DETERMINATION OF EVAPOTRANSPIRATION RATE FOR TOMA[TO] CROP [ROMA], USING LYSIMETER METHOD AND BLANEY MORIN NIGERIA MODEL.

BY

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BEING A FINAL YEAR PROJECT SUBMITTED TO THE DEPARTMENT OFAGRICULTURAL ENGINEERING IN PARTIAL FULFILMENT FOR THE AWARD OF BACHELOR DEGREE OF ENGINEERING

[B.ENG]

SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA,

NIGER STATE, NIGERIA.

OCTOBER, 2003.

CERTIFICATION

This is to certify that this project work as carried out by Mahamane Alma Ahamadou Toudjani under the supervision of Engr. Dr N. A. Egharevba, has been read and found to meet the requirement for the award of Bachelor Degree of Engineering in the Department of Agricultural Engineering, Federal university of Technology, Minna.

.... 4/12/2003

Engr. Dr. N. A. EGHAREVBA DATE

PROJECT SUPERVISOR

.... 4. 12. 03

Engr. Dr. D. ADGIDZI DATE

HEAD OF DEPARTMENT

.... 28/11/03

EXTERNAL EXAMINER DATE

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ABSTRACT

In this project work a determination of crop evapotranspiration rate for tomatoes using lysimeter and Blaney Morin Nigeria model was carried out in Agricultural Engineering laboratory, Federal University of Technology; Minna within Bosso Campus located in Bosso Local Government, Niger State. A system of indoor outdoors was adopted to conduct this project experimentation, which took a length of five months for the growing season of tomatoes crop. The equipment was set up according to the conditioning procedure. A pot was filled with soil and then saturated with water. The plant was watered throughout the season. A peak daily evapotranspiration rate was experimentally found to be 24.12 mm/day, while 6.48 mm/day was obtained by mathematical computation from Blaney Morin Nigeria (BMN.) model. Also a cumulative evapotranspiration of 1,519 mm/season and 515.04 mm/season was found from the Lysimeter measurement and BMN model respectively. Moreover the irrigation and drainage water quality tests was carried out where the Sodium Absorption Ratio (SAR) of 8.99 and the Exchangeable Sodium Percentage (ESP) of 11.89% were found for the irrigation water, while the values of SAR and ESP was 15.67 and 19.03% for the drainage water respectively. Finally an estimation of crop coefficient (Kc) values was generated from Lysimeter measurement and BMN model given average values of 0.23, 0.7 and 1.6 for vegetative, flowering and fruiting to maturity stages, respectively.

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NOTATIONS

A = AREA

D = DRAINAGE

ESP = EXCHANGEABLE SODIUM PERCENTAGE

ET = EVAPOTRANSPIRATION

ETa = ACTUAL EVAPOTRANSPIRATION

ETc = CROP EVAPOTRANSPIRATION

ET p = POTENTIAL EVAPOTRANSPIRATION

ETr = REFERENCE EVAPOTRANSPIRATION

FC = FIELD CAPACITY

I = IRRIGATION

K = HYDRAULIC CONDUCTIVITY

Kc = CROP COEFFICIENT

MC = MOISTURE CONTENT

OM = ORGANIC MATTER

Rf = RADIATION FACTOR

RH = RELATIVE HUMIDITY

ΔS = CHANGE IN WATER STORAGE

SAR = SODIUM ABSOEPTION RATIO

T = TEMPERATURE

WR = WATER REQUIREMENT

V = VOLUME

Y = YIELD

CHAPTER ONE

INTRODUCTION

With the increase in population, the need for increasing food productivity becomes the major concern of Agricultural Engineers. This could be achieved by means of irrigation, which deals with water supply as well as water distribution in relation to the soil and plants growth.

The supply of water by means of irrigation is a common practice especially in Africa and particularly in arid, semi-arid, and tropical regions and also during dry season where the amount of rainfall intensity cannot satisfy the crops water requirement for effective plants growth.

Tomato is one of the several fruiting vegetable crops that are used in the home as row food or industrially processed food. The high demand of tomato as row materials makes it to be the most important salad crops available throughout the year. That is it is grown annually either in dry season or rainy season.

To achieve the cultivation of tomato throughout the year, there is a great need for determining its evapotranspiration rate for irrigation planning and scheduling and also for the management of available water resources used to irrigate tomatoes. So there is need for accurate and consistent measurement of evapotranspiration rate. This can be obtained by using a lysimeter method and Blaney Morin Nigeria method among the several methods used for this purpose. Hence these two methods have been chose in this project based on their degree of accuracy and consistency.

1.1 SCOPE OF THE PROJECT

In this project, the lysimeter method and Blaney Morin Nigeria Model were used to measure and compute respectively the crop evapotranspiration for tomatoes (Roma). Also the crop coefficient K_C values are estimated from these methods.

1.2 JUSTIFICATION OF THE PROJECT

As the population increases, the pressure survival and the need for additional fruiting vegetable such as tomatoes becomes a necessity. So the all year round cultivation is of vital important in order to achieve self-sustainability in term of salad crop widely used in soup and industries. Thus during the dry spells, an appropriate water management must be planned base on the rate of evapotranspiration and the crop water requirement of this crop.

