine the suitability for rice cultivation. Three representative sites were studied in detail in pits of 30 cm depth subdivided into six layers each of 5 cm thickness. Core sampling was carried out from each horizon or layer and the following parameters obtained in the laboratory: (a) bulky density = 1.6 g/cc (b) saturation point = 35.5 % v/v, (c) field capacity = 32 % v/v (d)permanent wilting point = 23.7 % v/v, (e) available water 8.3 % v/v, and infiltration rate = 5.73 mm/hr . These values were obtained through pressure plate apparatus with an exception of the infiltration rate which was obtained in the field through ring infiltrometer test. From these soil parameters it can be deduced that the soil category at the site is clay loam of semi-arid region and thus suitable for rice cultivation as compared to values given by Stern (1979).

3.1.2 Farming systems

The survey conducted by Senkondo et al. 1993, indicates that the major occupation for more than a half of the households is agriculture. However, the main constraints that affect crop production as reported by farmers indicated that non reliability of rainfall was the most critical problem. Traditionally sorghum, bulrush millet, are the staple food crop. Maize and Rice are becoming increasingly popular only that their potential are greatly hit by long dry spells. Other crops include ground nuts, bambara nuts and cassava.

3.1.3 Rainfall distribution during 1994/95 growing season

Daily rainfall data was collected from the weather station of Hombolo, from November 1994 to May 1995. (Table 3.1)

Table 3.1: 1994/95 Monthly rainfall (mm) distribution of Hombolo.

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
Dry days	31	29	22	19	19	22	29	30
Wet days	0	1	9	12	11	6	2	1
Rainfall 94/95	0	18	95	116	182	199	46	10
20 years Rainfall	4	32	107	138	124	120	57	5

Source: Hombolo Meteorological station.

3.2 Treatments and experimental design

Three treatments T1, T2 and T3 were conducted as follows:

T1 under RWH with CA : CB ratio of 8 : 1 with storage;

T2 no RWH with CA : CB ratio of 0 : 1 without storage;

T3 under RWH with CA : CB ratio of 8:1 without storage.

T1 comprised the catchment area (CA), the storage reservoir (SR) and the cropped basin (CB). CA had an area of 2261 m^2 demarcated by earth bunds of 0.75 m high and 1 m wide situated at a slope of 2 % for runoff collection. The total SR volume was 125 m^3 subdivided into three compartments (C1, C2 and C3). The dimensions of each compartment were 6 m x 6 m (top), 2.7 m x 2.7 m (bottom) and 1.55 m (depth) assuming the shape of an inverted frustum of a pyramid. The construction work of this reservoir started from mid November 1994 up to mid January 1995. CB was split into four equal plots each of 10 m x 7 m. These plots were demarcated by earth bunds of 0.75 m high and 1 m wide.

These basins were under supplementary irrigation, which was made in three occasions; on 23 March 1995, 7 April 1995 and 14 April 1995. In each occasion 12.8 m^3 of water was applied using a water pump to CB of 240 m^2 or 3.2 m^3 of water was supplied per plot. This water was equivalent to 53 mm of rainfall per occasion or 160 mm for the three occasions. Besides, another 210 mm of water was supplied for nursery establishment making a total of 370 mm of water requirement as supplementary irrigation. The difference between the crop water requirement (938 mm) over the growing season leaves 568 mm as the effective amount of rainfall.

T2 constituted the CB alone, split into four plots to represent replications. Each plot was 10 m x 7 m in size and demarcated by earth bunds of the same size as for T1. The CB was situated at a flat area and had no surface storage nor under supplementary irrigation.

T3 encompassed CA (for runoff collection) and CB situated at 2 % and flat area respectively, demarcated and made of the same size as in T1 and T2. Treatment layout at the site for all the treatments are as shown in Fig.3.2, 3.3 and 3.4.

Field operations comprised ploughing, harrowing and subdividing into three blocks separated by a 2 m wide paths. These operations were carried out in November 1995, the nursery was seeded on 18 December 1994 and transplanted on 8 February 1995. Weeds were adequately controlled by hand weeding while fertilizer (80 kgN/ha) application was done on 8 March 1995 after puddling. Harvesting operation took place on 18 June 1995 and sampled for yield data analysis.

The variety used was TxD 85, which is an improved cultivar with the following characteristics (Kanyeka, Z.L. personal communication, 1994): (a) drought tolerant; (b)Semi-tall;

(c) Disease resistant especially blast disease and, (d) Medium maturing (135 days). Also agronomic practices requires: (i) spacing 20 cm x 20 cm; (ii) yield expectation 6 to 8 tons/ha and, (iii) fertilizer 80 kgN/ha for normal yield.

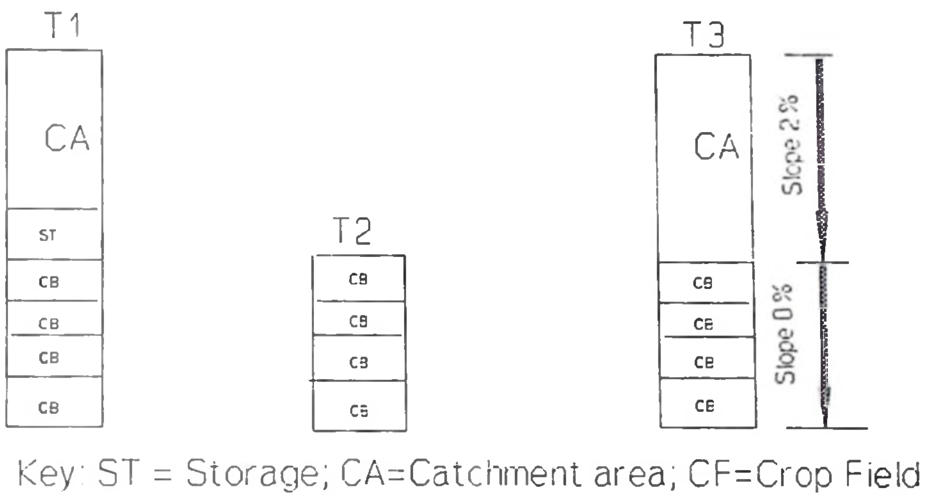


Figure 3.2 Treatment layout.

