CERTIFICATION

This is to certify that this work was carried out by Mr. **OGUNDOKUN, Moses Olugbenga** in partial fulfillment for the requirements for the award of Master of Engineering in Soil and Water Engineering at the Department of Agricultural Engineering, Federal University of Technology, Akure.

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17/8/20

Date

EXPERIMENTAL AND EMPIRICAL ESTIMATION OF REFERENCE CROP EVAPOTRANSPIRATION

BY

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DEDICATION

This thesis is dedicated to my mother Mrs. Alice Omolewu Ogundokun.

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NOMENCLATURE

SYMBOL	UNIT	
ET	mm of water	Evapotranspiration
RET	mm of water	Reference Evapotranspiration
AET	mm of water	Actual Evapotranspiration
PET	mm of water	Potential Evapotranspiration
MET	mm of water	Maximum Evapotranspiration
T	°C	Air temperature
γ	mm Hg °C^{-1}	Psychometric Constant
Δ	mm Hg °C^{-1}	Slope of saturation Vapour Pressure curve
Rn	MJ/m^2/day	Net radiation
Ra	MJ/m^2/day	Short-wave radiation
n		Actual hour of bright sunshine
N		Possible hour of bright sunshine
P	m	Elevation above sea level
RH	%	Relative humidity
L	J/g	Latent heat of vapourization
R		Coefficient of correlation
RMSE	mm	Root-mean-square-error
AAD	mm	Absolute average deviation
Y	mm/day	Predicted reference ET

SYMBOL	UNIT	
X	mm/day	Observed reference ET
B-C	mm/day	Blaney-Criddle method
PEN	mm/day	Penman formula
J-H	mm/day	Jensen-Haise method
PM	mm/day	Penman-Monteith method
HG	mm/day	Hargreaves method
e_a	mm Hg	Saturation Vapour pressure of water at air temperature
e_d	mm Hg	Saturation Vapour pressure at dew point.
U	mm/day	Wind Speed
DAP	day	Days after planting
TT	°C/day	Thermal Time
Kc		Crop Coefficient
WAP	week	Weeks After planting
Kp		Pan coefficient
Ep	mm/day	Pan evaporation

ABSTRACT

Efficient and good water management strategy requires knowledge of crop water use of which reference evapotranspiration (RET) and crop curves are important inputs. Field experiments on bahama grass (*cynodon dactylon*) were conducted to estimate consumptive use using one weighing and four drainage microlysimeters. The grass was planted on 12m by 16m plot in which the microlysimeters were installed. The weighing microlysimeter was construction based on hydraulic principles using mercury-in-glass manometer. Its calibration was carried out using a static load process.

Ten years of climatic data were used to estimate reference evapotranspiration using the following empirical methods; Penman (PEN), Jensen-Haise (J-H), Blaney-Criddle(B-C) and Hargreaves (HG) models. The values obtained were compared to experimental values and were also subjected to standard statistical analysis.

Crop curves were obtained from the ratio of lysimeter to reference evapotranspiration values (using empirical formulae). The crop curves were presented as a function of independent variables which were Days After Planting (DAP) and Thermal Time (TT) . For the crop curves based on DAP, the coefficient of determination(R^2) and standard errors (SE) in the crop coefficients (K_c) estimates were 0.90 and 0.17 respectively for the J-H ; 0.90 and 0.09 for PEN; 0.89 and 0.07 for B-C; 0.81 and 0.18 for HG. Based on TT method, R^2 and SE for J-H were 0.90 and 0.18 respectively. 0.90 and 0.09 for PEN; 0.89 and 0.07 for B-C; and 0.81 and 0.18 for HG.

CHAPTER ONE

INTRODUCTION

Evapotranspiration (ET) is one of the major terms of soil water balance (Itier, 1994). It is an essential part of the hydrologic cycle and it provides a major mechanism for the redistribution of energy within an ecosystem and throughout the atmosphere (Blad, 1987) ET represents water loss, water unavailable for exploitation by man and hence it plays and important role in water resources management (Ayoade, 1988).

The study of ET is particularly important in West Africa since a large proportion of the area is vegetated (Ojo, 1977). According to Ahmed and Ahmed (1989), the accurate estimation of crop ET is prerequisite to effective water management, hydrological studies and irrigation scheduling and design. A review of literature has clearly indicates a large number of methods for estimation of ET. These methods vary from simple empirical relationships to the complex methods based on physical processes such as the Penman (1948) combination method. When the required data are available and reliable, the Penman method is superior to all other methods (Amatya et al, 1995).

Monteith (1965) further modified the Penman method by incorporating a stomatal resistance (r_s) term specific to the type of crop in addition to the existing aerodynamic resistance term. This formulation is the Penman - Monteith (PM) reference evapotranspiration model. The reliability of the PM method for estimating reference ET (RET) has been extensively studied (Jensen et al 1990; FAO, 1990; McNaughton and Jarvin, 1984). Jensen et al (1990) reviewed methods for computing ET and recommended the PM equation as presented by Allen et al (1989) as the preferred method for daily reference ET.

Various methods of measuring ET are described by Hatfield (1988). Weighing lysimeter is described as one of the most accurate methods of determining ET. Abtew and Hardee (1993) designed a lysimeter which consisted of a circular polyethylene tank of 3.5m diameter and 90 cm depth with 4.8mm thickness. Ekern (1958) was known for constructing the first workable hydraulic load cell lysimeter. Van Bavel (1966) used mini- or micro-lysimeters located between crop rows to measure evaporation. Tanner (1967) described both weighing and non-weighing lysimeters and their uses. He further stated their accuracy or sensitivity in fractions of a millimeter of ET.

The main purpose of this research work is to determine experimentally the reference evapotranspiration using micro lysimeters and comparing the results with four (4) different methods of estimating reference ET as recommended by FAO.

1.1 Objectives

The specific objectives of this study are:

(i) To determine the reference crop evapotranspiration for bahama grass (cynodon dactylon) using the drainage and weighing lysimeters.

(ii) To estimate the reference evapotranspiration using different empirical formulae.

(iii) To compare the reference crop evapotranspiration estimated using different formulae with those obtained by lysimetric measurements.

(iv) To develop crop curves with different empirical formulae.

1.2 Justification of the Study

Knowing the amount of water directly evaporated from the soil or through transpiration from plant's leaf is a point of interest not only for agronomists but also for meteorologists, hydrologists and irrigation project managers (Itier, 1994). Although numerous studies have been carried out on ET in the developed countries, few of these studies came from developing nations such as Nigeria. A larger number of those few studies are concentrated on the evaluation of potential ET (PET) in determination of consumptive use of swamp rice (Udeh, 1979); Cowpea (Lawson, 1979); Cotton, Maize, groundnut and millet (Duru, 1979).

However, little attempt has been made to work on the evaluation of reference ET in developing countries especially Nigeria. In the light of this, there is need for an accurate estimation of reference ET under the Nigeria climatic conditions which can be subsequently used in the evaluation of agricultural calendar as well as in the activities of water resources management. This studies on reference ET using an hydraulic micro-lysimeter is the first of its kind in the study area and it will then serve as a new research tool upon which the interpretation of other ET experiments can be assessed for a better reliability.

1.3 Important Definitions of Evapotranspiration

Definitions according to Burman et al (1983) are extremely important in estimating ET because consistency with respect to different reference crops is essential. ET is a compound term describing the physical process of water transfer into the atmosphere by evaporation from soil and transpiration through vegetation. It constitutes an important component of the hydrologic balance (McKenney and Rosenberg, 1993). ET according to Jensen (1974) is the process by which water is transferred from the earth's surface to the atmosphere. It includes evaporation of liquid or solid water from soil and plant surface plus transpiration of liquid water through plant tissues expressed as the latent heat transfer per unit area or its equivalent depth of water per unit area.

Some hydrological interpretation of ET is given as the Actual ET, Potential ET, Maximum ET and Reference ET. The actual ET is defined as the amount of evaporation and transpiration that occurs over a vegetated area under the prevailing climatic conditions. Its values are controlled not only by the prevailing climatic conditions but also by non-climatic factors like soil and plant characteristics (Ayoade, 1988). Thornthwaite (1948) defined Potential ET as the loss of the maximum amount of water to the atmosphere from a fully moist and vegetated surface by the process of evaporation and transpiration. Penman (1956), using the term "Potential transpiration" regards PET as "the amount of water transpired in unit time by a short green crop completely shading the ground, of uniform height and never short of water.

Maximum ET (MET) according to Doorenbos et al (1980) refers to conditions when water is adequate for unrestricted growth and development and it represents the rate of maximum ET of a healthy crop, grown in large fields under optimum agronomic and irrigation management. Two definitions of reference ET are commonly used. Doorenbos and Pruitt (1977) defined reference ET as "the rate of ET from an extensive surface of 8 to 15cm, green grass cover of uniform height, actively growing, completely shading the ground and not short of water". The second definition of reference ET is based upon alfalfa (Medicago Sativa L.) and was first proposed by Jensen et al (1971). In their definition, RET represents "the upper limit or maximum ET that occurs under given climatic conditions with a field having a well watered agricultural crop with an aerodynamically rough surface, such as alfalfa, with 30 to 50 cm of top growth". Various forms of ET are illustrated as shown in Fig.1.

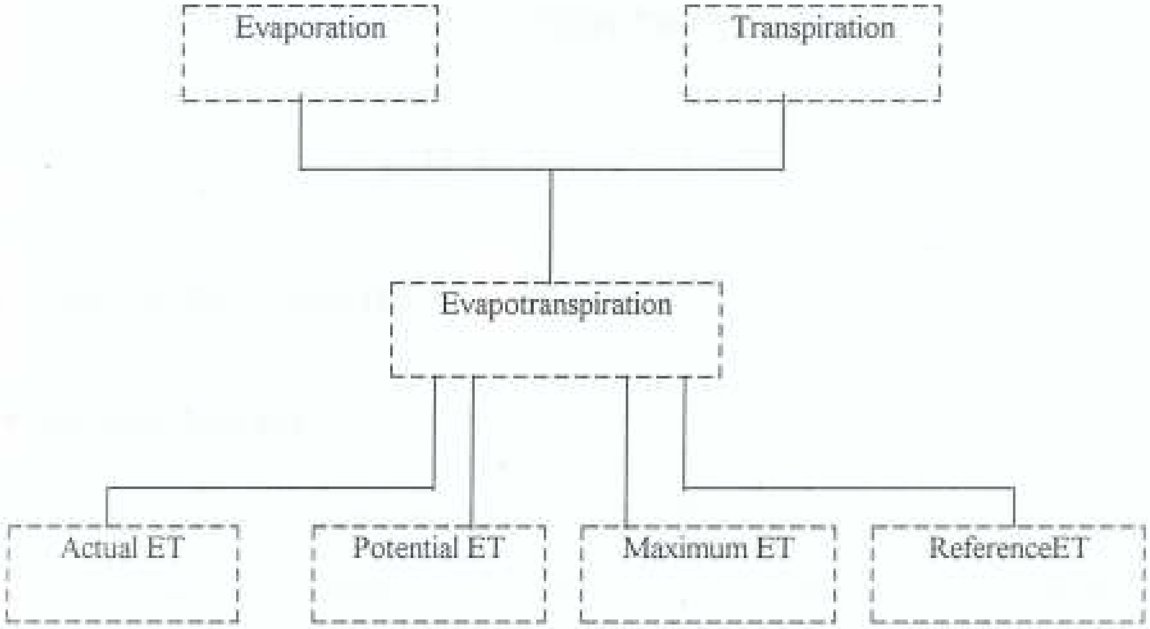

Fig. 1: Various forms of Evapotranspiration.

CHAPTER TWO

LITERATURE REVIEW

2.1 REVIEW ON LYSIMETRY

2.1.1 General Concept

Many observations of evapotranspiration are made in soil containers variously known as tanks, evaporimeters, and lysimeters. The first two terms customarily refer to containers with sealed bottoms, while there has been an attempt to restrict the word lysimeter to the containers with pervious bottoms or with a mechanism for maintaining negative pressure at the bottom (Linsley et al, 1988).

Lysimeters are used to measure rates of evapotranspiration (Ayoade, 1988). They are tanks buried in the ground to measure the percolation of water through the soils and they provide the most reliable and accurate method for the direct measurement of ET provided the necessary precautions in its design operation and siting are taken (Ojo, 1977). A simple evapotransporimeter was designed by Thornthwaite (1955) at the laboratory of climatology, Seabrook, New Jersey (USA). The aim was to make an inexpensive instrument for measuring potential ET. It is being used in West Africa, sometimes in a modified form (Ojo, 1977).

Microlysimeters of various sizes have been put to use in various places. According to Oad et al, (1997), in 1869 in Austria, small lysimeters (18.5cm diameter and of various depths) were constructed and used; small floating hydraulic lysimeters (0.2 m^2 surface area and 1.5m deep) were used in the former USSR in 1950s; and small weighing-type lysimeters (0.11m^2 surface area and depths of 0.6-1.2m) were used in England to estimate potential ET for grass and vegetable crops.

2.1.2 Various Forms of Lysimeter

There are two basic types of lysimeters (Ayoade, 1988). These are the weighing lysimeter and the drainage lysimeter.