1.3 OBJECTIVES OF THE PROJECT

i. To determine the daily and peak evapotranspiration rate for tomatoes (Roma), using weighing lysimeter.

ii. To compute the potential and crop evapotranspiration rate for tomatoes, by using the B.M.N. model.

iii. To estimate the crop coefficient and compare it with the F.A.O standard.

1.4 LIMITATION OF THE PROJECT

i. The restricting soil layer will cause a concentration of roots above that layer; this is due to the size of the lysimeter tank.

ii. The conditions within the lysimeter are assumed to match those of the surrounding environment.

iii. The thermal properties of the lysimeter pot are assumed to be the same as the surrounding soil.

iv. Regulations of water supply and some times environment are other limitations.

CHAPTER TWO

LITERATURE REVIEW

Many experimentation had been conducted on the determination of evapotranspiration rate of several crops, by some researchers. Although, with reference to the project area, few studies have been carried out so far on crops evapotranspiration, among such studies Kowa and Faulkner, (1975} Kassam and Kowal (1976}, measured the water requirement of several crops type using a hydraulic weighing lysimeter at Samaru Zaria. Also in a paper presented on evapotranspiration of selected cereals in Niger State at the 21st annual conference of Nigeria Society of Agricultural Engineering, Egharevba and Mohammed (1999) presented the annual water requirements of $2.42x10^3$; $3.214x10^3$; $3.292x10^3$ and $4.002x10^3$ m^3/ha/annum for millet, maize, sorghum and wheat respectively, as computed from modified Penman equation based on reference evapotranspiration (ETr). Recently, experimentation on weighing lysimeter was carried out for the measurement of Amaranthus of consumptive use or crop evapotranspiration (ETc), by George, [2002]; where a peak period consumptive use rate of 7.0mm/day was recorded during the dry season and 6.1mm/day was measured during the rainy season.

Crop Evapotranspiration is determined either by direct measurement or by calculation from crop and climatic data.

2.1 LOCATION OF THE PROJECT AREA

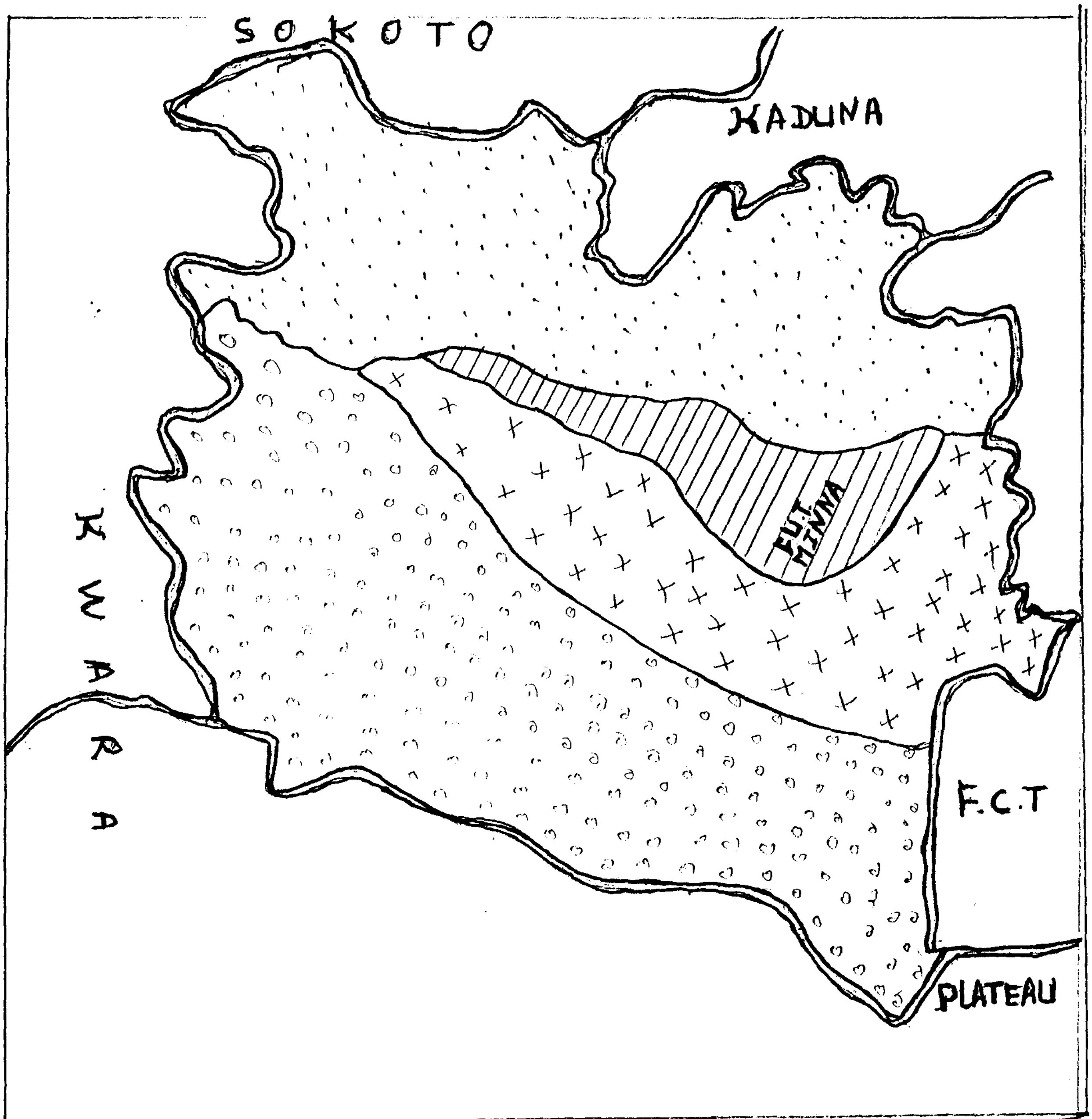
The Case Study of this Project is F.U.T. Minna;.Bosso Campus located in Bosso, a Local Government of Niger State, which is located within longitude 06^0 28'E and latitude $09^0$39'N with an elevation of 848M, It is one of the state in Nigeria that lies in the semi arid zone.