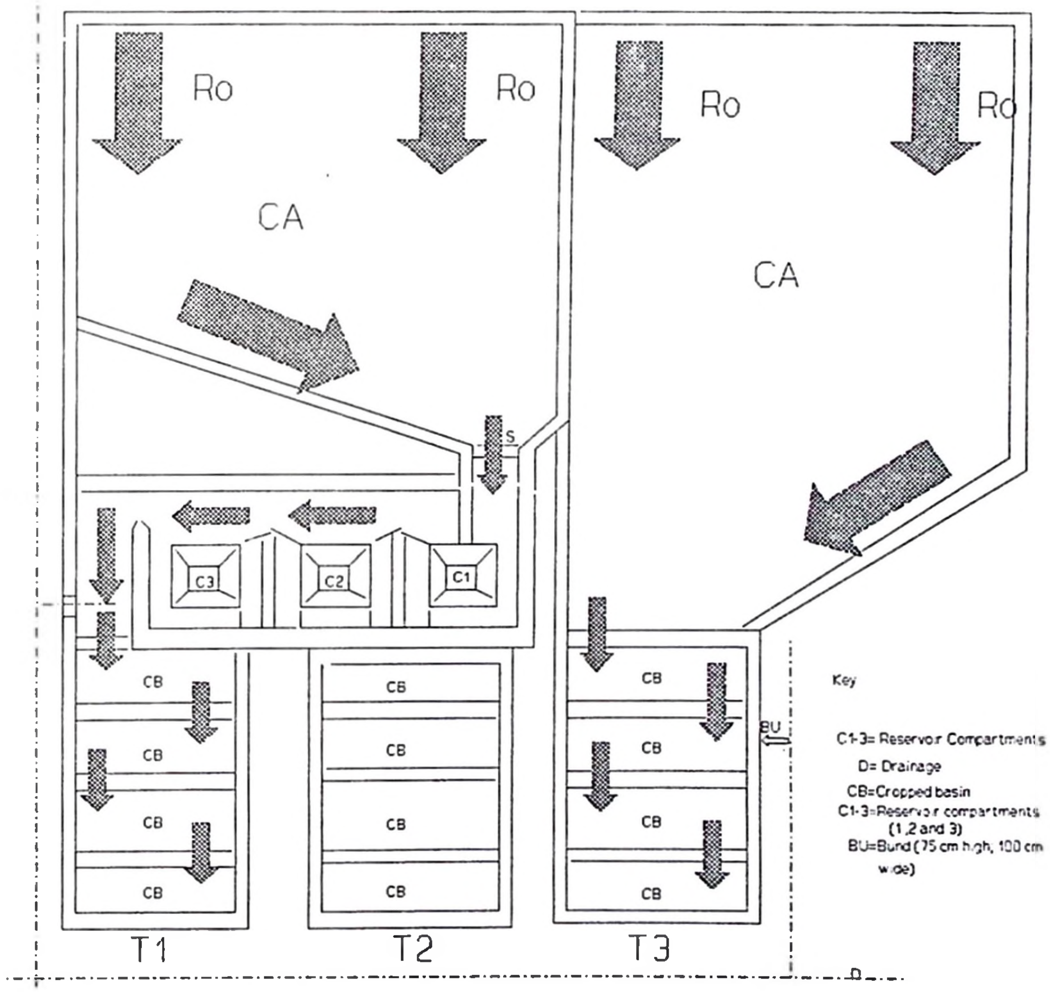


Figure 3.3 Treatment details at the site.

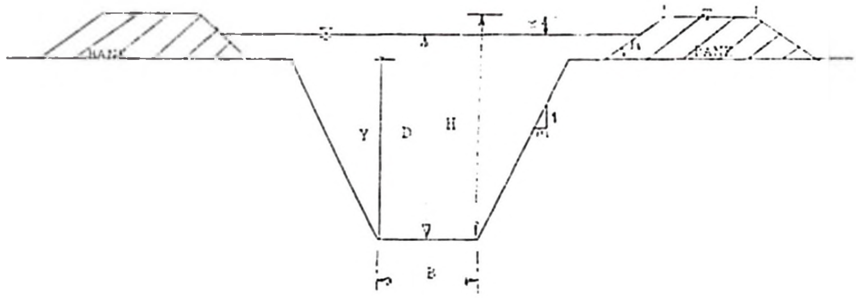


Figure 3.4: Reservoir section

3.3 Economy consideration of the reservoir

For achieving economy of the section, the depth of excavation is so arranged that the quantity of earth excavated from the reservoir section is just sufficient to construct the banks by assuming a trapezoidal section. When the depth of cutting is adjusted to achieve this condition the section is said to be most economical section. The depth of excavation is then called the balancing depth. This depth can be calculated from the following mathematical expression derived from Figure 3.4 (Sahasrabudhe, 1984).

$$Y^2 - Y(\frac{B}{2} + 3H + T) + H(T + \frac{3}{2}H) = 0 \quad (9)$$

Where;

Y = Balancing depth(m);

D = Full supply depth(m);

H = Height of the top of the bank above the bed of the reservoir (D + Freeboard)(m);

B = Bed width of the reservoir (m);

T = Top width of the reservoir banks(m);

m : 1 (Horizontal : vertical) is the side slope in cutting;

n : 1 (Horizontal : vertical) is the side slope in filling;

m : 1 was set at 1 : 1 and n : 1 was set at 1.5 : 1. The solution of the above equation leads to the quadratic equation. 'B' was set at 2.7 m, 'Z' at 0.40 m and 'T' as 1.8 m. Thus the balancing depth was computed as 1.55 m.

3.4 Measurements

3.4.1 Storage losses

Water levels was measured on two occasions over a period of 3 days in each occasion, using a three meter graduated stick by dipping in the reservoir. The baseline level was taken as the depth caught after every rainfall event, while the decrease in depth represented the loss through evaporation and seepage. Any increase in depth represented the recharge due to rainfall run-off.

3.4.2 Soil profile moisture changes

Soil profile moisture at different growth stages and at five different depth was carried out on weekly basis or immediately after every rainfall events using CPN NEUTRON PROBE (Model 503 DR) moisture meter.

3.4.3 Paddy yield

Rice harvesting operation was conducted manually on mid June 1995 at 14 % moisture content using sickle, a hand tool most popular to farmers in the area. This task was followed by thinly spreading the swath under the shade and left to dry for 7 days down to 13 % moisture content, a level considered safe for grain keeping quailities. Threshing was accomplished by simply applying a gentle impact force on a heaped swath using a stick. The resulting grain was eventually weighed on the weighing scale.

3.5 Data analysis

Yield data were analyzed for significance of treatment. The statistical model for randomized complete block design (RCBD)was used and Analysis Of Variance (ANOVA)was carried out on paddy yield (Probability (P) = 0.05) with the help of MSTAT, a computer package for statistical analysis. Treatment means were compared using New Duncan's Multiple Range Test (NDMRT) (Duncan, 1955) cited by Kwanchai and Arturo (1976).

4 RESULTS AND DISCUSSION

4.1 Storage losses

Water level changes of practical importance were considered from 15 March to 24 April 1995 (Table 4.1). This was the period of the longest dry spell of 38 days. Rainfall amount of 44.9 mm on 14 March 1995 capable of filling all reservoirs, led to the reference run-off inflow volume of 41.67 m^3 for a single compartment. This was the volume of the compartment when full at 1.55 m depth. However, after 38-day dry spell the water level dropped to 0.8 m (Table 4.1), equivalent to 13.90 m^3 as a result of seepage and evaporation. Thus the reservoir performance was 67 % (Equation 1).

Also, applying the reservoir water balance Equation 1 for the same period of 38 days. The seepage and evaporation loss were found to be 560 mm and 190 mm respectively , by considering 1550 mm as initial reservoir depth, 800 mm final depth for a time interval of 38 days dry spell and an evaporation of 5 mm/day. Other parameters like daily rainfall, amount of water added and gross daily irrigation are all taken as zero within this period.

These results suggests that although the reservoir sides were lined with cement- soil plaster to minimize seepage loss, still there was a leakage due to crack development, implying that proper materials for lining to reduce seepage need to be explored further. The reservoir performance is well supported by Sahasrabudhe (1983). He reported that it is impossible to come across a fully impervious and impermeable basin. Water surface of a reservoir is exposed to the atmosphere as well as in contact with soil surface. Hence loss of water always occur from the water reservoir.

Equally important is the evaporation loss. The value of evaporation suggests that water loss by evaporation was significant. Therefore, technical methods for evaporation control need to be studied.

Table 4.1: Storage level changes for 1994/95 rain season.

DATE	C1 (cm)	C2 (cm)	C3 (cm)	Rainfall (mm)
23/1/1995	9	6	6	17.4
24/1/1995	7	5	6	-
31/1/1995	80	35	28	47.8
2/2/1995	70	30	23	-
9/2/1995	155	25	20	43.7
19/2/1995	155	145	35	13.9
27/2/1995	155	155	155	53.8
4/3/1995	155	155	155	54.7
14/3/1995	155	155	155	44.9
15/3/1995	150	150	150	-
24/4/1995	80	80	80	-

C1-3 = Compartments 1-3

4.2 Soil moisture content variations in paddy fields

The effect of RWH was clearly shown by the changes of soil moisture taken at different stages; that of tillering, booting and ripening stages (Table 4.2 and at varying depth Appendix 7).

Soil moisture measurements taken after rainfall events showed that there was more moisture in paddy fields with RWH under supplemental irrigation from storage and with RWH without storage. Further, after rainfall cessation, supplementary irrigation made much difference in the soil moisture content for the first treatment. Also it can be noted that after supplementary irrigation on the paddy fields for the first treatment, some water seeped to treatments under non supplemental irrigation.

The average soil moisture regime for paddy fields under supplemental irrigation was 284 mm, paddy fields under purely rainfed condition without RWH was 268 mm and paddy fields under rainfed conditions with RWH was 268 mm at booting stage, which is the most sensitive stage.