2.1.2.1 Weighing Lysimeter

The weighing lysimeter is a rather sophisticated piece of equipment consisting of a tank filled with soil and vegetation similar to that in the surroundings and supported by a weighing mechanism. This involves various weighing principles and devices that are based on mechanical weighing with varieties of scales and balances or electronic weighing with strain gauge load cells or a combination of both, or finally on hydraulic weighing systems (James, 1988).

The weighing lysimeters are used for measuring the actual ET as well as the potential ET. They can be used for periods of measurements as short as ten minutes (Ojo, 1977). ET values are obtained by calculating changes in the weight of the soil and vegetation system within the tank (Ayoade, 1988). Kowal et al (1974, 1975, 1976) used a weighing lysimeter to measure actual ET for cotton, maize, groundnut and millet in Samaru, Zaria.

Hydraulic Weighing Lysimeter

Hydraulic weighing lysimeter are popular tools for evapotranspiration research during the past several years. They are widely used for determining the rates of ET of many agricultural crops. They are inexpensive and easier to construct than lysimeters with sophisticated electronic weighing system (Kruse and Neale, 1989).

Ekern (1958) constructed the first hydraulic load cell lysimeter. The large area of tank per unit of contact area with the hydraulic load cells gave it a sensitivity of 0.025 mm. Hanks and Shawcroft (1965) described a lysimeter using a hydraulic weighing mechanism. They used a "dummy" standpipe of the same height as the standpipe used to measure pressure on the lysimeter pillows in order to correct the temperature drift errors. They suggested the use of a dummy pillow located under the lysimeter for improved temperature correction.

Hydraulic weighing lysimeter works on the principle that increase in lysimeter load by either irrigation or precipitation results in an increase in lysimeter weight which subsequently depressed the tyre-tube and cause movement of water from tyre tube into mercury pot and finally into manometer tube. The fluctuation of water level in the manometer tube is a result of gains and losses of water by weighing lysimeter (Kruse and Neale, 1989).

Sources of Errors in Hydraulic Weighing Lysimeter

Kruse and Neale (1989) listed the following sources of errors in the hydraulic system of weighing lysimeters:

(I) Effect of temperature changes on mercury pot, manometer tube, and hydraulic pillows or hydraulic elastic tube.

(ii) Wrong period of manometer readings

(iii) Wrong calibration method

(iv) Variation is size of manometer tube.

Error Prevention in Hydraulic Weighing Lysimeter

I) Locate the manometer system below the ground or in manholes with insulated covers that are removed only when the manometers are to be read or adjusted (Kruse and Neale, 1989).

(ii) Daily manometer readings should be taken at a fixed period of time. (Kowal and Stockinger, 1973).

Watering of the lysimeters must be done at a fixed time each day either early in the morning or late in the afternoon (Ojo, 1977).

2.1.2.2 Drainage Lysimeter

The drainage lysimeter is more widely used and is otherwise known as evapotransporimeter or the percolation gauge (Ayoade, 1988). It operates on a simple water balance method and is normally used to measure the rates of potential ET (Chang, 1964).

Drainage water is measured on daily basis after addition of water, which therefore provides a non-limiting condition for potential evaporation. The measured evapotranspiration from drainage lysimeter is computed using the following simple water balance equation that is expressed as follows:

$$ET = R + I - D_D \pm \Delta S \qquad (1)$$

Where,

ET is the measured evapotranspiration in mm; I is the quantity of water applied (irrigation) in mm, D_D is the quantity of water drained in mm, R is the rainfall amount in mm; and ΔS is the change in water storage. By taking measurements only at the end of each drainage period following addition of water, storage remains essentially constant and the change in storage is therefore, zero (Eldin et al., 1969, Tanner, 1967).

2.1.3 General Limitations of Lysimeters

There are many problems with lysimeter measurements (Ayoade, 1988; Ojo, 1977). These include:

In Nigeria, according to Adeogun et al (1998), lysimeter works appear to have stopped completely. The lysimeter that existed at Samaru, Zaria and at Kadawa, Kano ceased to function 15-25 years ago. Probably, the drainage lysimeter at IITA, Ibadan may be the only existing lysimeter today.

A lot of research work are being carried out by individual research institutes and universities and there is hope that the technological advancement will soon put the history of lysimetry in Nigeria on the right path.

2.2 EVAPOTRANSPIRATION

2.2.1 Calculating Evapotranspiration

To compute crop ET we use the following equation

$$ET = KcETo \qquad (2)$$

where:

ET = Evapotranspiration for a specific crop

ETo = Potential ET or reference Crop ET

Kc = Crop coefficient

ETo may be either potential ET or reference crop ET. Potential ET is the maximum rate at which water, if available, can be removed from soil and plant surfaces. Potential ET depends on the amount of energy available for evaporation and varies from day to day. Reference crop ET is the potential ET for a specific crop (usually either grass or alfalfa) and a set of surrounding (advective) conditions. Reference crop ET is preferred over potential ET, since potential ET can vary from crop to crop due to differences in aerodynamic roughness and surface reflectance (albedo), and from location to location because of differences in the amount of sensible and latent heat transferred into the area (James, 1988).

The concept of reference crop ET is now widely accepted by both engineers and agronomists (Doorenbos and Pruitt, 1977). The aim is to determine the water consumption of a reference crop making things comparable worldwide. This implies avoiding both aerodynamic differences and biological regulations (Itier, 1994).

2.2.2 *Estimation of Reference Crop Evapotranspiration*

Reference crop ET is largely determined by the characteristics of the reference crop, solar radiation, air temperature; and advective energy (Hargreaves, 1989). Three ways are currently being used to obtain reference crop ET values. They include, measurements with lysimeters, estimation with pan evaporimeters and calculation through formulae using climatic factors (Itier, 1994).

2.2.2.1 Measurements with Lysimeters

Drainage lysimeters according to Gilbert and Van Bavel (1954) give weekly estimate of reference ET while weighing lysimeters enable daily estimates possible with an accuracy of more than 10% (Perrier et al, 1974). Failures in representation of surroundings can lead to over 30% in error on ET (Allen et al, 1994). Lysimeters have been and are still largely used to calibrate both evaporimeters and formulae (Itier, 1994). Full discussions on lysimeters are given in previous chapter of this work.

2.2.2.2 Pan Evaporation Method

Reference Crop ET (RET) is related to pan evaporation, Ep by the following equation

$$RET = K_pE_p \qquad (3)$$

where, Kp is a pan coefficient that accounts for differences in pan type and conditions upwind of the pan, and for dissimilarities between plants and evaporation pans (James, 1988).

The shape and colour of evaporation pans significantly influences Kp. Colour differences between pans affect the reflection of radiation and hence evaporation. Screens mounted above pans to prevent birds and animals from drinking from evaporation pans reduce pan evaporation by as much as 10 percent (Doorenbos and Pruitt, 1977).

2.2.2.3 Calculation from Meteorological Data

There are various different empirical methods that had been tested and applied for estimation of reference ET in various location especially in the humid region They include Turk, Hargreaves, Makkink, Penman-Monteith, Priestley-Taylor, Hargreaves-Samani, Thomthwaite, Penman, Blaney-Criddle, Jensen-Haise etc. (Mohammed, 1978; Jensen et al, 1990).

2.3 Significance of Water to Plants

Almost every process occurring in plants is affected by water availability but the links are complex. The relationship varies with plant characteristics, stage of development, soil and climatic conditions (Chang, 1968). In simple terms, water is absorbed by the plants roots and lost by the evaporative process termed transpiration (Jackson, 1977). The major ways by which water is important to plants are listed as follows:

(i.) Water is a major constituent of plant protoplasm

(ii) Water takes part in a number of chemical reactions like photosynthesis.

(iii) Water acts as a solvent for dissolution of other substances during chemical reactions in the plants.

(iv) Water serves as a medium of movement for dissolved substances as they move from cells to cells and from organs to organs.

2.4 *Factors Affecting the Rate of Evapotranspiration*

Several factors influencing the rate of ET can be categorized into climatological factors and non-climatological factors (Ayoade, 1988). Four climatological factors as listed by Handerson-Sellers and Robinson (1986) are:-

(i) Energy availability

(ii) The humidity gradient away from the surface

(iii) The wind speed immediately above the surface

(iv) Water availability

Other climatic factors are mere derivatives of the above factors (Ayoade, 1988).

The non-climatological factors include:

(i) Method of irrigation

(ii) Cultural practices

(iii) Soil factors.

2.5 *Grass-Based Evapotranspiration*

Burman et al (1983) described the major advantage of using either grass or alfalfa as a standard. They listed the pros and cons of grass and alfalfa as follows:

(a) Grass grows over a wider range of climatic conditions throughout the world than does alfalfa. Evapotranspiration from grass vary considerably (Borrelli and Burman, 1982). Reference ET may be assumed to be based upon a local cultivar of grass adaptable to the location in question by calibration with independent methods such as lysimeters or eddy correlation methods.

(b) The use of alfalfa as a reference crop is desirable because alfalfa is aerodynamically rough like many field crops and therefore its ET reaches about the maximum possible for a crop in any particular location (Jensen et al, 1971).

The use of grass tends to spread worldwide while alfalfa is being restricted to Western U.S.A (Itier, 1994).

CHAPTER THREE

MATERIALS AND METHODS

3.1 *The Study Area*

The study area for this research is Akure which is located within the humid region of Nigeria, at latitude 7° 14' N and longitude 5° 08' E. It lies in the rain forest zone with a mean annual rainfall of between 1300 mm-1600 mm and with the average temperature of 27.5°C. The relative humidity ranges between 85% and 100% during the rainy season and less than 60% during the harmattan period. The elevation of Akure is about 351 m above the mean sea level.

The site for field experiment in this study is located at Agricultural Engineering Farmland of the Department of Agricultural Engineering, Federal University of Technology, Akure. The site is located at Obanla part of the University Campus, and it is with dimension 12 m by 16 m. Fig. 2 shows the field plan for the arrangement of apparatus.

3.2 *Micro Lysimeter Tank*

The total number of five micro-lysimeters (one weighing lysimeter and four drainage lysimeters) were used in this study. Each was constructed of a cylindrical shaped container of about 58-cm diameter and 45 cm deep. Each is opened at top, sealed at bottom and welded with perforated drain pipe at the lowest point of its side with surface slope of 10% to create a potential difference at bottom of lysimeter. The perforated drain pipe is 15cm long with 10mm internal and 14mm external diameters. The perforated drain pipe serves as a passage for drained water to the receptacles.

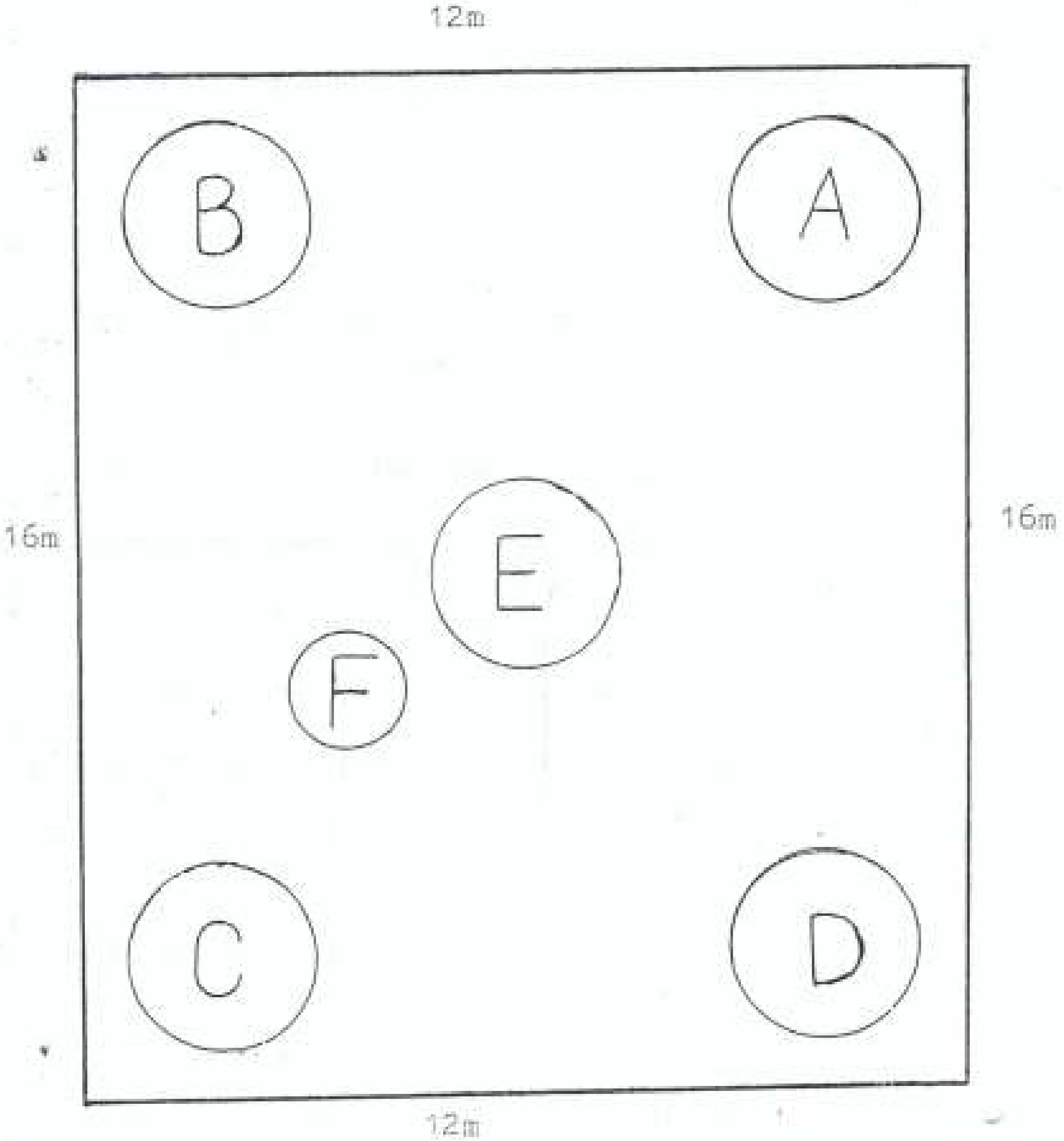

Fig. 2: FIELD PLAN SHOWING THE ARRANGEMENT OF APPARATUS: A-D(DRAINAGE LYSIMETERS); E(WEIGHING LYSIMETER);F (RAINGUAGE).