2.1.1 CLIMATE OF THE PROJECT AREA

Nigeria climate is characterized by two distinct seasons: Wet and Dry Seasons, particularly in Niger State the wet season starts in April and ends in October with a mean maximum rainfall record in August. A maximum and minimum main temperatures is recorded in March and August respectively, and a relative air Humidity highest in August but lowest in January.

The figure (fig1} below shows the location of the Project Area: F.U.T; Minna, in the land capability class (series) map of Niger State developed in accordance with the soil conservation service of the U.S Department of Agriculture; The interpretation of the map's legend is as follows:

- Soil Series I: soil has few or no limitations that restrict their uses for plant cultivation.
- Soil Series II: soil has some limitations that reduce the choice of plant or require moderate conservation practices.
- Soil Series III: soil has severe limitations that reduce the choice of plant, requires special conservation practices or both.
- Soil Series IV: soil has very severe limitations that restrict the choice of plants, require very careful management or both.



SCALE: 1,000,000

LEGEND:

	STATE BOUNDARY
	Soil Series I [SSI]
	Soil Series II [SSII]
	Soil series III [SSIII]
	Soil Series IV [SSIV]

FIGURE: 21 = MAP OF NIGER STATE SHOWING THE SOIL TYPES AND THE LOCATION OF THE PROJECT AREA: F.U.T. MX

2.1.2 EVAPOTRANSPIRATION

From the hydrologic cycle, water is transferred to the atmosphere by direct evaporation of solid and liquid, water from the soil and plant surface as well as by transpiration. Since these processes each involve evaporation and are not easily separated, they are combined and called **evapotranspiration**.

Hence Evapo-transpiration denotes the quantity of water transferred by plants during their growth, or retained in the plant tissue, plus the moisture evaporated from the surface of the soil and the vegetation.

The term consumptive use is used to designate the losses due to evapotranspiration and the water that is used by plant for its metabolic activities. Since the water used in the actual metabolic processes is insignificant (less than 1% of ET) the term ***Consumptive use*** is generally taken equivalent to ***Evapotranspiration.*** It thus includes all the water consumed by plants plus the water evaporated from bare land and water surface in the area occupied by the crop.

❖ **POTENTIAL EVAPOTRANSPIRATION**

The concept of potential evapotranspiration PET was suggested by Thornth Waibe (1948) who defined it as the evapotranspiration from a large vegetation covered land surface with an adequate moisture at all times Thus it may be defined as the evapotranspiration (ET) that occurs when the ground is completely covered by actively growing vegetation and where there is no limitation in soil moisture. It may also be considered to be the upper limit of evapotranspiration of a crop in a giving climate.

❖ **REFERENCE CROP EVAPOTRANSPIRATION**

The reference crop evapotranspiration is defined as the potential evapotranspiration (PET) for a specific crop (usually either grace or Alfa Alfa) and set of surrounding conditions.

❖ **SEASONAL CONSUMPTIVE USE**

This is the total amount of water used in evapotranspiration by a cropped area during the entire growing season.

❖ **PEAK PERIOD CONSUMPTIVE USE**

This is the average daily water used rate during a few days of the highest consumptive use of the season. It is the design rate to be used in planning an irrigation system.

2.2 SOIL MOISTURE CONTENT

The moisture content of a sample of a soil is usually defined as the amount of water lost when dried at 105°C, expressed either as a weight of water per unit weight of dry soil or as the volume of water per unit volume of bulk soil.

2.2.1 SOIL SURFACE TENSION

The surface tension is a force pulling inward at a surface of a liquid, tending to make the surface area as small as possible. One of the phenomenons of surface tension in soil is capillarity, the attraction of water into "hair-like" openings or capillary pores.

2.2.2 SOIL MOISTURE TENSION

This is a measure of the tenacity with which water is retrained in the soil and shows the force per unit area that must be exerted to remove water from a soil. The tenacity is measured in terms of the potential energy of water in the soil measured, usually with respect to free water. It is expressed in atmospheres.

2.2.3 SOIL MOISTURE CONSTANT

It has been found experimentally that certain moisture content describe below are of particular significance in agriculture and these are often called soil "moisture constants".

Saturation capacity: When all the pores of the soil are filled with water, the soil is said to be under saturation capacity or maximum water holding capacity.

Field capacity: This is defined as the moisture content after drainage of gravitational water has become very slow and the moisture content has become relatively stable. The field capacity is also defined as the upper limit of available moisture range in soil moisture and plant relations.

Moisture Equivalent: It is defined as the amount of water retained by a sample of initially saturated soil material after being subjected to a centrifugal force of 1000 times that of gravity for a definite period of the time, usually half an hour.