At yield formation stage, the average soil moisture content was 306 mm, 213 mm and 211 mm for same treatments explained above respectively, while at ripening stage the average soil moisture content was 296 mm, 252 mm and 211 mm again for the respective treatments explained above.

On average there was a better soil moisture regime for paddy fields under supplemental irrigation than paddy fields under purely rainfed conditions.

These observations reveals that surface storage had a positive influence on crop performance (Plate 4.3). The drought period which occurred immediately after rainfall cessation covered 38 days causing severe soil moisture depletion for treatments under rainfed conditins (Plate 4.1 and 4.2).

Table 4.2: Soil Moisture Content Variations in the field

Date	Rainfall (mm)	Depth (cm)	T1 (mm)	T2 (mm)	T3 (mm)	Stage
3.2.95	0.0	80	268	254	275	A
8.2.95	43.7	80	307	293	307	B
11.2.95	4.4	80	292	291	291	B
18.2.95	13.9	80	292	283	279	B
22.2.95	0.0	80	288	284	286	B
25.2.95	53.8	80	318	302	304	C
27.2.95	42.6	80	321	303	304	C
28.2.95	10.2	80	321	304	306	C
4.3.95	54.7	80	322	315	320	C
8.3.95	23.8	80	321	304	306	C
11.3.95	30.6	80	318	301	290	C
13.3.95	44.9	80	322	300	303	C
22.3.95	IRRIG.	80	300	284	284	D
29.3.95	0.0	80	285	272	272	D
6.4.95	0.0	80	270	248	247	D
7.4.95	IRRIG.	80	305	248	247	E
14.4.95	IRRIG.	80	307	178	175	E
19.4.95	0.0	80	293	238	238	F
25.4.95	0.0	80	300	264	255	F
2.5.95	0.0	80	299	263	248	F

A = Puddling; B = Transplanting followed by recovering tillering; C = Peak tillering; D = Booting; E = Yield formation and F = Ripening.

Plate 4.1: Effect of long dry spell on paddy (T2) (14 March and 22 April 1995).

Plate 4.2: Effect of long dry spell on paddy (T3) (between 14 March and 22 April 1995).

Plate 4.3: Effect of supplementary irrigation on paddy (T1) (booting stage in April 1995).

Plate 4.4: Soil moisture saturation in the cropped basin (March 1995).

Plate 4.5: Storage reservoir full of runoff (March 1995).

4.3 Performance of supplementary irrigation in basins.

The mean soil moisture data before an irrigation event was 270 mm and after irrigation event was 305 mm on 7 April 1995 for T1. Considering a root zone depth of 80 cm, the performance of a supplementary irrigation system is determined by the efficiency with which water is diverted, conveyed and applied. Also it is determined by the adequacy and uniformity of application in each paddy field. Water diversion to the field was performed by a water pump. This , collected water from the storage reservoir to the field at a distance of 5 to 35 m without significant losses. Therefore conveyance efficiency, field canal efficiency were all assumed to be 100 %.

4.3.1 Uniformity of application.

Uniformity of application was computed using the following equation (James, 1988).

$$C_u = 100 - 80\left[\frac{S}{x}\right] \tag{10}$$

Where:

Cu = Coefficient of uniformity;

S = Standard deviation of the observations;

x = Average depth/Volume caught/infiltrated;

From the mean soil moisture data after irrigation, the value of coefficient of uniformity was found to be 99 %. Indicating that water was uniformly applied.

4.3.2 Storage efficiency

When the desired depth of irrigation fills the soil to FC a term called the storage efficiency is used as an index to adequacy (James, 1988). Storage efficiency is mathematically expressed as;

$$E_s = 100\ [\frac{S_{rz}}{S_{fc}}] \tag{11}$$

Where:

E_s = Soil storage efficiency;

S_{rz} = Amount of water in the root zone during irrigation (cm).

and

$$S_{fc} = [\frac{\theta_{fc} - \theta_i}{100}]\,D_{rz} \tag{12}$$

S_{fc} = the amount of water to fill the root zone to field capacity (cm);

θi = Soil moisture content after irrigation (% v/v);

D_{rz} = Root zone depth (cm);

θ_{fc} = Soil moisture content at field capacity.

The storage efficiency was found to be 75% at S_{rz} equal to 2.4 cm. and S_{fc} of 3.2 cm. These values are in close agreement with 3.2 m^3 of irrigation water supplied per plot. A ponding depth of 10-20 cm was only for 1 to 6 days. This depths was decreasing from the first to the sixth day.

4.4 Impact of supplementary irrigation

There was a significant difference in yield between treatments, with coefficient of variation of 32.6 % (Table. 4.4). Nen Duncun's Multiple Range Test (NDMRT) indicated that yield from paddy fields non supplemental irrigation (T2 and T3) were significantly different from paddy fields under supplemental irrigation (T1), but not significantly different from each other ($P \le 0.05$). Also, yield differences due to replications was insignificant.

On average T1 produced 3.2 tons/ha , while T2 produced 0.1 tons/ha and T2 produced 0.2 tons/ha respectively (Table 4.3). The yield increase by supplemental irrigation over rainfed treatments combined was very high (2.9 tons/ha). These results suggests that supplementary irrigation from the storage reservoir had a positive influence on T1, irrespective of the 38 - day dry spell.

A total of 160 mm of water was applied for three supplemental irrigations; that is for each irrigation 53 mm of water was considered. The first irrigation was applied at the booting stage, the second and third were implemented at the heading to milking stage (yield formation).

The crop water requirement of lowland rice was taken as 10 mm/day (De Datta, 1981), including seepage and percolation. Therefore, 53 mm of supplemental irrigation at a time will help to maintain standing water in the field for about 4 to 6 days and another 3 to 4 days will be required to reach subsequent field capacity (0.32 v/v) without any yield loss. The value of 159 mm as a result of three supplemental irrigation was found to be adequate to overcome the water stress for not more than 38 days consecutively.

The current National paddy yield per hectare from continuous standing water in irrigated ecosystem (Table 1.1) is lower than the yield from the study under supplemental irrigation. Therefore, from this study, it can be deduced that during the growing (rain) season it is not necessary or wise to maintain continuous standing water, provided supplemental Irrigation can be given in proper time.

This observation is well supported by De Datta (1981). He reported that, water use and moisture stress effect vary at different growth stages. Sufficient moisture supply is more important in critical growth stages than it is in other stages. Further, he pointed out that good water management was highly important for raising the production of rainfed lowland rice. If the water supply to the crop is good under rainfed conditions, grain yield will be similar to irrigated rice. Also, Majunder and Chouldhury (1981) reported that, one timely irrigation input can have a better input on yields compared to 2 or more irrigation inputs which are not applied at the proper timing.

Table 4.3: Paddy yield (tones/ha)

Treatment	Rep1	Rep2	Rep3	Rep4	Mean
T1	2.9	2.4	3.4	4.0	3.2
T2	0.3	0.0	0.0	0.1	0.1
T3	0.0	0.1	0.4	0.4	0.2
Mean	1.1	0.8	1.3	1.5	1.2

Table 4.4: ANOVA

Source	df	SS	MS	F-Value	Prob.
Reps	3	0.73	0.242	1.67	0.27
Treats	2	24.23	12.12	83.72	0.00
Error	6	0.87	0.145	26.76	0.00
Total	11	25.83			

Coefficient of variation = 32.6 % ; Lsd at 0.05 % = 0.658

4.5 Crop dry matter content at harvest

The influence of drought on yield components during the study period was mainly limited to dry matter content of paddy yield at harvest. Results from laboratory analysis (oven dry weight analysis) indicated that the dry matter content which is the percentage of filled grain was 86.4 % (T1) under supplemental irrigation and 77.3 % (T2) to 80.7% (T3) under rainfed conditions.

It is remarkable that the percentage of filled grain under supplemental irrigation (T1) was higher than that under rainfed conditions (T2 and T3), the difference of filled grain among the treatments was 9 % as a result of supplemental irrigation which produced 2.9 tons/ha more yield than the rainfed conditions. Therefore, the study observed that high yield of rice was mainly dependent on the percentage of filled grain, which was seriously affected by drought at the last stages of crop growth. These results are well supported by Yoshinda (1981) who mentioned that 3 days drought at 3 to 11 days before heading reduces yield significantly by causing a high percentage (59 to 62 %) of sterility. If sterility occurs once, there is no way for the plant to compensate for it.