A receptacle consisted of a small plastic bucket, (with cover) of about 8 litres in capacity. Fig. 3 showed the side view of a typical drainage lysimeter.

3.3 Installation of Micro-lysimeters

The preliminary activities started with land preparation operations (i.e. bush clearing, bush packing, stubble removed etc.) and soil sampling. The installation procedure started with digging of lysimeter pits as well as receptacle pits of about 40 cm and 70 cm depths respectively.

Careful loading of lysimeter with dugged soil layers began with a layer of coarse and fine gravels (5 cm deep), sand layer (2 cm deep), clay layer (15 cm deep) and topsoil of loam (18 cm deep). After installation, the surface of the soil inside and outside the lysimeters was at the same surface level and also, the top of the lysimeter was about 5cm above the ground surface. Lysimeter installation and soil loading were carried out in about a month before experimentation. This is to ensure good soil compaction Fig. 4 shows the picture of land preparation stage for weighing microlysimeter installation.

3.4 Sensor Manometer System

The materials used in setting up the hydraulic weighing lysimeter in this study include elastic motor tyre-tube, flexible rubber hoses, a mercury pot and a pipette-form-manometer. A water-filled elastic tyre-tube (on which the weighing lysimeter tank rests) was connected to a mercury pot by means of a flexible rubber hose. Another flexible rubber hose connected the mercury pot to the graduated pipette-form manometer glass. For conveniences of in and out movement of water, the mouth (valve) of the tyre-tube was transferred to outside before installation. The mercury (inside the mercury pot) assists in reducing pressure intensity on

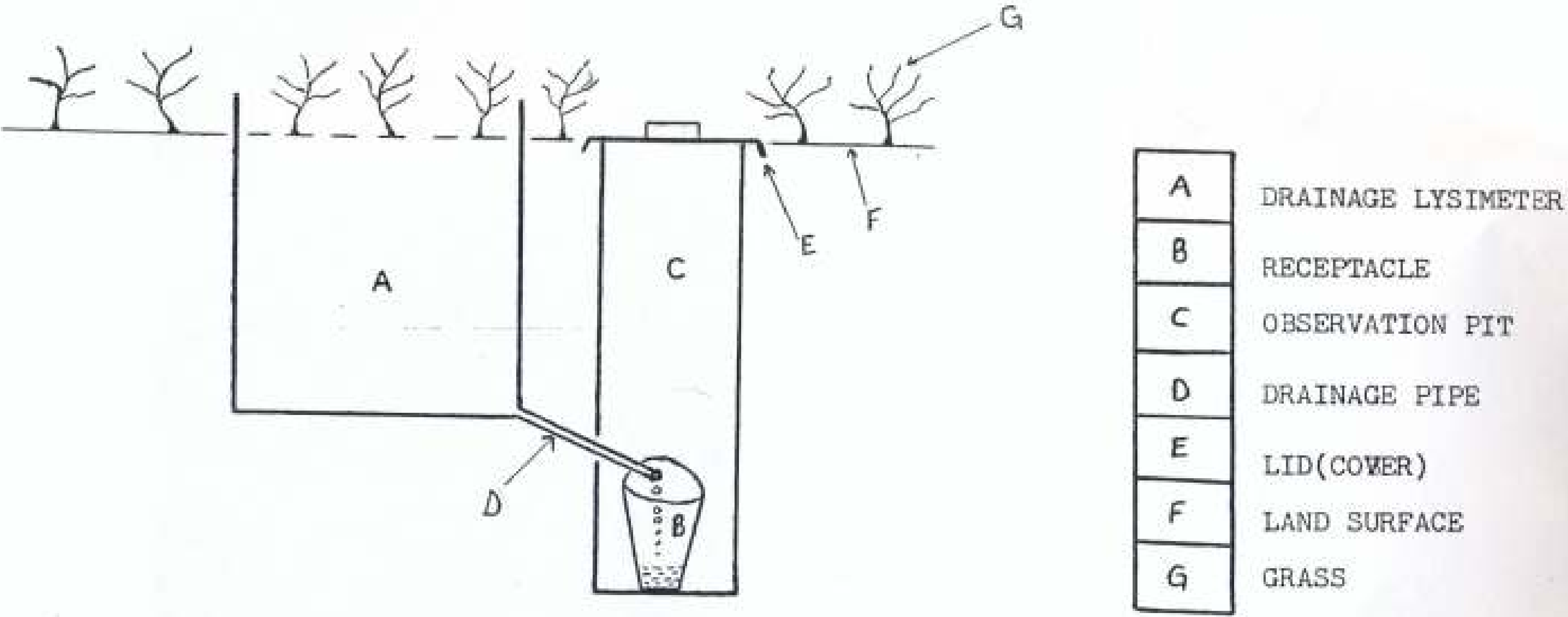

Fig 3: DIAGRAM OF SIDE VIEW OF INSTALLED DRAINAGE LYSIMETER.

Fig;4: The Picture of Land Preparation Stage for Weighing Microlysimeter Installation manometer water (Kruse and Neale, 1989). Fig. 5 shows the diagram of weighing micro-lysimeter with connected manometer.

3.5 Cropping

Bahama grass (cynodon dactylon) is used in studying reference crop ET in this work. According to Terry and Michieko, (1987), the cynodon dactylon is a perennial grass which occasionally be a troublesome weed of arable land. It has fibrous root, culm stem and flat leaf of about 16cm long and 6mm wide. It has green colour with some scattered hairs on its body. Its propagation is by stolons and grains. It is also widespread in Africa especially Nigeria. Fig. 6 shows the field pictures of bahama grass at (a) 2 weeks and (b) 10 weeks after planting.

3.6 Galibration Test of Weighing Lysimeter

The calibration test of weighing lysimeter was carried out by using a static procedure. This involved loading the lysimeter with known moveable weights and noting the consequent rise in mercury level in the manometer scale (Adeogun et al, 1998). The loading is determined by equal increment of load (water quantity) in kilograms (Kruse and Neale, 1989). The loading increment of 2 kg were made after every 5 min. period and the off-loading process was also carried out in a decrement order of 2 kg after every 5-min. Off-loading process was necessary so as to ascertain the results of loading process. The response of the lysimeter to loading was measured over a range of 15 loads and the corresponding changes in manometer value were determined. The cumulative effect of load placed on the lysimeter was indicated by manometric height increase on the scale. When the load was removed, the mercury level returned to its original position. Using the analysis of Appendix 5, the effect of cumulative loads of the lysimeter was then converted to equivalen

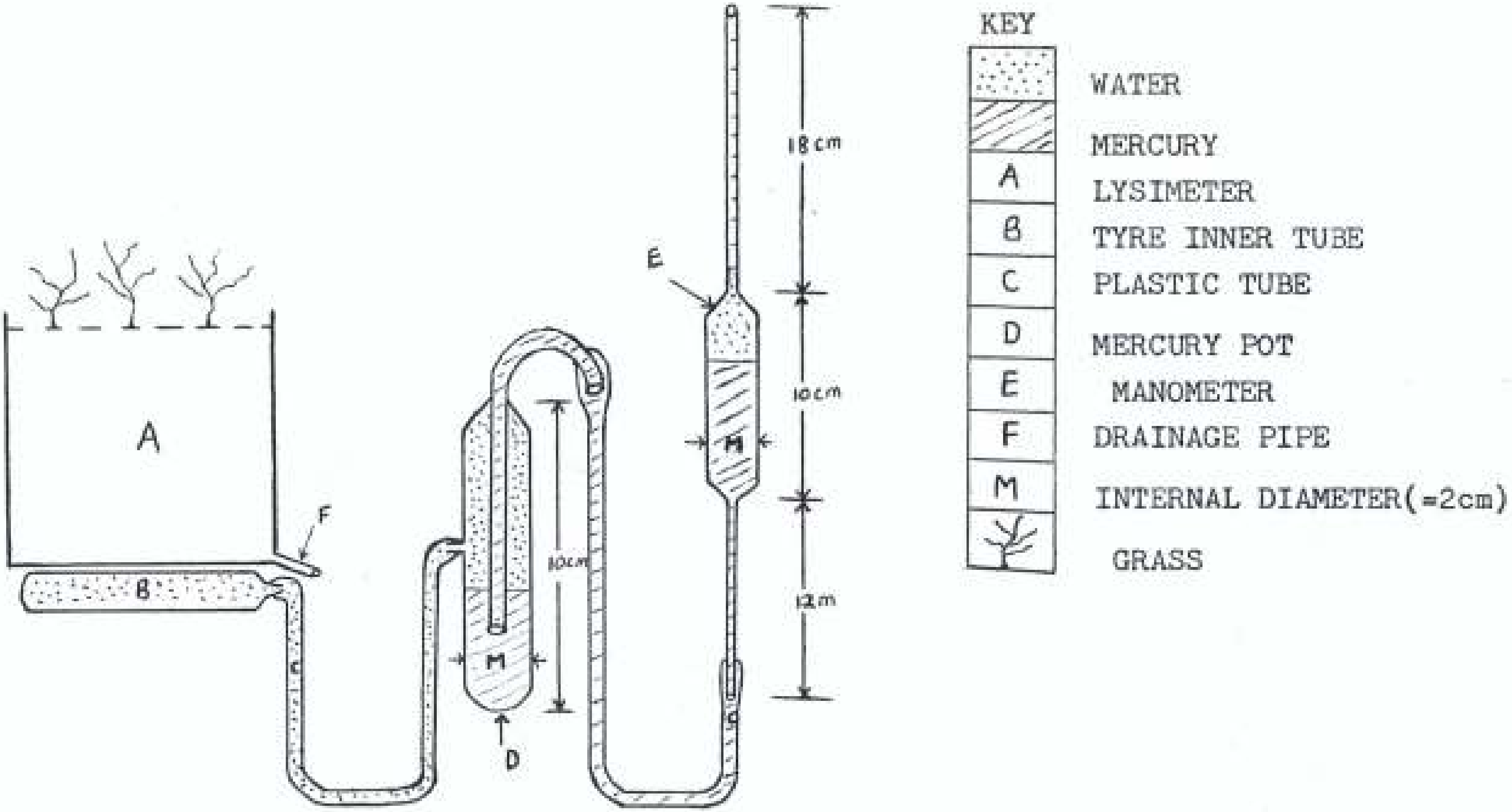

Fig 5: DIAGRAM OF SIDE VIEW OF WEIGHING LYSIMETER WITH CONNECTED MANOMETER

(a)

(b)

Fig; 6: The Field Pictures of Bahama grass at (a) two weeks and (b) ten weeks after planting water depth in the lysimeter, which gives equal lysimeter weight changes corresponding to mercury level on the manometer scale.

Regression method of statistical analysis was performed (Kowal and Stockinger, 1973) on the results of the calibration test of weighing lysimeter. A form of regression equation used was shown as follow.

$$Y = a + bX \tag{4}$$

where, Y is the predicted variable (dependent variable), X is the independent variable, a is the regression constant (intercept), and b is the regression coefficient (slope).

Additional observations were made on the behaviour (response) of manometer to an instantaneous loading and unloading of the weighing microlysimeter. At an average temperature of 23.5°C, a large loading weight of 30kg was made while the manometer reading was taken every two minute for a total period of 20 minutes. The subsequential study was made by instantaneous removal of that 30 kg of load while the manometer reading was taken every two minutes.

3.7 Collection of Meteorological Data

The source of climatic data used in this study is the weather station of the Department of Meteorology, Federal University of Technology, Akure. The department is a World Meteorological Organisation (W.M.O.) designated center. Some collected data include, rainfall, maximum and minimum temperatures, wind speed, sunshine hour, solar radiation and relative humidity. Other specific data collected for some methods include latitude and elevation of the study area. The collected meteorological data covers a period of ten years (1990-1999).