Permanent Wilting Point: This is also known as wilting co-efficient or permanent wilting percentage. It is define as the soil moisture content at which plant can no longer obtain enough moisture to meet transpiration requirement, and remain wilted unless water is added to the soil.

Wilting Range: It is the in soil-moisture content to which plant undergo progressive degrees of permanent or irreversible wilting, from wilting of the oldest leaves to complete wilting of all leaves.

Available Water Or Moisture Holding Capacity: This is the soil moisture between field capacity ands permanent wilting point. It is the moisture available for plant use.

A.W (M.H.C) = FC – PWP..(1.0)

Where: FC= the field capacity

AW= available water: which is equal to the moisture holding

Capacity (MHC)

PWP= the permanent wilting point.

2.2.4 TOMATO

Under the family of annual fruiting vegetable, tomato crops ranks high among the important vegetables of the world and is grown in large quantities in most regions. The tomato apparently originated in South America but may have been first cultivated in Mexico. Spanish explorers took the tomato back to Europe by the middle of sixteenth century, but it was not widely utilized for many years. Even through it was introduced into the United State in eighteenth century, it was not widely accepted as an edible fruit for another hundred years. The reputation of Tomato varies from being considered poisonous to being associated with love, as indicated by the French name "pomme d'amour" or "love apple".

2.2.5 BOTANY

Tomatoes are dedicated plants and cannot stand by themselves (except the brush varieties), and therefore need a stake. The flowers are small and insignificant, and thus do not attract inserts for pollination. The corolla is yellow. Flowers arise in "trusses" (grouped of flowers on short branches), which in turn form a buch of fruits.

2.2.6 CLIMATIC CONDITION

Tomato varieties grown in Temperate and Medirranean climates display daily and seasonal thermoperiodism. Thus, plant growth is better when daily maxima are 10^0C or more above the minima, as long as temperatures do not exceed 30^0C.

When temperatures are at or above 35^0C every day, as they are in the summer/hot season, fruit formation is interrupted because of lack of fertilization, such temperatures being lethal for pollen grains.

Tomatoes are grown almost universally, as there are varieties, which grow outdoors in hot tropical condition, and others can be grown under glass in quite cold climates. They are sun loving, and do best in low rainfalls when they can be irrigated from below.

2.2.7 VARIETIES

There are many tomatoes varieties. Some tomatoes are golden yellow, others red; some are spherical, others elongated; some plants are tall and must be staked, other are short and bushy so that they can stand unsupported.

This project deals only with a Roma variety. This is an elongated fruit tomato, which is derived from the Italian type "San Marzano". The Roma is a medium early maturing variety of tomato. It has determinate plant type and produces an abundance of pear-shaped fruit, weighting about 60g each; sweet, firm and tasty flesh. It has also a tolerance to Verticilum and Fusarium 1 diseases. This type of tomato is widely used for Tomato paste and sauce, because of its meatiness.

2.2.8 CULTIVATION

Plants are first raised in a very seedbed of rich black soil with sand. This soil should be sterilized, and made into a very fine damp tilt. The seed boxes should be kept in the shade, and lightly watered regularly.

Seeds can be mixed with plenty of sand so that when they are scattered on the seedbed, they spread well. The shade must not be too low; otherwise the plants will grow out sideways towards the light. Young seedling, if too close together, may be "pricked out" on to another nursery bed, still under shade about 5cm apart.

The seedlings are transplanted to the farm or pots when they are about 12cm height. They should have a ball of earth attached to their roots, which should be disturbed as little as possible.

Tomato never fail to produce flowers but sometimes the flowers on the first truss fail to open because the plant is growing so fast that they are bypassed and abo'rt.

In particular, poor growing condition and condition that are too dry, will also cause the plant to carry a much-reduced pod-load. So it is important that the roots are kept moist and proper attention has been paid to the nutritional needs of the crops. If this is done and you pick thoroughly and frequently, you should get goods crops and a long picking period.

Tomatoes are particularly sensitive to soil moisture condition at the time the first fruits start to develop. This plant is most responsive to soil moisture condition from the start of fruit set onwards. This differential response is due to the pattern of root growth, because within an adequate soil volume during the early stage of rapid root growth the plant is no very responsive to watering, whereas at the start of fruiting, when the root activity almost ceases the plant becomes very sensitive to water shortage.

Irrigation requirement will vary, depending upon the duration of the crop and the season when grown. So it is essential to schedule irrigation of Tomato to maintain a continuous high soil moisture level in the soil. Irrigation should be scheduled by observing soil moisture level, and not by observation of the crop itself.

2.2.9 CLASS AND AVAILABILITY OF SOIL WATER

Soil water has been classified as hygroscopic, capillary and gravitational. Hygroscopic water is on the surface of the soil grains and is not capable of significant movement by the action of gravity or capillary forces. Capillary water is that parts in excess of the hygroscopic water, which exist in the pore space of the soil and is retained against the force of gravity in a soil that permits unobstructed drainage. Gravitational water which is that part in excess of hygroscopic and capillary water which will readily move out of the soil if favorable drainage is provided. There is no precise boundary or line of demarcation between these three classes of soil water. The proportion of each class depends on the soil texture, structure, organic matter content, temperature, and depth of soil column considered.