4.6 Rainfall pattern and supplemental irrigation

The rainfall amount during the study period indicates that the maximum rainfall was 199 mm and the minimum was 10 mm. Monthly rainfall data are presented in Table 4.5. From this table it can be observed that the rainfall distribution was very poor during the growing season. For example the rainfall ceased the second week of March when the crop was at the transition from peak tillering to reproductive stage (booting). As a result 2.9 tons additional yield per hectare over rainfed was achieved with three supplemental irrigations. However, rainfed treatments suffered severely because of drought. The amount of rainfall was high in the month of January, February and early March . Still , this had no impact on yield because of uneven distribution and high amount of rainfall at a time which was not sensitive to the crop and simply accelerated loss through run-off.

From the rainfall pattern, the following fact can be deduced that, the severity of drought depends on the distribution of rainfall and the phases of crop growth, not on the total amount of rainfall alone. This fact is well supported with the amount of rainfall in March (199 mm); in actual fact March had a drought period of two weeks at the end. Thus reliance on the monthly average rainfall data could be a misinterpretation of the evidence.

Therefore, the study reveals that drought from 14 March to 24 April reduced the yield severely. This rainfall pattern is well supported by Kassase (1992): He mentioned that early cessation of rainfall reduces the effective length of the growing season and ultimately the crop yield.

De Datta and Vergara (1975) reported that daily rainfall is actually more critical than monthly or annual rainfall. A precipitation of 100 mm/month distributed evenly is preferable to 200 mm per month which all falls in 2 or 3 days.

Table 4.2: 1994/95 Daily rainfall (mm) distribution of Hombolo.

DATE	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
1	0.0	0.0	0.0	1.9	0.0	0.0	0.3	0.0
2	0.0	1.8	0.0	2.8	0.0	3.5	0.0	0.0
3	0.0	0.0	0.0	0.0	0.0	54.7	0.0	0.0
4	0.0	0.0	0.0	7.0	0.0	21.7	0.0	0.6
5	0.0	0.0	0.0	0.9	0.0	0.2	0.0	0.0
6	0.0	0.0	6.7	3.9	0.0	0.0	0.0	0.0
7	0.0	0.0	0.0	0.0	0.0	7.3	0.0	0.0
8	0.0	0.0	0.4	0.0	43.7	23.8	0.0	8.3
9	0.0	0.0	0.0	0.0	0.2	0.0	9.7	0.4
10	0.0	0.0	1.2	0.0	1.9	1.3	1.2	0.0
11	0.0	0.0	2.0	0.0	4.4	30.6	0.2	0.0
12	0.0	0.0	8.7	0.0	3.0	0.0	0.0	0.0
13	0.0	0.0	4.9	0.0	0.0	44.9	0.0	0.0
14	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0
15	0.0	0.0	0.0	0.0	0.0	4.0	0.0	0.0
16	0.0	0.0	0.0	2.8	0.0	0.0	0.0	0.0
17	0.0	0.0	0.0	0.0	0.0	6.7	0.0	0.0
18	0.0	0.0	11.4	0.0	13.9	0.0	0.0	0.0
19	0.0	0.0	54.2	1.1	1.2	0.0	0.8	0.0
20	0.0	0.0	0.0	11.2	0.0	0.0	0.7	0.0
21	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0
22	0.0	0.0	0.0	17.4	4.8	0.0	0.0	0.0
23	0.0	0.0	0.0	7.4	0.0	0.0	31.4	0.0
24	0.0	0.0	0.0	5.4	0.0	0.0	0.5	0.0
25	0.0	0.0	1.3	0.0	53.8	0.0	0.0	0.4
26	0.0	0.0	0.0	6.6	42.6	0.0	0.0	0.0
27	0.0	15.9	0.0	0.1	0.2	0.0	0.0	0.0
28	0.0	0.0	0.0	0.0	10.2	0.0	0.0	0.0
29	0.0	0.0	0.0	0.0	0.0	0.0	1.4	0.0
30	0.0	0.0	0.0	47.8	0.0	0.0	0.0	0.0
31	0.0	0.0	4.3	0.0	0.0	0.0	0.0	0.0
TOTAL	0.0	17.7	95.1	116.3	181.6	198.7	46.2	9.7

5 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

From the study the following conclusions can be made:

1. In the context of relative water scarcity in semi - arid areas three timely supplemental irrigation of 53 mm each can overcome dryspell of 38 days.

2. Rainwater Harvesting system incorporating supplemental irrigation from reservoir resulted into sustained water availability and significantly higher yields (3.2 tons/has) compared to rainfed systems without supplemental irrigation (0.3 tons/ha).

3. The storage reservoir performance was fairly high (67 %). Storage losses were 33 %. The cement : sand: soil lining of the storage reservoir significantly reduced the seepage losses.

5.2 Recommendations

From the study the following recommendations can be made;

1 Since one season is not enough to assess all the important aspects like: effect of yield components to drought, yield response to water; economic aspects of rainwater harvesting with storage; effect of sediment load from the soil loss in catchment to the reservoir performance, and the effect of various lining materials to reservoir losses; Further research work is required to develop an optimum size of rainwater harvesting system incorporating water reservoirs for paddy production.

6 REFERENCES

Adair, C. R. and Engler, K. (1955) *The irrigation and culture of rice in water.* US. Department of Agriculture. pp 389 - 394.

Adair, C. R., Miller, M. D. and Beachell, H. M. (1962) Rice improvement and culture in the U.S.A. In: *Journal of Advanced Agronomy* 14, 61 - 104.

Ayoade, J. O. (1983) *Introduction to climatology for the Tropics*. John Willey and Sons, New York. pp 258.

Boers, Th. M. and Ben-Asher, J. (1982). A review of rainwater harvesting . In: *Agriculture Water Management* 5: 145 - 158.

Boers, Th. M. (1994). *Rainwater Harvesting in Arid and Semi-arid Zones*. pp 127.

Chandler, R. F. J. (1963) An analysis of factors affecting rice yield. In: *Journal of International Rice Communication* 12 (4), 1 - 17.

Chatterjee, B. N. and Maiti, S. (1988) *Principles and practice of rice growing*. Primlani, M. New Delhi. pp 203.

Childs, E. C. (1969) *An Introduction to the Physical basis of Soil Water phenomena*. John Wiley and Sons, New York. pp 493.

Cluff, C. B. (1980). The use of the compartmented reservoir in water harvesting agrisystems. In: *Goodin, J. R. and D. K. Northington (Editors) Arid Land Plant Resources*. Texas Technical University, Lubbock, TX, pp 482 - 500.

Critchley, W. R. S. (1987). Some lessons from water harvesting in Sub - Saharan Africa. In: *proceedings of a Workshop held in Baringo, Kenya, 13 - 17 October 1986*. World Bank, Eastern and Southern Africa Projects Department, Washington D. C. pp 250.

Das, K. C. (1983) Water management in rice. In: *Proceedings of the Workshop on Rice Production Technology in India*. 1 - 8 December 1983, Central Rice Research Institute, Cuttack - 753 006. pp 152.

De Datta, S. K. and Vergara, B. S. (1975) Climates of Upland Rice. In: *Major Research in Upland Rice*, IRRI, Phillipines 5, pp 126.

De Datta, S. K. (1981). *Principles and Practices of Rice Production*. John Willey and Sons, New York. pp 618.

Dibwe, M. (1984) Effects of rotational irrigation on water use efficiency, growth and yield of direct seeded lowland rice. M. Sc. Dissertation, University of Dar - es - Salaam pp 120.

Doorenbos, J. and Prutt, W. O. (1984). Crop Water Requirements. *FAO Irrigation and Drainage Paper No.24*, FAO, Rome,Italy. pp 144.

Doorenbos, J. and Kassam, A. H. (1979). Yield Response to water. *FAO Irrigation and Drainage* paper No. 33. FAO, Rome, Italy. pp 193.