3.8 *Meteorological Methods of Estimating Reference ET*

Some grass-based empirical methods of estimating the reference ET used in this study are listed as follows:

3.8.1 Blaney-Criddle Method

Original Blaney-Criddle (1950) formula does not compute reference ET (James, 1988). A further modification of this formula was made by Doorenbos and Pruitt (1977) using the concept of reference crop ET based upon grass. Their version of Blaney-Criddle method according to Burman et al (1983) is written as follows:

$$RET = a_b + b_b F \qquad (5)$$

$$F = P(0.46T + 8.13) \qquad (6)$$

$$a_b = 0.043RH_{min} - n/N - 1.41 \qquad (7)$$

$$b_b = ao + a_1 RH_{min} + a_2\, n/N + a_3\, Ud + a_4\, RH_{min} + a_5\, RH_{min}\, Ud \qquad (8)$$

where RET is the reference ET in mm, T is average air temperature (°C), P is the percent of daylight hours of the month, n/N is the ratio of actual to possible sunshine hours, RHmin is the minimum daily humidity, and Ud is daytime wind at 2 m elevation (m sec^{-1}).

The regression coefficients ai(from Frevert et al, 1982) are as follows: $a_0 = 0.81917$, $a_1 = -0.0040922$, $a_2 = 1.0705$, $a_3 = 0.065649$, $a_4 = -0.0059684$, $a_5 = -0.0005967$.

3.8.2 Jensen-Haise Method

The basic Jensen- Haise (1963) equation according to Burman et al (1983) is:

$$RET = C_T\,(T - Tx)\, Rs \qquad (9)$$

$$C_T = 1/(c_1 + 7.3C_H) \qquad (10)$$

$$C_H = (50\ \text{mbar}) / (e_2 - e_1) \qquad (11)$$

$$C_1 = 38 - E/152.5 \qquad (12)$$

$$T_x = -2.5 - 0.14(e_2 - e_1) - E/550 \qquad (13)$$

where RET is the reference ET (mm day-1), T is the mean daily air temperature (°C), e_2 is the saturation vapour pressure of the long-term mean daily maximum air temperature of the warmest month in the year (mbar), e_1 is the saturation vapour pressure of the mean daily minimum air temperature of the same month, T_x is the intercept of the temperature axis and E is the site elevation (m), and Rs is solar radiation in equivalent depths of evaporation (mm).

3.8.3. Hargreaves Method

Hargreaves based his work on data from grass lysimeters. The Hargreaves equation according to Hansen et al (1979) is written as:

$$RET = 0.0135(T + 17.78)\ Rs \qquad (14)$$

where RET is reference crop ET from well watered grass (mm/day); T is average daily temperature (°C), Rs is incident solar radiation (mm/day).

Allen (1996) suggested the use of Hargreaves and Samani (1982) method of estimating solar radiation Rs values. Their method is given as:

$$Rs = Kr\ (T_{max} - T_{min})^{0.5}\ Ra \qquad (15)$$

where T_{max} and T_{min} is mean maximum and minimum daily air temperature (°C), Ra is extraterrestrial solar radiation (mm/day) (see Ra value in Appendix 6), and Kr is empirical coefficient with values 0.16 for 'interior' regions and 0.19 for coastal regions. Kr value of 0.16 is used in this study.

3.8.4 Combination (Penman) Method

Penman (1948) combined the aerodynamic and energy budget methods to obtain an equation for computing ET. James (1988) computed grass reference ET on daily basis using combination equation of the form:

$$RET = \frac{\Delta R_n + \gamma Ea}{\Delta + \gamma} \tag{16}$$

where

$$\Delta = \frac{4098 e_{sa}}{\left(T_a + 237.3\right)^2} \tag{17}$$

= Slope of the saturation vapour pressure versus temperature curve at air temperature, Ta (mbar/°C);

$$e_{sa} = \exp\left(\frac{19.08 T_a + 429.4}{T_a + 237.7}\right) \tag{18}$$

= Saturation vapour pressure at air temperature Ta (mbar);

$$\gamma = \frac{1615 Pa}{2.49(10)^6 - 2.13(10)^3 Ta} \tag{19}$$

= Psychometric constant (mbar/°C);

$$Pa = 1013 - 0.1152E + 5.44(10)^{-6} E^2 \tag{20}$$

= air pressure(mbar);

E = Elevation above mean sea level (m);

$$Ea = (0.27 + 0.2333u)\,(e_{sa} - e_a) \text{ (Doorenbos and Pruitt, 1977).} \tag{21}$$

= aerodynamic term = $f(e_{sa}, e_a, u)$ (mm/day);

$$e_a = e_{sa}\,(RH/100) \tag{22}$$

= vapour pressure at mean air temperature;

u = wind velocity (m/s);

Net radiation (mm/day); Rn (according to Doorenbos and Pruitt, 1977)

$$= 0.75Rs - 2.00(10)^{9} (Ta + 273.16)^{4} (0.34 - 0.044 \sqrt{e_a}) (-0.35 + 1.8 Rs/Ra) \qquad (23)$$

Statistical Analysis of Data

The relationship between the reference ET along with the lysimetric measured data and the imated data of empirical methods were examined using the regression equation. Verification of linearity of the methods used were made with the determination of correlation coefficient. aluation of the reliability of the methods used were made using the root mean square error MSE) system. Further studies on, the coefficient of determination (R^2), the slope of the gression and the absolute average deviation between the estimated and measured reference ET re also determined.

10. Preliminary Soil Studies

A thorough study on the physical and chemical properties of the soil of the site griculture Engineering Farmland) had been previously carried out and reported by Malumi and gundokun (1997). Some results of their study were used in this project. Some results of the echanical and chemical compositions of the farmland are shown in the tables of Appendix 1 and The slope of the farmland in the North direction is - 0.83% and the slope in the east direction is 55%.

The topsoil was experimentally determined to be sandy loam while the sub-soil horizon is predominantly clay soil. There is great variation in the depth of topsoil and sub-soil from one point to another. The oven-dried, gravimetric method of determining soil moisture content were carried out on collected soil samples. The moisture content were computed using the formula shown below.

$$\text{Soil Moisture Content, } M = \frac{W2 - W3 \quad X\ 100}{W3 - W1} \qquad (24)$$

where M is soil moisture content (%), W1 is weight of the cans (g), W2 is weight of cans and moist soil (g), W3 is weight of cans and dry soil (g).

3.11 Crop Curves

Crop curves are the ratio of actual crop water use to reference crop evapotranspiration presented as a function of an independent variable such as days after planting, phenological development, fraction of season, or Thermal time. Crop curves are one means of irrigation scheduling (Steele et al, 1996). Irrigation scheduling is the process of determining when to irrigate and how much water to apply per irrigation for the benefits of improved crop yield, water and energy conservation, and lower production costs (James, 1988).

According to Wright (1982), daily crop coefficients (kc) can be determined from reference crop ET (RET) data based on climatological data and daily ET measurements from weighing lysimeters. The relationship is expressed as:

$$Kc = \frac{ET}{RET} \qquad (25)$$

Crop curves have the benefits of estimating the RET and hence Crop ET from climatic data and Kc (Steele et al, 1996). When Kc values were referenced to thermal time, T T.since planting base temperature, Tb of 10°C and no upper limit temperature was used to compute daily thermal time. The thermal time, TT was computed using the equation as written by Mailhol et al (1997). The equation is written as:

$$TT(j). = \sum_{k=1}^{k=j}(Tm - Tb) \qquad (26)$$

where Tm is daily mean temperature (°C),Tb is the base temperature (°C) and j=105

The crop curves were generated with fifth-order, least squares regression polynomials of kc versus days after planting, DAP and Kc versus TT for the general form of the polynomial equation:

$$Kc = C1 + C2X + C3X^2 + C4X^3 + C5X^4 + C6X^5 \qquad (27)$$

where X is the time base, i.e. DAP or TT and parameters C1, C2 ...., C6 are coefficients.

The crop curves reported here are mean curves in contrast to basal crop curve reported by Wright (1982). Basal curves reported by Wright (1982) represent time periods with a dry soil surface, when evaporation from the soil surface was minimal, yet when soil moisture in the root zone was not depleted enough to produce stress on the crop. In this study, the crop curves include all time periods and therefore include periods with a wet soil surface.

3.12. Weekly Observation on plant Parameter

Weekly estimations on plant parameters which include, average plant height, hc and fraction of grass coverage, Fc were carried out during the period of study. The displacement height, d and aerodynamic roughness, Zo were also computed from estimated values of hc and Fc data using the following equations as presented by Abtew and Obeysekera (1995). The equations are:

$$d = 0.85\, Fc\, hc \qquad (28)$$

$$Zo = a(hc - d) \qquad (29)$$

where values of 'a' ranges between o.13 and 0.36 in the humid region. A value a = 0.36 was used in this study.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Plant Parameters

The results of weekly estimates of hc, Fc, d and Zo were shown in Fig. 7. The trend of the curve revealed that the plant height as well as grass coverage began to rise from planting day until the maximum height and coverage are reached within the 10th week of growth. Immediately after 10th week, an inappreciable decline in the height and coverage of the plant growth were noticed. These observations were in good agreement with similar observations made by Abtew and Obeysekera (1995).

A much lower value was revealed in the results of computation made on displacement height and aerodynamic surface roughness when compared to the values of grass height and grass coverage. Fig. 7 showed that there were gradual increases in the value of displacement height and aerodynamic roughness from the day of planting. This trend continued until the peak were reached in the 10th week after which it declined This observation was in good agreement with the one made by Abtew and Obeysekera (1995). James (1988) described aerodynamic roughness as one of many factors responsible for the variation of evaporation from one location to another.

4.2 Results Of Calibration

The results of the calibration test are presented in Fig. 8. The curve showed a linear relationship between the load (Kg) and manometer scale readings (mm) on one hand, and similarly between the equivalent water depth (mm) and manometer scale reading (mm). It was observed that

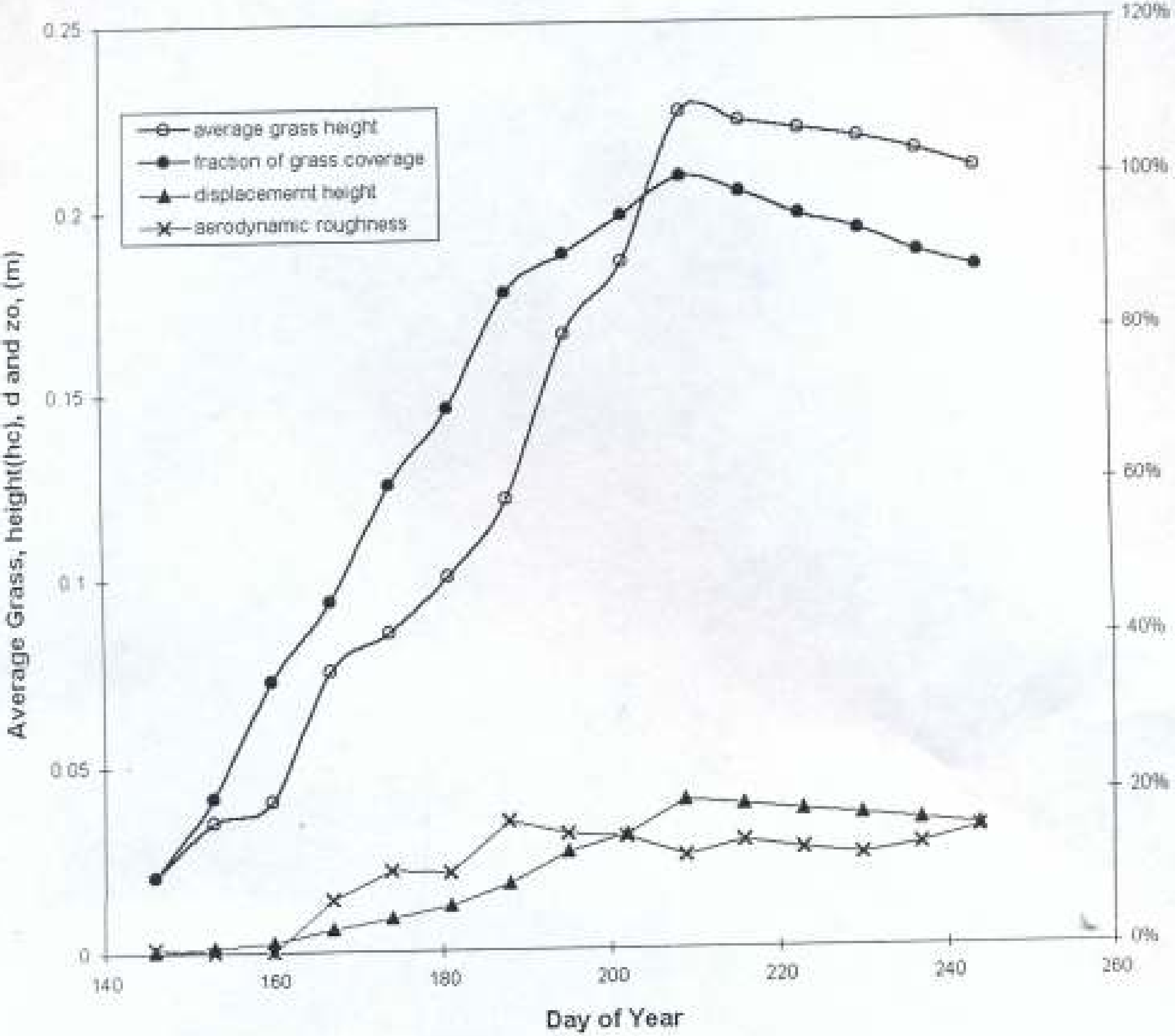

Fig. 7 : Estimated Average Grass Height (hc), Displacement height (d), Aerodynamic roughness (zo) and Fraction of cover (Fc)