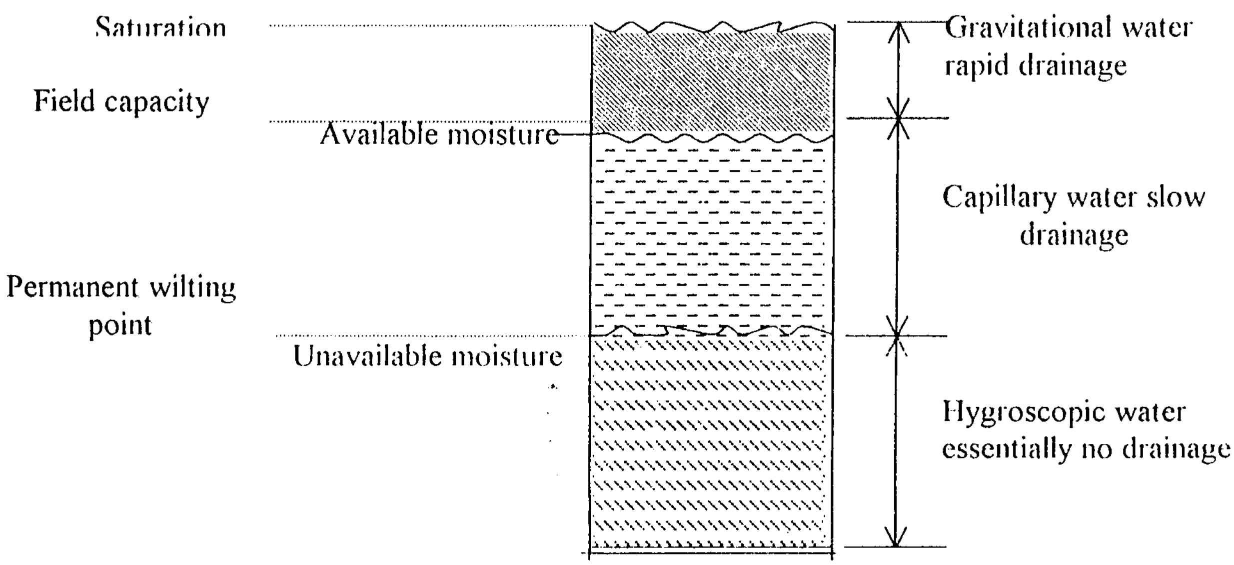


Figure 2.2 Class of soil-water availability to plants and drainage characteristics.

Source: Hansen, Israelsen and Stringham (1979)

2.3 EFFECTIVE ROOT ZONE

Effective root zone is the depth from which the roots of an average mature plant are capable of reducing soil moisture to the extent that it should be replaced by irrigation.

Table 2.1: Effective root zone depth of some common crops.

ROOTING CHARACTERISTICS			
SHALLOW ROOTED	MODERATELY DEEP ROOTED	DEEP ROOTED	VERY DEEP ROOTED
DEPTH OF ROOT ZONE			
60cm	90cm	120cm	180cm
Rice	Wheat	Maize	Sugarcane
Potato	Tobacco	Cotton	Citrus
Cauliflower	Castor	Sorghum	Coffee
Cabbage	Groundnut	Pear millet	Apple
Lettuce	Musk melon	Soybean	Grapevine
Onion	Carrots	Sugar beet	Safflower
	Beans	Tomato	Lucerne
	Chilli		

SOURCE; Gandhi, et al (1970).

2.4 MOISTURE EXTRACTION PATTERN WITHIN ROOT ZONE

The moisture extraction pattern shows the relative amount of moisture extracted from different depths within the crop zone. It may be seen that about 40% of the total moisture used is extracted from the first quarter of the root zone, 30% from the second, 20% from the third and only 10% from the last quarter. As water is extracted from the soil-water reservoir through Evapotranspiration, the surface tension is increased. A 15 atm, plant can no longer extract the water and they will permanently. The soil water content at that time, on a dry-weight basis is defined as the permanent wilting point (PWP) or simply wilting point (WP). Once this is reached, the soil-water reservoir is empty.

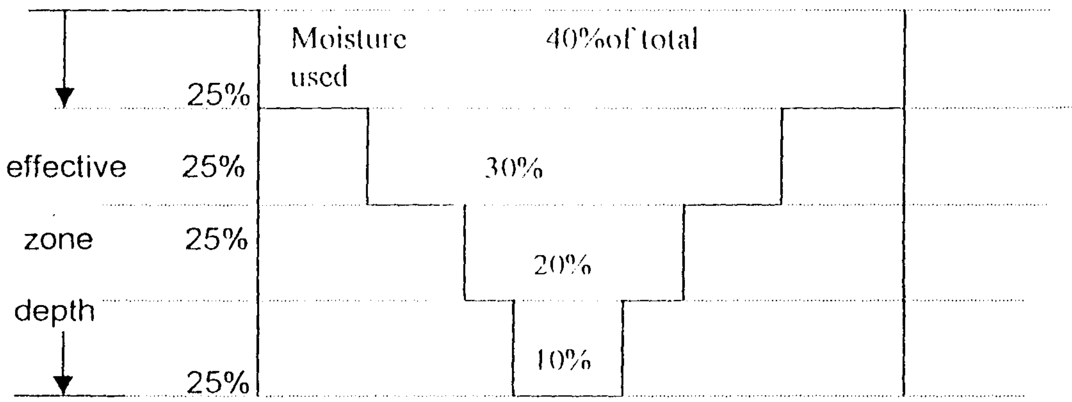


Figure 2.3: Average moisture- extraction pattern of plants growing in a soil without restrictive layers and with adequate supply of soil moisture.