Dutt, G. R., Garduno, M. A. and Hutchnson, C. F. (1981). Rainfall Collection for Agriculture in Arid and Semi - arid Regions. *In: proceedings of a Workshop at University of Arizona (USA) and Chapingo Postgraduate College, Mexico*. pp 250.

Economic Research Bureau (ERB) (1989). *Tanzania Economic Trends; a Quarterly Review of Economy 1 (4)*, Dar - es - Salaam. pp 142.

El Amani, S. (1983). Traditional technologies and development of the African environments, utilisation of runoff waters: The ' Meskats 'and other techniques in Tunisia. In: *African Environment* 3 (3/4): 107 - 120.

Evans, A. C. (1955). A study of crop production in relation to Rainfall reliability.In: *Journal of East African Agriculture*. Vol.20. pp 263 - 267.

Evenari, M., Shanan, L. and Tadmor, N. H. (1971). *The Nigev, The Challenge of a Desert*. Harvard University Press, Cambridge, Mass. pp 324.

Evenari, M., Shanan, L., and Tadmor, N. T.(1968). Runoff farming in the desert. Vol. I. Experimental layout. In: *Journal of Agronomy*. 60: 29 - 32.

Fallon, L. E. (1963). Water spreading in Turkana, a hope for an impoverished people. USAID, Nairobi, Kenya. pp 236.

Fink, D. H., Frasier G. W, and Myers, L. E. (1979). Water harvesting treatment evaluation at Granite Reef. In: *Water Research Bullettin*. 15: 861-873.

Finkel, H. J., Finkel, M. and Naveh, Z. (1987). Engineering measures: Water Harvesting. In: *Semi-arid Soil and Water conservation*: 93-101, CRC Press Inc: Florida, USA. 10, 86-95.

Finkel, M. (1986). Water harvesting in Turkana, Kenya. In: *proceedings of a Workshop on Water Harvesting in Sub - Saharan Africa, Baringo Kenya*, 13 - 16 October 1986.

Finkel, M. (1984). Report on water harvesting in Turkana, Kenya. Draft. Document GCP/KEN/048/MOD, FAO, Rome. pp 120.

Food and Agriculture Organization (1982) Rice Development and rainfed rice production. In: *Journal of FAO Plant Production and Protection* . 41. p103.

Food and Agriculture Organization (FAO) (1995) *Special Programme on Food Production in Support of Food Security in Tanzania*. Exploratory Mission Report. FAO Rome, Italy. pp 39.

Frans, R. M. and Breemen, N. (1978) *Rice Soil and Water Land*. IRRI, Los Banos, Laguna, Phillipines. pp 185.

Gardner, H.R. 1975. An analysis of the efficiency of micro-watershed systems. In: *Proceeding of water harvesting symp., Phoenix, AZ, ARS W-22*. *USDA*, pp 244-250.

Gilbertson, D. T. (1986). Run-off (floodwater) farming and rural water supply in arid lands. In: *Applied geography*. 6(1): 5-11.

Grist, D. H. (1965) *Rice*. Longman. Inc. publisher, New York. pp 601.

Hillel, D. (1967). *Runoff inducement in arid lands*: Final Technical Report: USDA Project A10-SWC-36, USDA, Rehovot, Israel. pp 142.

Hillel, D. (1980). *Fundamentals of Soil Physics.* Academic Press, London Inc. pp 413.

Hodges, R. J. (1957) Rice a big business on the Gulf Coast Prairie. In: *Journal of Agricultural Extension Service* 14, 872-875.

International Rice Research Institute (IRRI) (1982) *Rice Research Strategies for the future.* IRRI, Los Banos, Laguna, Phillipines. pp 553.

International Rice Research Institute (IRRI),(1993-95). *Rice Research Almanac.* IRRI, Los Banos pp 65.

James, G. L. (1988). *Principles of Farm Irrigation System Design.* John Willey and Sons, Inc. Canada pp 543.

Kassase, C. I. (1992) Determination of effective length of growing season in Tanzania. M.Sc. Dissertation, Sokoine University of Agriculture. pp 104.

Kilimanjaro Agricultural Training Centre (KATC) (1995) Rice and People in Tanzania. In: *Journal of Training for Agricultural Development* 2,1 - 7.

Kingamkono, R. M. L. (1993) The Effective Length of Growing Season in Tanzania. M. Sc. Dissertation, Sokoine University of Agriculture. pp 92.

Kolarkar, A. S., Murthy, K. and Singh, N.(1983). Khadin- a method of harvesting water for agriculture in the Thar desert.In: *Journal of Arid Environments* 6:59-66.

Krantz, B. A. (1979) *Small Watershed Development for Increased Food Production.* International crops Institute for the Semi - arid Tropics, Hyderabad, India. ICR 79 - 0019. pp 152.

Krishnamoorthy, K. K. (1979) Breeding for tolerance to drought and Salinity. *Proceedings of Rice Production under Environmental Stress Workshop, CRRI. Cuttack,* 24 December 1979. pp 152.

Kwanchai, A. G. and Arturo, A. G. (1976). *Statistical Procedures for Agricultural Research.* Friedreich - Ebert - Stiftung, Bonn, Federal Republic of Germany pp 680.

Majunder, D.K. and Choudhury, R. (1981). Nitrogen response to Irrigation. In:*Journal of Agriculturist*, Phillipines 25(4), 241 - 247.

Mwakalila, S. S. (1992). *Performance evaluation of Rainwater Harvesting for paddy production in Tanzania*. M. Sc. Dissertation, Agric. Engineering, Sokoine University of Agriculture, Morogoro. pp 126.

Ngana, J. O. (1993).Rainfall and Agriculture: Drought and Famine in Dodoma District.*BRALUP Research Report No.* 60 (New series) University of Dar-es - Salaam. pp 30.

Pacey, A. and Cullis, A. (1986). *Rainwater Harvesting: The Collection of rainfall and runoff in rural areas.* IT publication, London, Uk. pp 453.

Pan, C. L. and Djimia, M. B. (1962). Tolerance of Rice to Water with different salt concentrations. In: *Journal of Institute of National Research Agronomy Tunisia*. 35, 207 - 216.

Rao, M. J. (1983) Problems of Rice Varietal Improvement in India. In: *Proceedings of the Workshop on Rice Production Technology in India, Central Rice Research Institute*, 1 - 8 December 1983, Cuttack - 753 006. pp 152.

Reij, C., Mulder, P. and Begeman, L. (1990). Water Harvesting for Plant Production. *World Bank Technical paper* No. 91 pp 236.

Sahasrabuthe, S. R. (1984) *Irrigation Engineering*. Katson publishers, Ludhiana, India. pp 394.

Senkondo, E. M. M. and Mwaseba, D. (1993). Socio-Economic Aspects of Soil - Water Management in Semi - Arid areas of Tanzania. In: *proceedings of a Research Planning Workshop* ,13 - 15 January 1993 Dodoma, Tanzania. pp 57 - 68.

Shayo, S.A. (1987) The importance of Rice in the economy of Tanzania. In: *Proceedings of IRRI/SUA/TARO Rice production training program*. 14 - 16 September 1987, Sokoine University of Agriculture, Morogoro, Tanzania, pp 200.

Simith, G.L. (1978). *Water Harvesting Technology Applicable to Semi-Arid Subtropical climates*. Colorado State University, Fort Collins, CO, USA. pp 95.

Stern, P. H. (1979). *Small-Scale Irrigation*. Intermediate Technology publications Ltd. 103 - 105 Southampton Row, London WC1B 4HH, UK. pp 152.

Tanzania Ministry of Agriculture and Livestock Development (1993).Annual *report; Irrigation Priorities in Tanzania*. pp 2 - 5.

United Nations Environmental Programme (UNEP). (1983). *Rain and Stormwater harvesting in rural areas*. Tycooly, Dublin. pp 413.

Yoshinda, S. (1981) Fundamentals of Rice Crop Science. In: *Major Research in Upland Rice* IRRI, Phillipines. pp 69 - 108.

7 APPENDICES

Appendix 1: Storage reservoir design for T1

The total net irrigation requirement was calculated as 125 m^3 (Table 2.3). This is for supplementary Irrigation which must be met for crop evapotranspiration and thus even out dry spells. Therefore this volume was divided into three compartments.