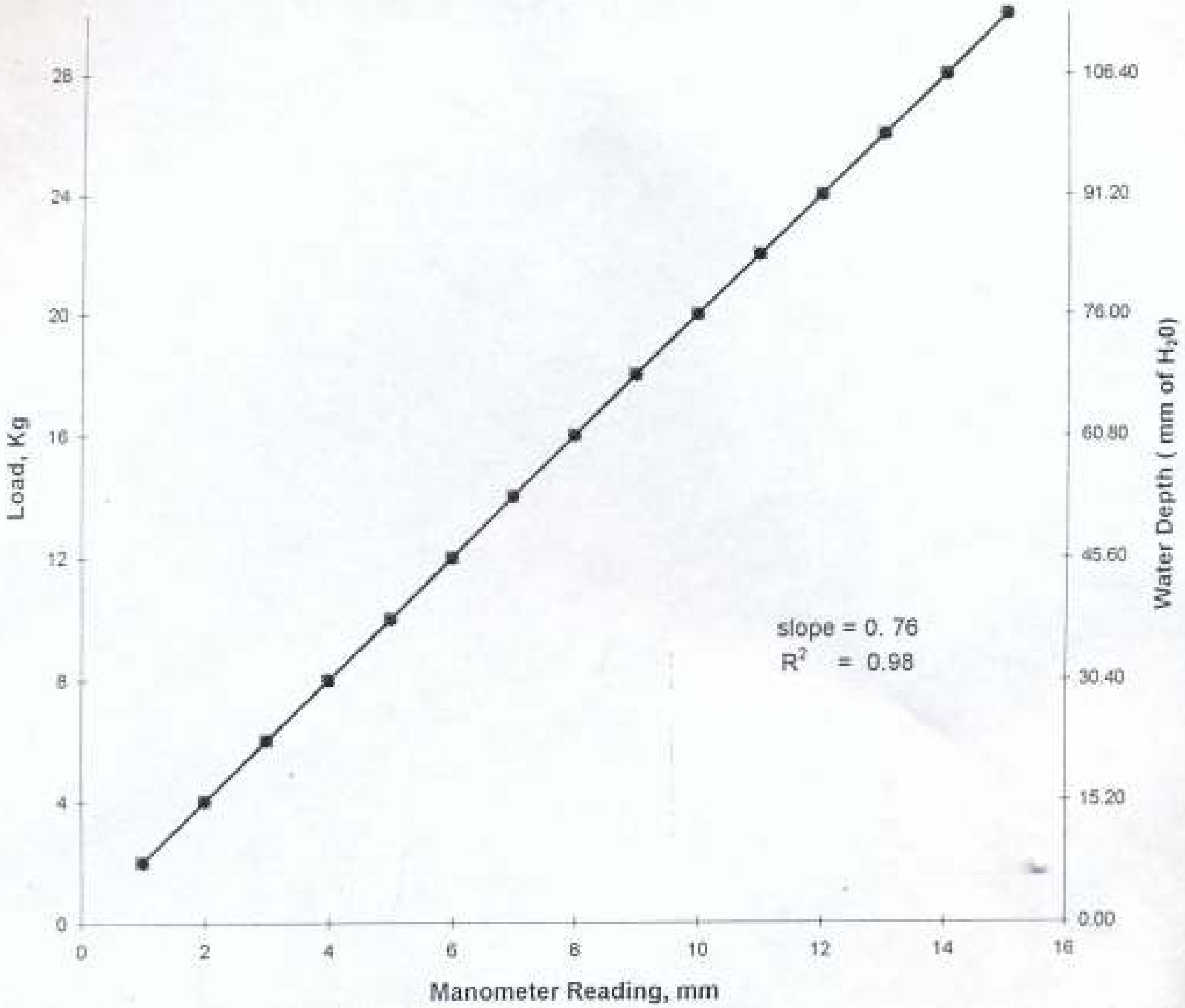

Fig.8 : Composite calibration curve

a small load increment (with its corresponding) water depth gave a gradual increment in manometer scale reading. A cumulative total load weight of 30kg placed on the microlysimeter gave equivalent water depth of 11.4 cm (or 114 mm) as shown in Table 1.

A calibration equation (30) which gives the relationship of actual water depth used in microlysimeter with the known values of manometer readings was derived using a linear regression model of equation (4).

$$Y = 0.76\ X\ -\ 0.15 \qquad (30)$$

Where Y represent the water depth in the microlysimeter and X represents the value of manometer reading.

The derived calibration equation (30) was therefore used to correct the microlysimeter readings in this study, and it was finally written as follows:

$$RET = 0.76\ M\ -\ 0.15 \qquad (31)$$

where RET represent the reference ET (mm) value and M represent manometer reading value.

The difference between manometer readings (M) is then substituted in equation (31) and the water depth (RET) used within a period of time would be determined. A length of time used in this study is a day (24 hours). The slope of derived calibration equation is 0.76 cm (or 7.6 mm) indicating that the average change in one unit scale reading on the manometer corresponds to a load of 2 kg or 0.76 cm of water depth in the microlysimeter.

High correlation was observed between the manometer responses and the lysimeter loading ($r^2 > 0.98$) similar results were obtained by Kowal and Stockinger (1973), Kruse and Neale (1989) and Adeogun et al, (1998).

Table 1: Changes in manometer reading and lysimeter water depth to gradual load increment

Load Weight (Kg)	cumulative load weight (Kg)	Equivalent water depth, (cm)	Manometer Scale Reading (mm)			
			Test1	Test2	Test3	Average
0	0	0	0	0	0	0
2	2	0.76	1	1	1	1
2	4	1.52	2	2	2.5	2.2
2	6	2.28	3	3.5	3	3.2
2	8	3.04	4	4	4	4
2	10	3.80	5.5	5	5.5	5.3
2	12	4.56	6	6.5	6	6.2
2	14	5.32	7	7	7	7
2	16	6.08	8.5	8	8	8.2
2	18	6.84	9	9	9.5	9.2
2	20	7.60	10.5	10	10	10.2
2	22	8.36	11	11.5	11	11.2
2	24	9.12	12	12.5	12.5	12.3
2	26	9.88	13	14	13.5	13.5
2	28	10.64	14.5	14.5	14	14.3
2	30	11.4	15	15	15.5	15.2

4.3 *Manometer Response to Loading*

The curve in Fig. 9a showed the results of manometer response to a large load of 30kg. The trend of the curve indicates a smooth and gradual increment in manometer reading with time. It was observed from the curve that, in the first 8-minutes, the gradual increase in manometer response took place at a reducing rate of 0.75 mm per minute which is later reduced to 0.25 mm per minute and finally reached the equilibrium level.

The results of an instantaneous unloading of 30kg of load were shown in Fig. 9b. The manometer responded by dropping down from height it previously reached. A sharp fall was observed within the first few minutes of the test and finally dropped to zero after 20 min. of the experiments.

4.4 *Comparison Of Reference Evapotranspiration (RET)*

Weighing Lysimeters are generally considered the standard for evapotranspiration measurements (Dugas and Bland, 1989). In this study, the comparison between the measured lysimetry RET values and estimated empirical RET values were therefore with reference to the weighing microlysimeter.

4.4.1 Empirical Methods

Of all empirical methods selected for estimation of RET in this study, Penman (PEN) method is the most data demanding. Table 2 reveals that PEN required climatic data such as temperature, T; Solar Radiation, Rs; Relative humidity, R.H; Wind Speed, U; Net radiation, Rn; and Elevation, E. The other empirical methods that followed PEN in terms of data requirement are

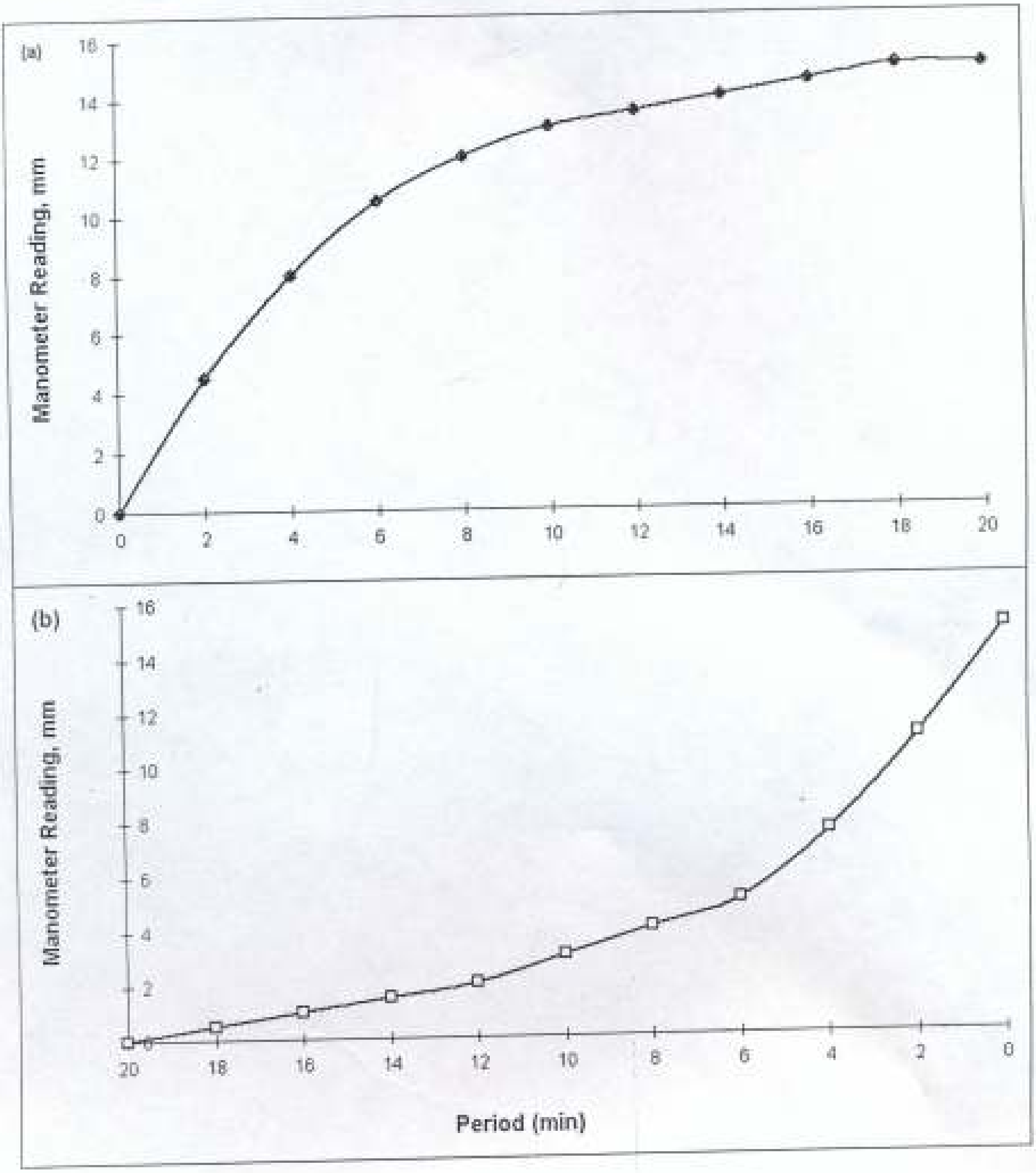

Fig.9 : Manometer Response to (a) Loading and (b) Unloading of 30Kg at Temperature of 23.5 °C

Jensen– Haise, J-H; Blaney-Criddle, B-C; and Hargreaves, HG methods in that order. Considering the complexity of estimation, the PEN was rated high (Duru, 1979). This is followed by J-H, B-C and HG in that order. Table 2 also shows the recommended period in which empirical methods could be estimated. PEN could be estimated on daily, weekly, monthly, and even yearly basis while the estimated period for J-H, B-C and HG should not be less than a week so as to be reliable. The capability of PEN to compute ET over relatively short period of time such as one day has made it more useful for irrigation planning (Duru, 1979).

Table 2 : Characteristics of Methods of Estimating REF-ET.

Method	Main Data Required						Recommended Period of Time
	T	Rs	R.H	U	Rn	E	
Blaney-Criddle	✓		✓				Weekly, Monthly
Jensen-Haise	✓	✓				✓	Weekly, Monthly
Hargreaves	✓	✓					Weekly, Monthly
Penman	✓	✓	✓	✓	✓	✓	Daily, Weekly, Monthly

T, temperature; Rs, solar radiation; R.H, relative humidity; u, wind; E, elevation, Rn, net radiation.

4.4.2. Lysimetry Results

The result of daily RET of bahama grass as measured by weighing microlysimeter is presented in Fig. 10a. The trend of RET curve immediately after grass planting is linear until about 155-day of the year (DOY) after which the points became scattered. The linearity of the curve in the initial stage of grass growth may be attributed to absence of rainfall and hence gradual rise in RET up till 210 DOY.

The scattering of points may be attributed to highly erratic rainfall during the field experimentation period. It was also observed that the scattering was more at the latter period of the experiment. This may be due to heavy downpour that characterized the last days of the experiment (corresponding to peak rainfall immediately after the August-break).