Source: Michael (1998)

2.5 CROP GROWTH AS A FUNCTION OF SOIL MOISTURE

The rate of crop growth depends on the moisture content of soil. There is an optimum growth rate condition in which the soil water content lies at a point somewhere between F.C. and P.W.P (see figure 2.3). However this point varies for different crops and for different stage of growth and so, it is not easy to adjust the irrigation intervals so that there is optimum crop growth.

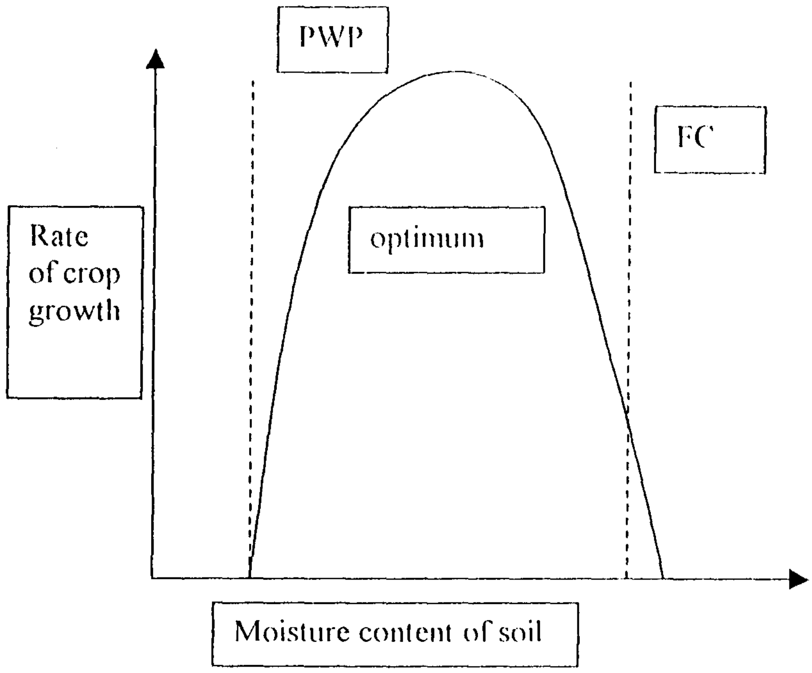


Figure 2.4: Rate of crop growth as a function of soil moisture.

Adapted from Egharevba (2002)

2.6 MEASUREMENT AND ESTIMATION OF EVAPO-TRANSPIRATION

Evapotranspiration can be measured by direct measurement and estimated by Empirical methods and Micro-meteorological methods (climatological data).

2.6.1 DIRECT MEASUREMENT OF EVAPOTRANSPIRATION

The principal methods for direct measurement of evapotranspiration are:

i) Field Experimental plot method:

These are measurements of water supply to the field and changes in soil moisture contents of field plots which are sometimes more dependable for computing seasonal water requirement of crops than measurements with small tanks not free from limitations. The seasonal water requirement (**WR**) is computed using the following relationship.

$$WR = IR + ER + \sum_{i=1}^{n} \frac{M_{bi} - M_{ei}}{100} \times A_i \times D_i \quad \text{.........................(2.1)}$$

Where WR = the seasonal water requirement (mm)

IR = Total irrigation water applied (mm)

ER = seasonal effective rainfall (mm)

M_{bi} = Moisture percentage at the beginning of the season in the i^{th} layer of the soil.

M_{ei} = Moisture percentage of the end of the season in the i^{th} layer

D_i = depth of the i^{th} layer the soil within the root zone (mm)

n = number of soil layer in the root zone D.

ii) Soil Moisture Depletion Studies:

The method is employed to determine the consumptive use of the irrigated field crops grown on fairly uniform soils when the depth to the ground water is such that it will not influence the soil moisture fluctuation within zone. It involves the root measurement of the soil moisture from various depths at a number of times throughout the growth period. Consumptive use (CU), is calculated from the following formula.

$$U = \sum_{i=1}^{n} \frac{M_{1i} - M_{2i}}{100} \times A_i \times D_i \text{..........................(2.2)}$$

Where: U = water use from the root zone from successive sampling period or within one Irrigation cycle, (mm)

n = number of soil layers sampled in the root zone depth

M_{1i} = soil moisture percentage of the first sampling in the i^{th} layer.

M_{2i} =soil moisture percentage at the time of the second sampling in the i^{th} layer.

A_i = apparent specific gravity of the i^{th} layer of the soil.

D_i = depth of the i^{th} layer of the soil, (mm).

Therefore the seasonal consumptive use (CU) is given by:

$$CU = \sum U \text{..(2.3)}$$

Where: CU = seasonal consumptive use

U = is the consumptive use values of each sampling interval.