The volume of each compartment was computed using the following mathematical expression;

$$V = \frac{[X + (X + 2h)]^2 * h}{2} \qquad 13$$

Where:

V = reservoir volume (m^3);

h = reservoir depth (m);

x =Top length/bottom width ratio of reservoir.

The dimensions were found to be 6 m x 6 m at the top, 2.7 m x 2.7 m at the bottom and 1.5 m deep, assuming a shape of frustum an inverted pyramid.

The amount of water which can be periodically accommodated in these compartments can rescue moisture stress effects for not more than 38 days dry spells. This water is used during dry periods as supplementary irrigation for paddy production at Hombolo site for T1 only.

Appendix 2: Operation of T1

The rainfall runoff (Ro) collected from uncleared catchment area (CA) of 2261 m^2 was first directed into the right hand compartment (C1). After this compartment is full the runoff overflows to the middle compartment (C2). Once the middle compartment is full, the runoff overflows to the third compartment (C3) and thereafter the runoff overflows through a spillway to the cropped basin. Before the runoff enters the right hand compartment it first passes through a silt trap (S) which, allows all sediments to settle before they can be bailed out. Further, a drainage (D) was also provided to evacuate any excess runoff (Fig. 3.3).

Appendix 3: Construction of storage reservoir for T1

Reservoir construction involved the most familiar hand tools to farmers, they included; axe, spade and wheel barrows. Surfacing was based on; Cement: Sand: soil ratio of 1:4:4 and 2.5 cm thickness. The silt trap was 0.5 m deep and 0.4 m wide constructed using cement-sand blocks.

Appendix 4: Catchment area design for T1 and T3

Catchment area design was achieved by considering the Net Irrigation requirement, and was computed using equation 2 and was found to be 125 m^3, after considering the run-off efficiency of 0.4 for uncleared catchment and run-off co-efficient of 0.25 as suggested by Hatibu et al.(1995). The catchment area designed for runoff collection was found to be 2261 m^3 using the same equation. The catchment area to cropped field ratio (CA: CB) was found to be 8:1, while the cropped basin (CB) was set at 280 m^2 subdivided into four small plots each with dimensions of 10 m x 7 m. This ratio is in agreement with values recommended by Pacey and Cullis (1986).

Appendix 5: Penman method for ETo

(a) Basic assumptions

The wind speed of day and night are equal

(i) December

Step 1 Vapour pressure deficit (ea-ed)

For all the cases altitude is 1037 m a.s.l.

Given: Tmax 30.7°C; Tmin 19.4 °C; Rhmax 65 %: Rhmin 41 %

Calculation.

Tmean = 25.1 °C; Rhmean = 53 %; ea (Table 5) = 31.7 mbar;

ed = ea * RHmean/100 = 16.8 mbar; (ea-ed) = 14.9 mbar

Step 2 Wind function f(u)

U (Wind speed at 2 m height) = 155.7 Km/day; f(u) from Table 7 = 0.69

Step 3 Weighting factor (1 - W)

Given; Altitude 1037 m; Tmax 30.7°C; Tmin 19.4°C; Tmean = 25.1°C; (1 - W) From Table 8 = 0.24

Step 4 Weighting factor (W)

Given; Altitude 1037 m; Tmax 30.7°C; Tmin 19.4°C; Tmean = 25.1°C; W From Table 9 = 0.76

Step 5 Net radiation (Rn)

Given; Hombolo; Latitude 5° 45' S; Longitude 35° 57' E;

Tmean = 25.1°C; Rhmean = 53 % Sunshine (n) mean 8.1 hr/day;

Ra From Table 10 =15.6 mm/day; Rs (0.25 + 0.50 n/N);

n = 8.1 hr; N (Table 11) = 12.4 hr; n/N = 0.65; Rs = 8.97 mm/day; Rns =(1-α)Rs From Table 12 = 6.7 mm/day;

Rnl = f(t).f(ed).f(n/N) From Table 13 f(T) = 15.7, From Table 14 f(ed) = 0.12, From Table 15 f(n/N) = 0.69; Rnl = 1.3 mm/day; Rn = Rns - Rnl = 5.4 mm/day

Step 6 Adjustment factor (c)

Given; Hombolo; December; Rs = 9.0 mm/day; Rhmax 65 % Uday/Unight = 1; U = 2 m/s; c From Table 16 = 1.01 (by interpolation)

Step 7 Sample calculation for ETo

ETo = C{W.Rn + (1 - W).f(u).(ea-ed)}

Given; Hombolo; December; W = 0.76; Rn = 5.4 mm/day; (1 - W)= 0.24; f(u) = 0.69; (ea - ed) = 14.9 mbar; c = 1.01

ETo = 1.01(0.76 x 5.4 + 0.24 x 0.69 x 14.9) = 6.6 mm/day

(ii) January

Step 1 Vapour pressure deficit (ea -ed)

Given; Tmax 29.9°C; Tmin 19°C; Rhmax 75 %; Rhmin 54 %;

Tmean = 24.5°C; Rhmean = 64.5 %; ea at 24.5°C = 30.8

mbar; ed = ea x Rhmean/100 = 19.8 mbar; (ea - ed) = 11.0 mbar

Step 2 Wind function f(u)

U (Wind speed at 2 m height) = 119.5 Km/day; f(u) From Table 7 = 0.59

Step 3 Weighting factor (1 - W)

Given; Altitude 1037 m; Tmax 29.9°C; Tmin 19°C; Tmean = 24.5°C; (1-W) From Table 8 = 0.25

Step 4 Weighting factor (W)

Given; Altitude 1037 m; Tmax 29.9°C; Tmin 19°C; Tmean= 24.5°C; W From Table 9 = 0.76

Step 5 Net radiation (Rn)

Hombolo; Latitude 5° 45'S; Altitude 1037 m; Tmean 24.5°C; Rhmean = 65 %; Sunshine (n) mean 7.9 hr/day.

Ra From Table 10 = 15.7 mm/day; Rs = (0.25 + 0.50n/N)*Ra

; n = 7.9 hr; From Table 11 N = 12.3 hr; n/N = 0.64; Rs = 8.9 mm/Day; Rns = (1-α)Rs From Table 12 = 6.6 mm/day;

Rnl = (f(T).f(ed).f(n/N) From Table 13 f(T) = 15.5; From Table 14 f(ed) = 0.12; From Table 15 f(n/N) = 0.67; Rnl = 1.2 mm/day; Rn = Rns - Rnl = 5.3 mm/day

Step 6 Adjustment factor (C)

Given; Hombolo; January; Rs = 8.9 mm/day; Rhmax 75 %, Uday/Unight = 1; Uday = 1.4 m/sec; c From Table 16 =1.03 (by interpolation)

Step 7 Sample calculation for ETo

Given; January; W = 0.76; Rn = 5.3; (1-W) = 0.25; f(u) = 0.59; (ea-ed) = 11.0; c = 1.03

$$ETo = 1.03(0.76 \times 5.3 + 0.25 \times 0.59 \times 11.0) = 5.8 \text{ mm/day}$$

Appendix 6: Tables for Penman Equation

Source: Doorenbos et al., 1984 (All tables)

Table 5 Saturation Vapour Pressure (ea) in mbar as Function of Mean Air Temperature (T) in °C 1/

Temperature °C	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
ea mbar	6.1	6.6	7.1	7.6	8.1	8.7	9.3	10.0	10.7	11.5	12.3	13.1	14.0	15.0	16.1	17.0	18.2	19.4	20.6	22.0

Temperature °C	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
ea mbar	23.4	24.9	26.4	28.1	29.8	31.7	33.6	35.7	37.8	40.1	42.4	44.9	47.6	50.1	53.2	56.2	59.4	62.8	66.3	69.9

1/ Also actual vapour pressure (ed) can be obtained from this table using available Tdewpoint data. (Example: Tdewpoint is 18°C; ed is 20.6 mbar)

Table 6a Vapour Pressure (ed) in mbar from Dry and Wet Bulb Temperature Data in °C (Aspirated Psychrometer)