Fig. 10b showed the results of the average RET from the four drainage microlysimeters. The curve is linear from initial stage of planting period. The linearity continued until the peak point at about 210 DOY and declined thereafter continuously until some days to the end of experiment. The linearity from the initial period until toward the end of experiment may be as a result of averaging method of statistic analysis performed on all the drainage microlysimeters. The RET results of measurements from weighing and drainage lysimeters in Fig.s. 10a and 10b showed that, these curves are linear at the initial stage of grass growth, and non-linear and scattered towards the end of experiment. The reasons, as previously explained, are due to absence of rainfall at the initial stage and occurrence of heavy rainfall at the last stage of the experiment.

The peak points of the curves also indicated the maximum RET measurement of 7.2mm by the weighing microlysimeter while the maximum RET value measured by drainage microlysimeter was 8.8mm. The higher RET value measured by the latter agreed with Ayoade (1988) that

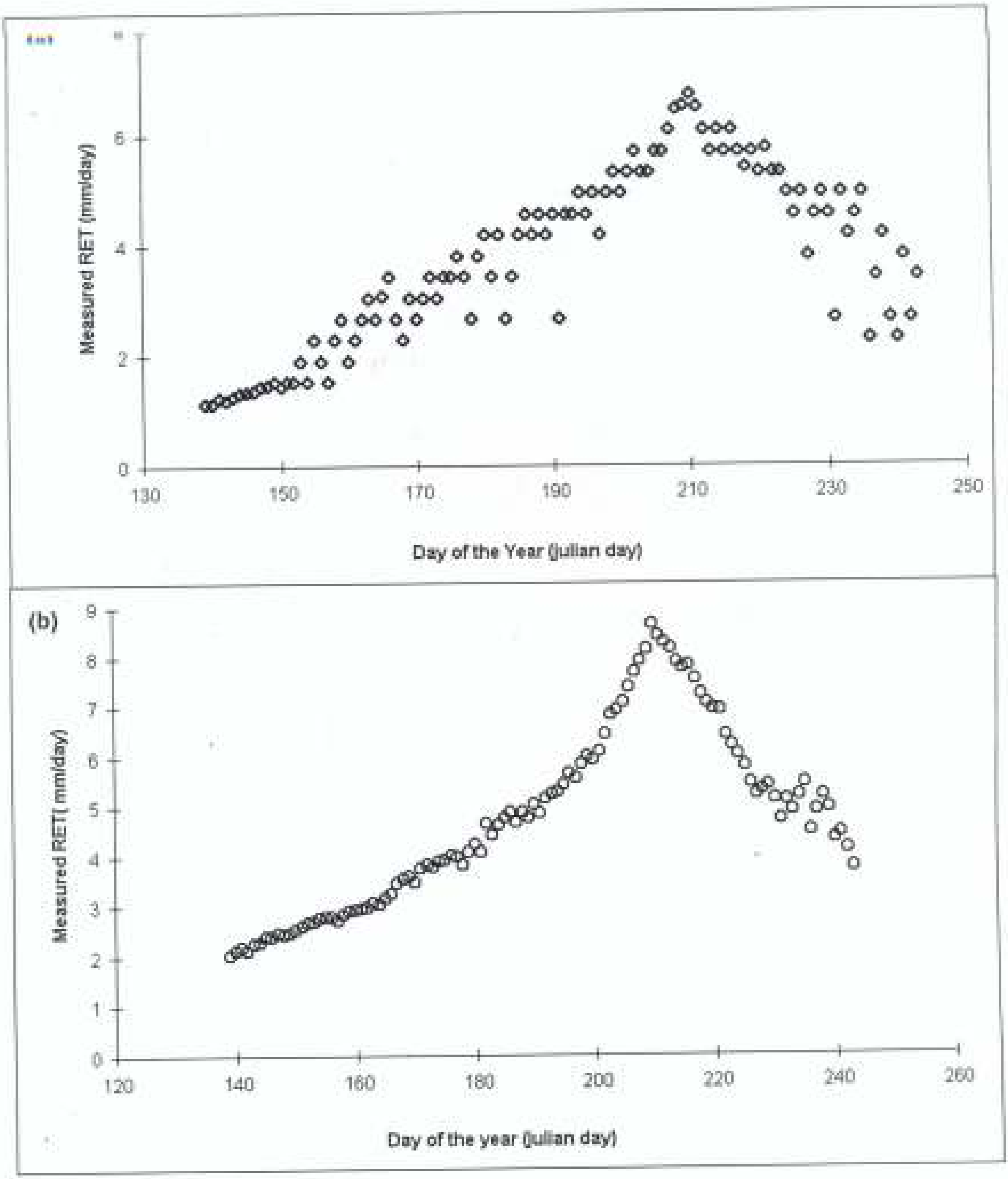

Fig.10: Daily Reference Evapotranspiration (RET) of Grass as Measured by (a) Weighing Lysimeter, and (b) Drainage Lysimeters

drainage lysimeter measures the ET at a possible maximum rate in any location while the weighing lysimeter measured the actual ET of the location.

4.4.3 Measured and Estimated Daily RET

Cumulative results of measured and estimated RET values for each method used in this study are shown in Fig. 11. It was observed that the cumulative RET values from weighing microlysimeter (WL) increased with time. A point of inflexion was noticed at about 70 DAP. Similar trend was noticed in the curve for drainage microlysimeter (DL) results. It was also observed that DL overestimates the RET values compared with the measured results from WL. Similarly, at about 70 DAP, it was noticed that the curve for Hargreaves method has an inflexion point.

The results indicated that all other methods overestimated using WL as the standard for comparison. The trend of J.H curve showed that J.H method overestimated the RET values from the initial stage of the experiment until about 85 DAP after which it started underestimating the RET. B.C. values appeared to have overestimated the RET most. This was followed by PEN, HG, J.H and lastly, DL. Each of the method was correlated with the results of W.L. Summary statistics for regression of daily RET measured by DL and other empirical methods against the RET measured by WL are presented in Table 3. The results of statistics showed that DL was highly correlated and ranked first with lowest root mean square error (RMSE) of 0.25, lowest standard error (S.E) of 0.50 and of highest coefficient of determination (R^2) of 0.90.

The second best predictor was J.H. with RMSE of 1.04, S.E. of 1.02 and R^2 of 0.58. PEN ranked method is B.C, which exhibited the values RMSE of 1.37, S.E. of 1.17 and R^2 of 0.45. The poorest method is was ranked third with RMSE of 1.20, S.E. of 1.10 and R^2 of 0.52. The fourth HG with

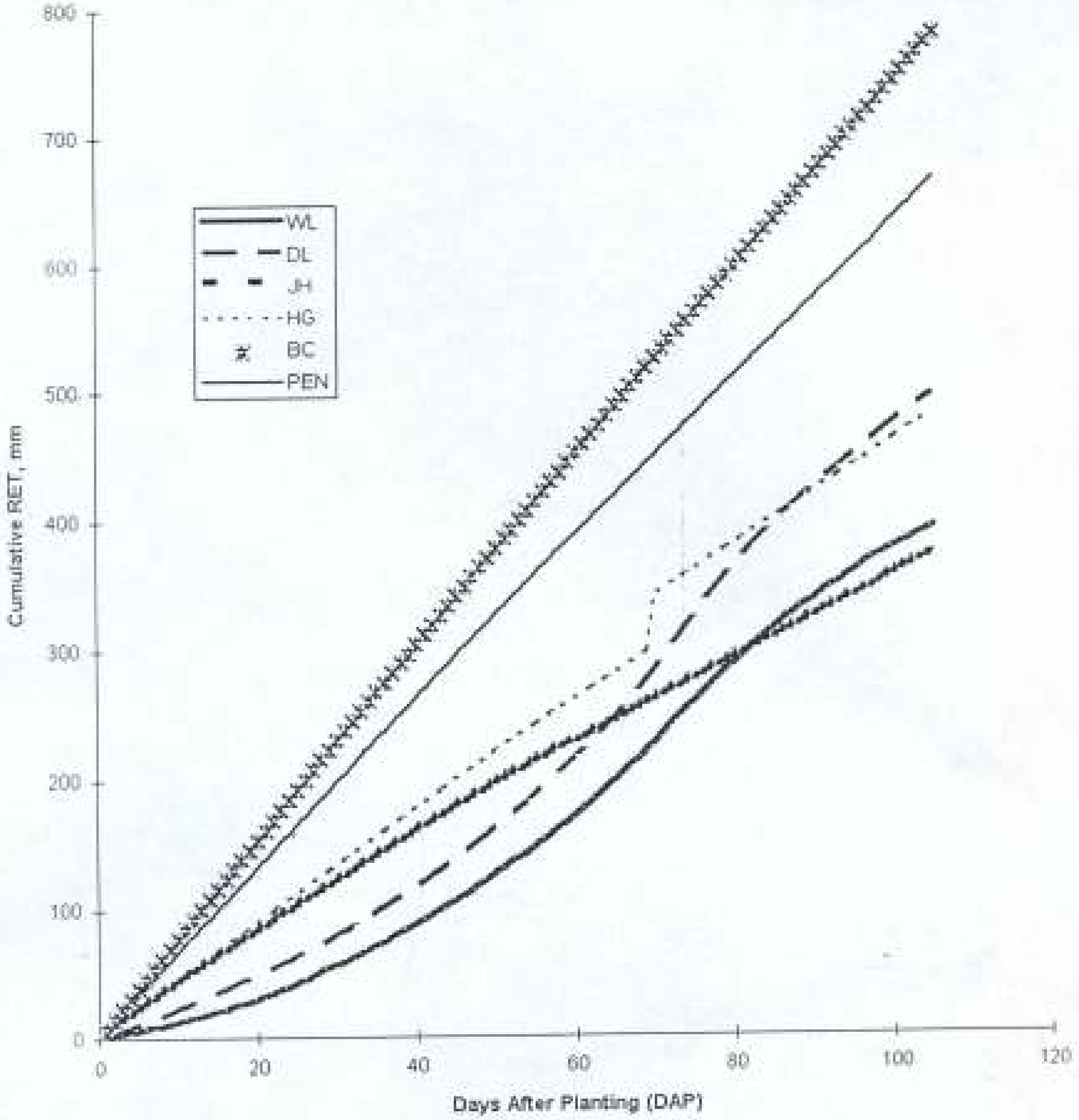

Fig.11 : Cumulative Values of Measured and Estimated Reference Evapotranspiration (RET)

values RMSE of 2.44, S.E. of 1.56 and R^2 of 0,02. The intercepts in the regression equations seemed high for all methods except for DL which are small.

Table 3: Summary Statistics for Linear Regression of Daily RET of the form, Y = a - bX (with values of weighing microlysimeter as the dependent variable, Y)

Method	Regression	R-Square	RMSE	S.E
PEN	Y=30.7-4.3X	0.515	1.20	1.10
B-C	Y=41.9-5.1X	0.447	1.37	1.17
J-H	Y=13.7-2.8X	0.579	1.04	1.02
HG	Y=3.53 +0.05X	0.015	2.44	1.56
D.L	Y = 0.22 +0.84X	0.900	0.25	0.50

Y = Predicted Weighing microlysimeter daily RET (mm/day); and X = Calculated daily RET by each of the five methods (mm/day)

4.4.4 Measured and Estimated Weekly RET

The results of weekly values for lysimetry and empirical methods are graphically illustrated in Fig. 12. The trend of curves for WL and DL showed an increase in the RET values from initial stage of the experiment and reached its peak 11-week after planting (WAP). The peak RET value for DL curve was about 8.2 mm/day while that of WL was about 6.6 mm / day, whereas daily comparison gave 8.8 mm/day and 7.2 mm/day respectively. The difference in the values may be attributed to the fact that the more the number of days involved, the higher the reliability of the RET values (Duru, 1979; James, 1988).