Limitation of soil moisture depletion methods (studies):

1) Water depletion sampling cannot be use over periods much shorter than about one week and usually is useful only over long periods.
2) Because of the drainage serious error maybe result and there is no way to insure that drainage will be negligible particularly when frequent and/or heavy precipitation may occur.

iii) Evapotranspiration Chambers:

This method uses an above ground chamber to enclose the vegetable area. The chamber transparent to radiation and prevent water exchange with the atmosphere. Though useful for many studies, the space inside the chamber is not representative of conditions out side the chamber, since radiation exchange and turbulent transfer within the enclosure chamber are altered. Reicosky and Peters (1977) have described a portable chamber for a rapid measurement of ET on field plots.

iv) Water Balance Method:

The field water balance method, also called the inflow-outflow method is based on the conservation of mass principles and is a suitable for large area over long periods. These methods necessitated adequate measurement of all factors. Evapotranspiration (ET) is calculated use the following equation called water balance equation:

$$ET = P_n + I - R_o - \Delta D_e - D_r \quad (2.4)$$

In Which: ET = evapotranspiration (mm)

P_n = precipitation (mm)

I = irrigation (mm)

R_0 = net surface run off (mm)

ΔD_e = the change in soil water storage or soil moisture (mm)

D_r = the drainage (mm)

Equation one (1) is obtain base on the conservation of mass principle which states that:

$\Delta S = D_{rz}(\theta_f - \theta_i)$ = Inflow – outflow..(2.5)

Where, Inflow , outflow = total flow into and outflow of the control volume.

ΔS = change in soil moisture within the control volume

D_{rz} = depth of the root zone

θ_f, θ_i = soil moisture contents by volume at end (final) and beginning (initial).

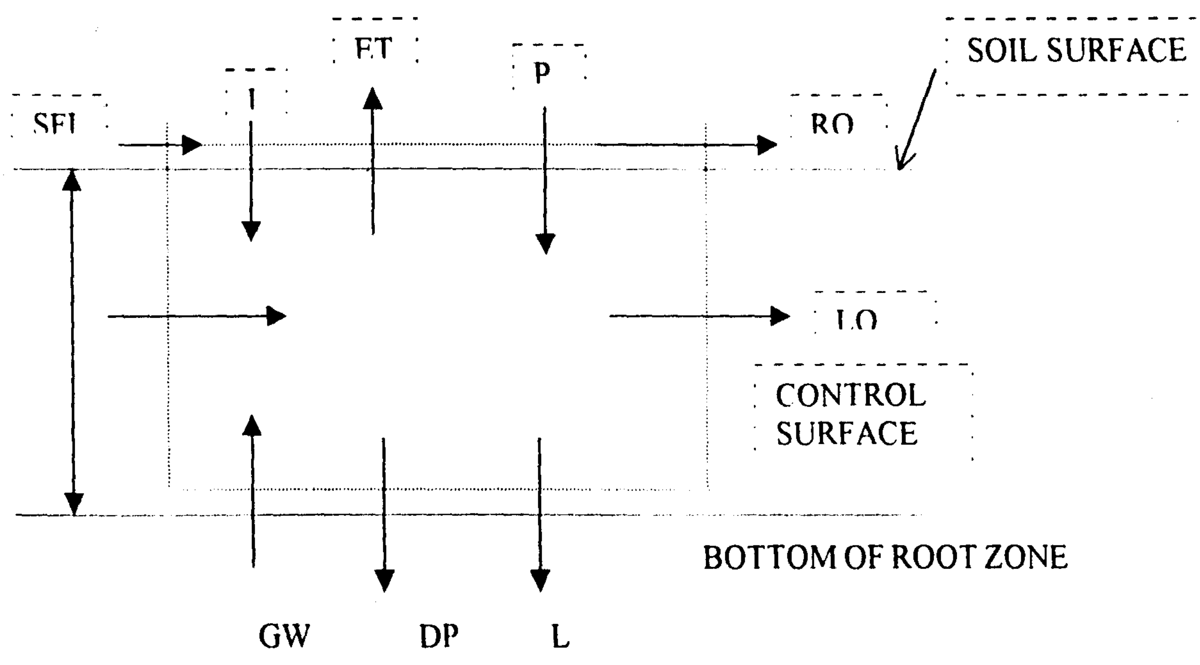


Figure 2.5: Definition sketch of water balance equation

From figure above:

Inflow = I + P + SFI + LI + GW..(2.6)

Outflow = ET + RO + LO + L + DP..(2.7)

Substituting these two equation into equation five gives:

$$\Delta S = Drz\ (\theta_f - \theta_i) = I + P + SFI + LI + GW - [\ ET + RO + LO + L + DP\ ] \ldots (2.8)$$

Where ET= Evapotranspiration, (cm, in);

I = Irrigation, (cm, in);

P = Precipitation, (cm, in);

SFI = Surface flow into the control volume (cm, in);

LI = Subsurface lateral flow into the control volume (cm, in);

GW = Ground water seepage into the control volume, (cm, in);

RO = Surface flow out of the control volume, (cm, in);

LO = Subsurface lateral flow out of the control volume, (cm, in);

L = Leaching requirement, (cm, in);

DP = Deep percolation, (cm, in).

v) Lysimeter Method:

Lysimeter studies involve the growing of crops in large containers (lysimeter) and measuring their water loss and gains. Lysimeters, though provide the means of precise and direct measurements of the amount of water supplied to and lost by the crops. The soil and crops in the lysimeter should be close to the natural conditions.