Depression wet bulb T°C altitude 0-1 000 m

drybulb T°C	0	2	4	6	8	10	12	14	16	18	20	22
40	73.8	64.9	56.8	49.2	42.2	35.8	29.8	24.3	19.2	14.4	10.1	6.0
38	66.3	58.1	50.5	43.6	37.1	31.1	25.6	20.5	15.8	11.4	7.3	
36	59.4	51.9	44.9	38.4	32.5	26.9	21.8	17.1	12.7	8.6	4.9	
34	53.2	46.2	39.8	33.8	28.3	23.2	18.4	14.0	10.0	6.2		
32	47.5	41.1	35.1	29.6	24.5	19.8	15.4	11.3	7.5	4.0		
30	42.4	36.5	30.9	25.8	21.1	16.7	12.6	8.8	5.3			
28	37.8	32.3	27.2	22.4	18.0	14.0	10.2	6.7	3.4			
26	33.6	28.5	23.8	19.4	15.3	11.5	8.0	4.7	1.6			
24	29.8	25.1	20.7	16.6	12.8	9.3	6.0	2.9				
22	26.4	22.0	18.0	14.2	10.6	7.4	4.3	1.4				
20	23.4	19.3	15.5	12.0	8.7	5.6	2.7					
18	20.6	16.8	13.3	10.0	6.9	4.1	1.4					
16	18.2	14.6	11.4	8.3	5.4	2.7						
14	16.0	12.7	9.6	6.7	4.0	1.5						
12	14.0	10.9	8.1	5.3	2.8							
10	12.3	9.4	6.7	4.1	1.7							
8	10.7	8.0	5.5	3.1	0.8							
6	9.3	6.8	4.4	2.1								
4	8.1	5.7	3.4	1.6								
2	7.1	4.8	2.8	0.8								
0	6.1	4.0	2.0									

Depression wet bulb T°C altitude 1 000-2 000 m

drybulb T°C	0	2	4	6	8	10	12	14	16	18	20	22
40	73.8	65.2	57.1	49.8	43.0	41.8	31.0	25.6	20.7	16.2	12.0	8.1
38	66.3	58.2	50.9	44.1	37.9	36.7	26.8	21.8	17.3	13.2	9.2	5.7
36	59.4	52.1	45.2	39.0	33.3	32.1	23.0	18.4	14.3	10.4	6.8	3.5
34	53.2	46.4	40.1	34.4	29.1	24.1	19.6	15.4	11.5	8.0	4.6	1.5
32	47.5	41.3	35.5	30.2	25.3	20.7	16.6	12.6	9.1	5.8	2.6	
30	42.4	36.7	31.3	26.4	21.9	17.7	13.8	10.2	6.9	3.8	0.9	
28	37.8	32.5	27.5	23.0	18.9	14.9	11.4	8.0	4.9	2.1		
26	33.6	28.7	24.1	20.0	16.1	12.5	9.2	6.0	3.2	0.5		
24	29.8	25.3	21.1	17.2	13.9	10.3	7.2	4.3	1.6			
22	26.4	22.3	18.3	14.3	11.5	8.3	5.5	2.7	0.2			
20	23.4	19.5	15.9	12.6	9.5	6.6	3.9	1.3				
18	20.6	17.1	13.7	10.6	7.8	5.0	2.5	0.1				
16	18.2	14.9	11.7	8.9	6.2	3.6	1.3					
14	16.0	12.9	10.0	7.3	4.8	2.4	0.3					
12	14.0	11.2	8.4	5.9	3.6	1.4						
10	12.3	9.6	7.0	4.7	2.6	0.4						
8	10.7	8.2	5.8	3.7	1.6							
6	9.3	7.0	4.8	2.7	0.7							
4	8.1	6.0	3.8	1.8								
2	7.1	5.0	2.9	1.0								
0	6.1	4.1	2.1									

Table 7 Values of Wind Function $f(u) = 0.27\,(1 + \frac{U_2}{100})$ for Wind Run at 2 m height in km/day

Wind km/day	0	10	20	30	40	50	60	70	80	90
	-	.30	.32	.35	.38	.41	.43	.46	.49	.51
100	.54	.57	.59	.62	.65	.67	.70	.73	.76	.78
200	.81	.84	.86	.89*	.92	.94	.97	1.00	1.03	1.05
300	1.08	1.11	1.13	1.16	1.19	1.21	1.24	1.27	1.30	1.32
400	1.35	1.38	1.40	1.43	1.46	1.49	1.51	1.54	1.57	1.59
500	1.62	1.65	1.67	1.70	1.73	1.76	1.78	1.81	1.84	1.90
600	1.89	1.92	1.94	1.97	2.00	2.02	2.05	2.08	2.11	2.15
700	2.16	2.19	2.21	2.24	2.27	2.29	2.32	2.35	2.38	2.40
800	2.43	2.46	2.48	2.51	2.54	2.56	2.59	2.62	2.64	2.65
900	2.70									

Table 8 Values of Weighting Factor (1-W) for the Effect of Wind and Humidity on ETo at Different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
(1-W) at altitude m																				
0	0.57	.54	.51	.48	.45	.42	.39	.36	.34	.32	.29	.27	.25	.23*	.22	.20	.19	.17	.16	.15
500	.56	.52	.49	.46	.43	.40	.38	.35	.33	.30	.28	.26	.24	.22	.21	.19	.18	.16	.15	.14
1 000	.54	.51	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.20	.18	.17	.15	.14	.13
2 000	.51	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12
3 000	.48	.45	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12	.11
4 000	.46	.42	.39	.36	.34	.31	.29	.27	.25	.23	.21	.19	.18	.16	.15	.14	.13	.12	.11	.10

Table 9 Values of Weighting Factor (W) for the Effect of Radiation on ETo at Different Temperatures and Altitudes

Temperature °C	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
W at altitude m																				
0	0.43	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77*	.78	.80	.82	.83	.84	.85
500	.44	.48	.51	.54	.57	.60	.62	.65	.67	.70	.72	.74	.76	.78	.79	.81	.82	.84	.85	.86
1 000	.46	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.80	.82	.83	.85	.86	.87
2 000	.49	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88
3 000	.52	.55	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.88	.89
4 000	.54	.58	.61	.64	.66	.69	.71	.73	.75	.77	.79	.81	.82	.84	.85	.86	.87	.89	.90	.90

Table 10 Extra Terrestrial Radiation (Ra) expressed in equivalent evaporation in mm/day

Northern Hemisphere													Southern Hemisphere											
Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Lat	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
3.8	6.1	9.4	12.7	15.8	17.1	16.4	14.1	10.9	7.4	4.5	3.2	50°	17.5	14.7	10.9	7.0	4.2	3.1	3.5	5.5	8.9	12.9	16.5	18.2
4.3	6.6	9.8	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7	48	17.6	14.9	11.2	7.5	4.7	3.5	4.0	6.0	9.3	13.2	16.6	18.2
4.9	7.1	10.2	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3	46	17.7	15.1	11.5	7.9	5.2	4.0	4.4	6.5	9.7	13.4	16.7	18.3
5.3	7.6	10.6	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7	44	17.8	15.3	11.9	8.4	5.7	4.4	4.9	6.9	10.2	13.7	16.7	18.3
5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2	42	17.8	15.5	12.2	8.8	6.1	4.9	5.4	7.4	10.6	14.0	16.8	18.3
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	18.3
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	18.2
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8	7.2	9.2	12.0	14.9	17.1	18.2
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
8.8	10.7	13.1	15.2	16.5	17.0	16.8	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.6	15.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.4	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

Table 11 Mean Daily Duration of Maximum Possible Sunshine Hours (N) for Different Months and Latitudes

Northern Lats	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Southern Lats	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
50°	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.1
48	8.8	10.2	11.8	13.6	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.3
46	9.1	10.4	11.9	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.7
44	9.3	10.5	11.9	13.4	14.7	15.4	15.2	14.0	12.6	11.0	9.7	8.9
42	9.4	10.6	11.9	13.4	14.6	15.2	14.9	13.9	12.6	11.1	9.8	9.1
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.3
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.8
30	10.4	11.1	12.0	12.9	13.6	14.0	13.9*	13.2	12.4	11.5	10.6	10.2
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.6
20	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.9
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.2
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.5
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.8
0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