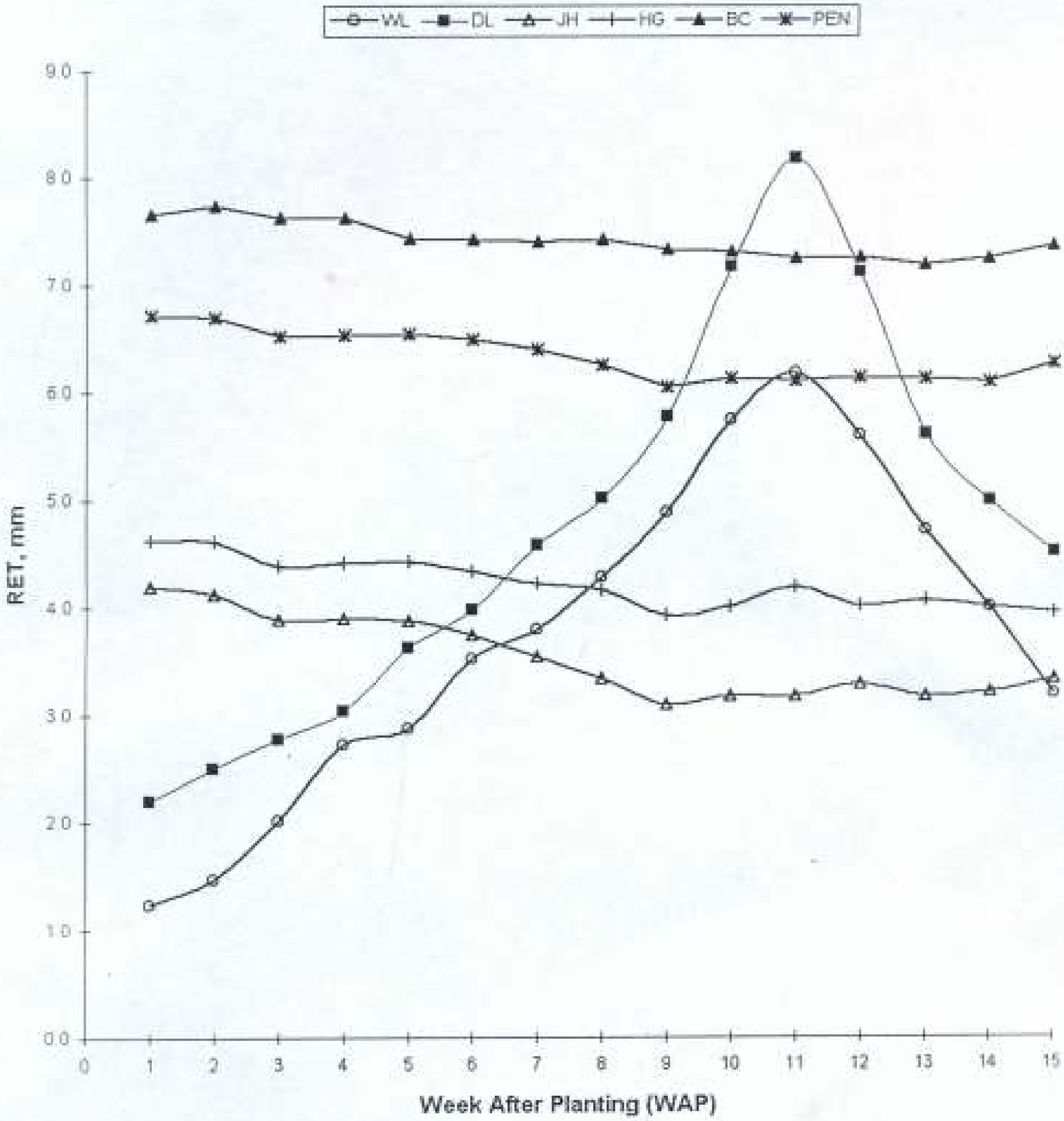

Fig. 12: Measured and Estimated Weekly RET

The trend of curves for the four empirical methods used showed that they are characterized by low fluctuation. B.C fluctuates at a higher RET value of 7.5 mm/day, followed by PEN which fluctuates at RET value of 6.6 mm/day, HG with RET value of 4.6 mm/day and finally, J.H. with RET value of 4.0 mm/day.

In general, while DL and B.C overestimated the RET values, HG and J.H underestimated RET Values. However PEN gave comparable values with WL. This may be one of reasons for preferring the choice of PEN values in the absence of a reliable weighing lysimeter measurements.

The summary statistics for regression of weekly RET measured by DL and estimated by each of four estimated methods of RET and that measured by the WL are presented in Table 4. The DL method was ranked first with RMSE of 0.10, S.E. of 0.31 and R^2 of 0.96. Followed by PEN with RMSE of 0.47, S.E of 0.69 and R^2 of 0.90; J.H with RMSE of 0.48, S.E of 0.69 and R^2 of 0.81; B.C of RMSE of 0.59, S.E. of 0.77 and R^2 of 0.77; while the most poor method is HG with RMSE of 2.39, S.E. of 1.55 and R^2 of 0.05.

4.4.5 Rainfall and Seasonal RET

Fig. 13 presents the seasonal values of RET as estimated by the different methods. The cumulative rainfall throughout the season exceeds the evapotranspiration calculated in all methods. This indicates that the crop was in good water regime in most of the time.

4.5 *Development of Crop Curves*

Table 5 shows the polynomial coefficients of equation (27). The data set of Kc values as a function of days after planting (DAP) and based on the Jensen-Haise (1963) reference ET calculation method are denoted as Kc = f [DAP, RETJ-H]. Also, the data set of Kc values as a

Table 4: Summary Statistics for Regression of Weekly RET values by five methods against weighing microlysimeter measured RET

Method	Regression	R-Square	RMSE	S.E
PEN	Y=42.6 – 6.13X	0.902	0.47	0.69
B-C	Y=62.7 – 7.94X	0.71	0.59	0.77
J-H	Y=16.6 – 3.62X	0.81	0.48	0.69
HG	Y=2.62 + 0.25X	0.05	2.39	1.55
D.L	Y= -0.19 +0.83X	0.96	0.10	0.31

Y = Predicted Weighing microlysimeter weekly RET (mm/day); and X = Calculated weekly RET by each of the five methods (mm/day)

function of thermal time, TT and based on J.H are denoted as Kc = f [TT, RETJ-H]. Similarly, the notations Kc = f [DAP, RETB-C] and Kc = f [TT, RETB-C]; Kc = f [DAP, RETPEN] and Kc = f [TT, RETPEN]; Kc = f [DAP, RETHG] and Kc = f [TT, RETHG] were used for B-C, PEN, and HG methods respectively.

4.5.1 Analysis Of DAP Crop Curves

The crop curves for Kc = f [DAP, RETJ-H]; Kc = f [DAP, RETB-C]; Kc = f [DAP, RETPEN] and Kc = f [DAP, RETHG] are presented in Fig. 14. These curves revealed the performance of each empirical method in respect of DAP. In all cases, Kc values for these curves increased from the first day of planting. This explained the vegetative propagation method of planting grasses resulting in corresponding increases in ET. The values of Kc in the initial stage of the grass development were low and increased to a peak at about 75 DAP.

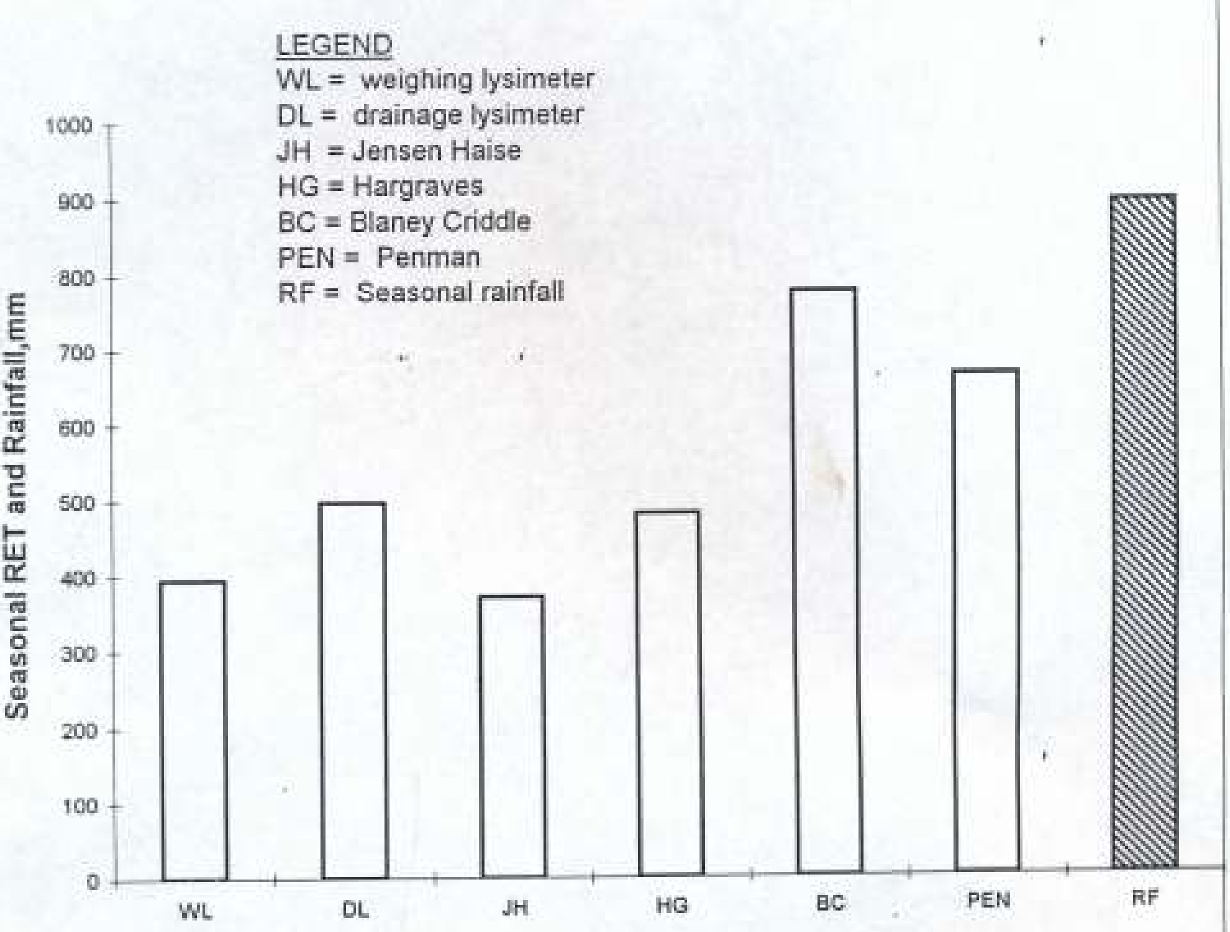

Fig. 13 : Seasonal Rainfall (RF), Reference Evapotranspiration (RET) by Lysimeters and the Emperical Models

Table 5 : Coefficients for, bahama grass Crop curve polynomial of DAP and TT based on field data for weighing microlysimeter

	Days After Planting, (DAP)				Thermal Time, (TT)			
Coeff*	PEN	B-C	J-H	HG	PEN	B-C	J-H	HG
C1	0.071	0.073	0.076	0.120	0.077	0.080	0.081	0.130
C2	0.031	0.023	0.062	0.039	0.002	0.002	0.004	0.003
C3	-0.002	-0.001	-0.004	-0.002	$-7.5x10^{-6}$	$-5.0x10^{-6}$	$-1.7x10^{-5}$	$-8.9x10^{-6}$
C4	$4.55x10^{-5}$	$3.19x10^{-5}$	0.0001	$5.63x10^{-5}$	$1.51x10^{-8}$	$1.02x10^{-5}$	$3.59x10^{-8}$	$1.85x10^{-8}$
C5	$-5x10^{-7}$	$-3.5x10^{-7}$	$-1.1x10^{-6}$	$-6.3x10^{-7}$	$-1.2x10^{-11}$	$-7.8x10^{-12}$	$-2.8x10^{-11}$	$-1.5x10^{-11}$
C6	$1.81x10^{-9}$	$1.25x10^{-9}$	$4.22x10^{-9}$	$2.3x10^{-9}$	$2.9x10^{-15}$	$1.93x10^{-15}$	$7.22x10^{-15}$	$3.69x10^{-15}$
R^2	0.900	0.893	0.902	0.814	0.899	0.892	0.900	0.813
S.Ekc	0.085	0.074	0.174	0.182	0.086	0.74	0.175	0.182
N	105	105	105	105	105	105	105	105

*The parameters C1, C2, - C6 are coefficients in the equation(27) where Kc is the crop coefficient and X is the time base (DAP or TT); S.Ekc is the standard error of the Kc estimates; and N is the number of data points.

Fig. 14e showed the results of comparison of all empirical methods used in respect of DAP. Considering the peak point values, Kc = f [DAP, RETJ-H]. and Kc = f [DAP, RET HG] have a higher values which are above the unity while Kc = f [DAP, RETPEN] and Kc = f [DAP, RET B-C] were below unity. The implication of these results on irrigation scheduling according to Steel et al (1996), are that J-H and HG methods may overestimate the crop water use, thereby resulting in higher irrigation amount over the season while the PEN and B-C methods may underestimates the