Table 12 Conversion Factor for Extra-Terrestrial Radiation (Ra) to Net Solar Radiation (Rns) for a Given Reflection α of 0.25 and Different Ratios of Actual to Maximum Sunshine Hours $(1-\alpha)(0.25 + 0.50\ n/N)$

n/N	0.0	.05	.10	.15	.20	.25	.30	.35	.40	.45	.50	.55	.60	.65	.70	.75	.80	.85	.90	.95	1.0
$(1-\alpha)(0.25 + 0.50\ n/N)$	0.19	.21	.22	.24	.26	.28	.30	.32	.34	.36	.37	.39	.41	.43	.45	.47	.49*	.51	.52	.54	.56

Table 13 Effect of Temperature f(T) on Longwave Radiation (Rnl)

$T^{o}C$	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36
$f(T) = \sigma \cdot Tk^{4}$	11.0	11.4	11.7	12.0	12.4	12.7	13.1	13.5	13.8	14.2	14.6	15.0	15.4	15.9	16.3*	16.7	17.2	17.7	18.1

Table 14 Effect of Vapour Pressure f(ed) on Longwave Radiation (Rnl)

ed mbar	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40
$f(ed) = 0.34 - 0.044\sqrt{ed}$	0.23	.22	.20	.19	.18	.16	.15	.14	.13*	.12	.12	.11	.10	.09	.08	.08	.07	.06

Table 15 Effect of the Ratio Actual and Maximum Bright Sunshine Hours f(n/N) on Longwave Radiation (Rnl)

n/N	0	.05	.1	.15	.2	.25	.3	.35	.4	.45	.5	.55	.6	.65	.7	.75	.8	.85	.9	.95	1.0
$f(n/N) = 0.1 + 0.9\ n/N$	0.10	.15	.19	.24	.28	.33	.37	.42	.46	.51	.55	.60	.64	.69	.73	.78	.82*	.87	.91	.96	1.0

Table 16 Adjustment Factor (c) in Presented Penman Equation

	RHmax = 30%				RHmax = 60%				RHmax = 90%			
Rs mm/day	3	6	9	12	3	6	9	12	3	6	9	12
Uday m/sec	Uday/Unight = 4.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.79	.84	.92	.97	.92	1.00	1.11	1.19	.99	1.10	1.27	1.32
6	.68	.77	.87	.93	.85	.96	1.11	1.19	.94	1.10	1.26	1.33
9	.55	.65	.78	.90	.76	.88	1.02	1.14	.88	1.01	1.16	1.27
	Uday/Unight = 3.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.76	.81	.88	.94	.87	.96	1.06	1.12	.94	1.04	1.18	1.28
6	.61	.68	.81	.88	.77	.88	1.02	1.10	.86	1.01	1.15	1.22
9	.46	.56	.72	.82	.67	.79	.88	1.05	.78	.92	1.06	1.18
	Uday/Unight = 2.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.69	.76	.85	.92	.83	.91	.99*	1.05*	.89	.98	1.10*	1.14*
6	.53	.61	.74	.84	.70	.80	.94	1.02	.79	.92	1.05	1.12
9	.37	.48	.65	.76	.59	.70	.84	.95	.71	.81	.96	1.06
	Uday/Unight = 1.0											
0	.86	.90	1.00	1.00	.96	.98	1.05	1.05	1.02	1.06	1.10	1.10
3	.64	.71	.82	.89	.78	.86	.94*	.99*	.85	.92	1.01*	1.05*
6	.43	.53	.68	.79	.62	.70	.84	.93	.72	.82	.95	1.00
9	.27	.41	.59	.70	.50	.60	.75	.87	.62	.72	.87	.96

Appendix 7: Variation of Soil Profile Moisture (v/v) with depth in paddy fields (Hombolo)-1994/95

DATE	Depth(cm)	T1	T2	T3
3.2.95	10	0.22	0.22	0.19
	30	0.31	0.28	0.29
	50	0.29	0.29	0.31
	80	0.26	0.24	0.29
	150	0.21	0.20	0.18
8.2.95	10	0.30	0.29	0.30
	30	0.35	0.32	0.31
	50	0.32	0.32	0.31
	80	0.28	0.27	0.30
	150	0.21	0.23	0.19
11.2.95	10	0.29	0.27	0.25
	30	0.32	0.32	0.31
	50	0.29	0.31	0.31
	80	0.28	0.28	0.29
	150	0.22	0.24	0.20
18.2.95	10	0.27	0.25	0.22
	30	0.33	0.31	0.31
	50	0.30	0.31	0.31
	80	0.28	0.28	0.28
	150	0.22	0.24	0.20
22.2.95	10	0.26	0.25	0.21
	30	0.33	0.31	0.30
	50	0.30	0.30	0.31
	80	0.27	0.28	0.31
	150	0.21	0.25	0.20

25.2.95	10	0.33	0.29	0.27
	30	0.36	0.33	0.32
	50	0.31	0.32	0.32
	80	0.29	0.28	0.31
	150	0.25	0.25	0.21
27.2.95	10	0.33	0.29	0.27
	30	0.36	0.32	0.32
	50	0.33	0.32	0.32
	80	0.30	0.29	0.31
	150	0.27	0.25	0.21
28.2.95	10	0.34	0.29	0.28
	30	0.35	0.32	0.32
	50	0.32	0.31	0.31
	80	0.30	0.30	0.31
	150	0.36	0.25	0.21
4.3.95	10	0.34	0.31	0.30
	30	0.34	0.33	0.34
	50	0.32	0.32	0.33
	80	0.31	0.30	0.32
	150	0.29	0.30	0.24
8.3.95	10	0.35	0.31	0.28
	30	0.35	0.32	0.32
	50	0.33	0.31	0.32
	80	0.29	0.29	0.31
	150	0.28	0.27	0.29
11.3.95	10	0.34	0.30	0.29
	30	0.35	0.32	0.32
	50	0.33	0.31	0.31

	80	0.29	0.29	0.26
	150	0.28	0.27	0.17
13.3.95	10	0.35	0.30	0.28
	30	0.38	0.31	0.32
	50	0.33	0.32	0.31
	80	0.30	0.29	0.30
	150	0.28	0.27	0.23
22.3.95	10	0.33	0.25	0.23
	30	0.33	0.31	0.31
	50	0.30	0.31	0.31
	80	0.28	0.28	0.28
	150	0.27	0.28	0.23
29.3.95	10	0.26	0.23	0.18
	30	0.31	0.29	0.29
	50	0.31	0.30	0.31
	80	0.27	0.27	0.29
	150	0.27	0.27	0.23
6.4.95	10	0.23	0.18	0.15
	30	0.29	0.24	0.24
	50	0.30	0.28	0.29
	80	0.27	0.27	0.28
	150	0.27	0.28	0.23
7.4.95	10	0.32	+	+
	30	0.34	+	+
	50	0.32	+	+
	80	0.27	+	+
	150	0.27	+	+
14.4.95	10	0.32	0.17	0.18

Appendix 8: Average Monthly Effective Rainfall as Related to Average Monthly ETcrop and Mean Monthly Rainfall

(USDA (SCS), 1969)

Monthly mean rainfall	mm	12.5	25	37.5	50	62.5	75	87.5	100	112.5	125	137.5	150	162.5	175	187.5	200
		Average monthly effective rainfall in mm															
Average monthly ETcrop mm	25	8	16	24													
	50	8	17	25	32	39	46										
	75	9	18	27	34	41	48	56	62	69							
	100	9	19	28	35	43	52	59	66	73	80	87	94	100			
	125	10	20	30	37	46	54	62	70	76	85	92	98	107	116	120	
	150	10	21	31	39	49	57	66	74*	81	89	97	104	112	119	127	133
	175	11	23	32	42	52	61	69	78	86	95	103	111	118	126	134	141
	200	11	24	33	44	54	64	73	82	91	100	109	117	125	134	142	150
	225	12	25	35	47	57	68	78	87	96	106	115	124	132	141	150	159
	250	13	25	38	50	61	72	84	92	102	112	121	132	140	150	158	167