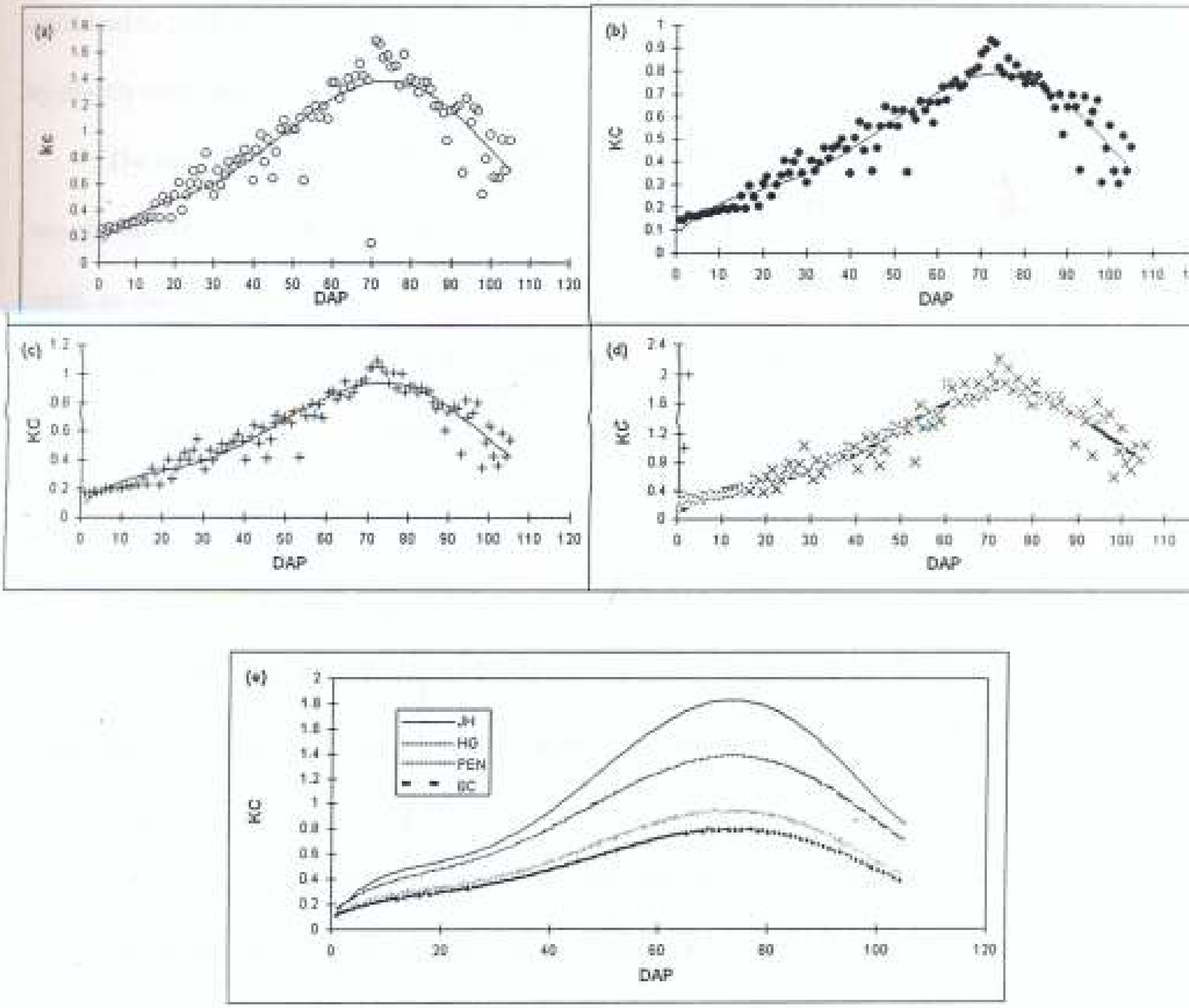

Fig. 14: The Crop Curves for : (a) Hargreaves (HG); (b) Blaney-Criddle (B-C); (c) Penman (PEN); (d) Jensen-Haise (JH) Methods as a function of Days After Planting (DAP); and (e) Combined Crop Curves.

crop water use which could result in under-irrigation. They further explained that, under-irrigation could lead to yield losses, which are more expensive than water costs and leaching losses produced by slightly over irrigating the crop.

The results of statistic analysis on each of the empirical methods with reference to DAP was also shown in Table 5. Although, the results of standard error (S.E) did not agree with ranking order, as indicated by the results of coefficient of determination. The first rated method is J.H model with highest value of $R^2 = 0.902$. Followed by PEN model with $R^2 = 0.900$; B-C model with $R^2 = 0.893$ and lastly HG model with $R^2 = 0.814$.

4.5.2 Analysis Of TT Crop Curve

Figure 15 show the crop curves for Kc = f[TT, RET J-H); Kc = f[TT, RET B-C); Kc = f[TT, RET PEN); and Kc = f [TT, RET HG). It was observed in all cases that, Kc values for TT crop curves were low at the initial stage of grass development and increased until the peak points were attained at about 1050 °C of TT.

It was revealed in Fig. 15e that J-H and HG methods were the only two methods that have their curves peak points exceeding Kc value of Unity, while PEN and B-C methods have their curves peak points below Kc value of unity. Considering these results from irrigation scheduling point of view, J.H and HG methods may overestimate crop water use while PEN and B-C methods may underestimate it.

The statistical analysis performed on each empirical method in respect of TT are also presented in Table 4. All the methods gave good results as indicated by R^2 values. J-H ranked first because of its highest value of $R^2 = 0.900$. Followed by PEN with $R^2 = 0.899$; B-C with $R^2 = 0.892$ and HG with $R^2 = 0.813$.

4.5.3 DAP and TT Crop Curves

By comparing the results of statistical analysis for DAP and TT crop curves as shown in Table 5. Results showed that J-H method had the highest value of R^2. Followed by PEN, BC and HG. According to Steele et al (1996), this result showed that JH method is the most accurate when considering the empirical methods under the crop curve analysis. Therefore, the preferential order is J-H > PEN > B-C > HG.

Furthermore, it was observed that the values of R^2 in the DAP crop curves are higher than R^2 values in the TT crop curves. This result according to Steele et al (1996) indicated that the DAP crop curves are more accurate than TT crop curves. They further explained that, users of the results may however find that TT-based curves more useful during unusually warm or cool seasons, when crop development is strongly affected by TT.

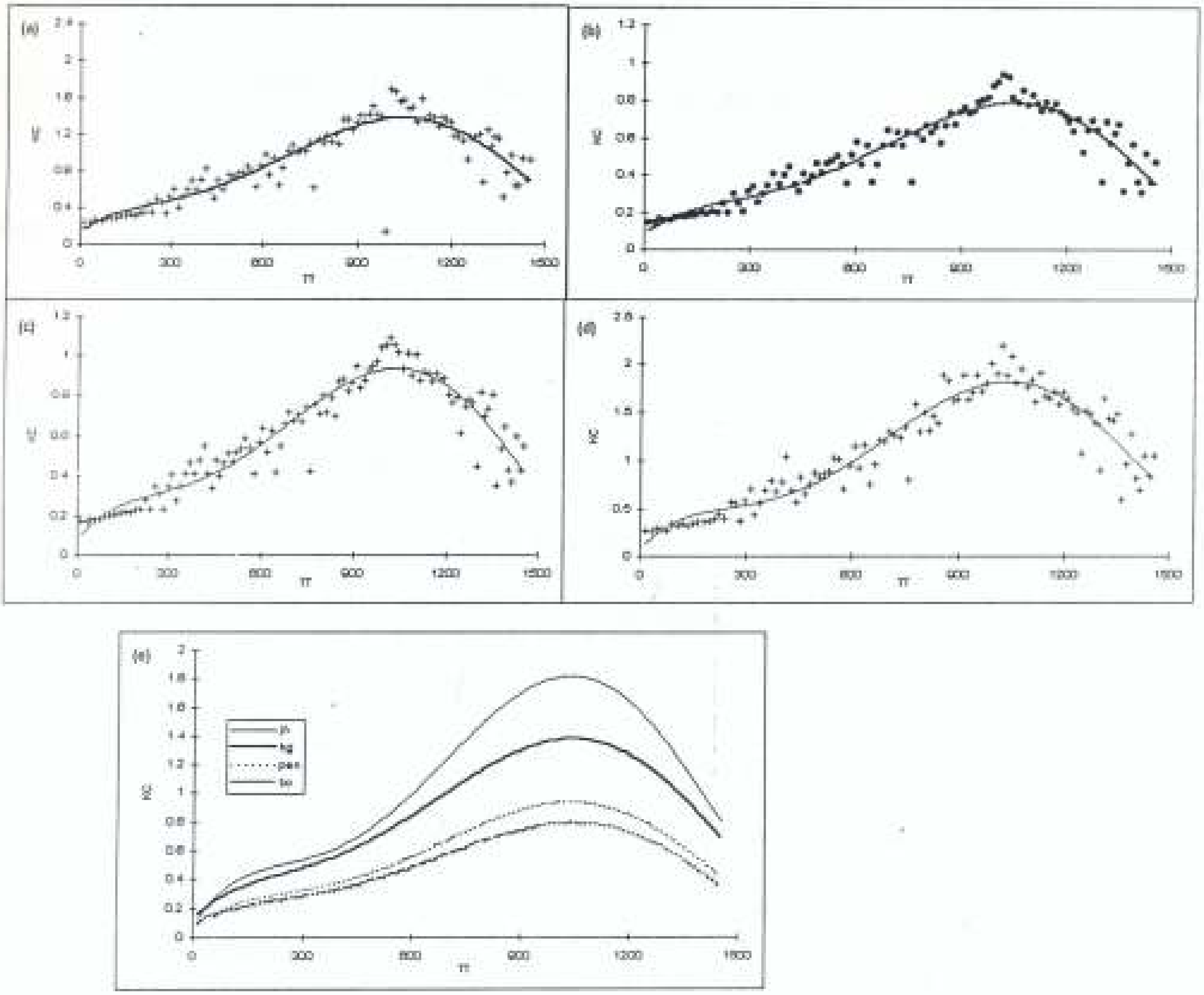

Fig. 15 The Crop Curves for : (a) Hargreaves (HG); (b) Blaney-Criddle (B-C); (c) Penman (PEN); (d) Jensen-Haise (JH) Methods as a function of Thermal Time (TT); and (e) Combined Crop Curves.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

In order to establish the crop curves for a reference crop in the study area, field experiments e carried out on bahama grass (cynodon dactylon) using weighing and non-weighing rolysimeters. The grass was planted on 12 m by 16 m plot in which a total number of five rolysimeters were installed. The design and construction of weighing microlysimeter was ed on hydraulic principles using mercury-in-glass manometer. Daily and other routine asurements included manometer scale readings, drainage water, plant height and percentage of f coverage. Weighing microlysimeter sensitivity was determined through calibration tests which s carried out on hydraulic weighing microlysimeter using a static load procedure.

Some empirical formulae such as FAO-24 version of Penman, Jensen-Haise, Blaney-iddle and Hargreaves methods were also used to estimate the reference evapotranspiration. The imeter measured RET and empirically estimated RET values were subjected to data analysis ng some standard statistical methods. Then, comparison of measured and estimated RET values re made using the weighing microlysimeter measured RET values as a reference of comparison.

Results showed that the two types of microlysimeters (weighing type and drainage type) ve comparable results, since the ET values obtained were not statistically different. The libration test of weighing microlysimeter showed that a sensitivity of 2 kg load weight caused a ange of 1 mm reading on the manometer scale which corresponds to 0.76 cm equivalent water pth in the lysimeter. The calibration test performed also revealed that the hydraulic icrolysimeter used in this study was stable, since when the load placed on the lysimeter were moved, the manometer scale reading returned to its original position.

The results of regression statistics performed on daily and weekly RET against the ghing microlysimeter RET value showed the ranking of the remaining methods in the following er DL>J-H>PEN>B-C>HG. In addition, the seasonal RET value by Jensen-Haise method is the y method that underestimated the seasonal RET with reference to weighing micro-lysimeter thod. Results of the statistical analysis showed that DAP-crop curves were more accurate than -crop curves. The ranking order of accuracy of all empirical methods according to statistical lysis on crop curves were thus J-H>PEN>B-C>HG.

With these results in mind, the following recommendations are made:

The drainage-type microlysimeters should be used only if sufficient number of them are installed to ensure that the mean of the desired measurement is representative of the reference ET value.

) For the purpose of regional comparison, further study should be carried out in other part of the country especially in research centres and Universities.

) Further work using the Blaney-Morin Nigeria (BMN) model and some other empirical methods should be carried out.

) Further study using large scale and a more precise weighing lysimeter should be carried out to verify these results.

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APPENDICES

Appendix 1:Soil Chemical Composition of the Experimental Site

Field point	Depth (cm)	Chemical composition(Meg/100g of soil)				
		PH	Organic Matter (%)	Nitrogen	phosphorus	Potassium
C1,1	1-10	6.092	2.22	0.11	1.40	0.22
C1,2	10-20	6.54	2.38	0.12	1.40	0.03
C3,1	0-20	6.59	2.37	0.12	0.70	0.16
C5,1	0-10	6.54	2.23	0.11	0.56	0.05
C5,2	10-20	7.54	3.95	0.20	4.20	0.47
G1,1	0-10	7.58	1.76	0.09	1.75	0.05
G1,2	10-20	7.18	3.19	0.16	2.8	0.18
G4,1	0-10	6.73	2.12	0.11	1.40	0.09
G4,2	10-20	6.94	3.01	0.10	2.10	0.05
G5,1	0-20	6.56	2.30	0.12	1.75	0.03
G5,1	0-10	6.96	3.05	0.15	0.70	0.27
G5,2	10-20	6.26	3.62	0.18	3.10	0.08

Appendix 2: Mechanical Composition of Farmland

Depth (cm)	Mechanical Composition (%)		
	Sand	Silt	Clay
0-10	37	42	21
10-20	40	42	18
20-30	38	50	12

Appendix 3: Calculation of Surface Area of Lysimeters

Diameter, D = 58 cm = 580 mm ; Height, H = 43 cm = 430 mm

Lysimeter Surface Area, $A = \pi D^2 / 4 = 2.642 \times 10^5 \text{ mm}^2$

Appendix 4 : Calculation of Surface Area of Rain-guage

Diameter, D = 12.5 cm

Rainguage Surface Area, $A = \pi D^2 / 4 = 1.23 \times 10^4 \text{ mm}^2$

Appendix 5: Determination of water Depth

For a given load (i.e. volume of water) the corresponding water depth in the lysimeter is calculated as follows:

Equivalent water depth, d(mm) = water volume mm^3 / Lysimeter Surface Area mm^2