Lysimeter hydrological isolated soil within them from surroundings soil and make it possible to eliminate SFI, LI and LO, while GW, RO, and DP are either eliminated or measured. ET can be calculated when I, P, D, θ_i and θ_f have been measured. The reliability of ET data collected with lysimeter depends on how well conditions within the lysimeter (i.e., soil structure and density, drainage characteristics, temperature, and density, height, etc... of the crop) match conditions surrounding the lysimeter. Lysimeters must be large enough to minimize boundary effects and to avoid restricting root development. Mainly there are two types of lysimeters that differ in the way in which ΔS is determined: **Weighing Lysimeter** and **Non Weighing Lysimeters:**

- **Weighing Lysimeters:** These are constructed so that ΔS(change in soil water storage)is determined by weighing. Weighing lysimeters have a second tank that retains surrounding soil so that the inside container is free for weighing. They also usually have a means for removing and measuring DP and L. From irrigation point of view, weighing lysimeters are set up to enable the operator to measure the water balances: water added, water retained by the soil, and the water lost through all sources-evaporation, transpiration and deep percolation. These measurements involves weighing which may be made with scales or by floating the lysimeter in water on a suitable heavy liquid, in which case the change in liquid displacement is computed against water loss from the tank. The technique yields a measurement of total water loss and is useful as an indicator of field water loss, provided suitable precautions are taken. The tank must be permanently buried in the ground and surrounded by a large area of crop of the same height, if the readings made are to bear relation to losses from the crop in the field. The water table is maintained at a specific depth in the tank. Water is applied in measured amounts to the lysimeter, as irrigation is applied to the surrounding cropped area. The overflow and deep percolation, if any, are measured. The water received either from the reservoir or precipitation excluding the outflow constitutes the water used by the crop.

Weighing lysimeters differ not only in the mode of weighing but also in features of construction that affect accuracy. The most common type employs mechanical balances to measure the weight loss.

Because non-weighing lysimeter cannot provide short estimates that are needed for many studies, several types of weighing lysimeters have been developed. These are:

- The large Coshocton weighing lysimeters that are the earliest examples in 1958 developed by Harrold and Dreibelbis as quoted by George (2002)
- The Davies California lysimeter developed in 1960 by Pruitt and Angus, which is an excellent example of a large weighing lysimeter (George, 2002). In 1961, they found that the soil in the lysimeter was unrepresentative at the wilting percentage with a perennial ryegrass (Lolium perenne) cover.
- The continuous weighing lysimeters such as:

- Csiro unit developed in 1963 by Mcllory and Agus (George, 2002)
- The Tempe, Arizonal unit developed in1962 by Van Bavel and Meyers.

- Hydraulic weighing lysimeter: They are basically of two types:

- Floating lysimeter: Two floating lysimeter have been constructed by Russian for weighing large monoliths, one by Federon in1954 and the other in 1952 by Popov (George, 2002)
- A very simple hydraulic load lysimeter originated in Hawai with the separate work of Miller and Ekern in 1958 placed water filled, inflammable air mattress under soil and read the pressure with a water manometer (George 2002). In 1958, Ekem constructed the first workable hydraulic load cell lysimeter by supporting a 15m by1.5m square container 0.45m deep on two autobile inner tubes, partially inflated with water. (George, 2002)

- Monolithic lysimeters, constructed by easing a block of soil in situ, have been proposed to insure that the water distribution the lysimeter is representative. This type of lysimeter appears desirable particularly for well aggregated. Fine textured soil.

- **Non Weighing Lysimeter**

In non weighing lysimeter, there is no weighing device for measuring change in soil moisture; so various techniques such as Neutron scattering, Gravimetric sampling, Electrical resistance, Soil matric potential etc are used to determine ΔS.

Non weighing lysimeters don't have the capability of having a means for removing and measuring Dp and L, and a second tank that retains surrounding soil so that the inside container is free for weighing as in the case of weighing lysimeter.

Non weighing lysimeter currently providing valuable data range in sizes from large area, deep, monolith lysimeters at Coshocton, Ohio USA to the small area shallow lysimeter constructed from oil drums,(George, 2002).

The Coshocton lysimeters are used for ET_a and the oil-drum type. Similarly, the water table Lysimeter in 1950 has been widely employed for ET_p measurement; the water required to maintain the water table level at a given depth is metered to give ET_p.

- **Lysimeter Area** Since the surface dimension of the lysimeter are dictated largely by the structure of the vegetation and also by the construction at the wall, the lysimeter area should be large compared to the uncropped area at the border (walls and air gap between the walls). This is necessary not only because this area contains no plants, but also because the walls and the air gap have different thermal and water properties than the soil and will affect the heat exchange. Thin-wall contains made either from steel or plastic fibber glass is preferable to concrete to keep the wall gape thickness minimal.

❖ **Lysimeter Thermal Properties**

The lysimeter container and soil may have different thermal properties than the surrounding soil. If the water distribution in the lysimeter differs from that outside, the heat transfer and storage will be affected. The surface layer (25 to 40m) is of greatest importance where hourly measurement is made. Through the seasonal soil heat flux is affected by much deeper layers, if the lysimeter is shallow (even though water control suction is used), discontinuity in thermal properties at the tank bottom can cause error in weekly or monthly measurements and temperature regulation at the bottom match the surrounds may be necessary for high accuracy. Thermal mismatch error decreases when the lysimeter is covered with vegetation because the soil heat balance is decreased.

Relative error in daily measurements is less than in hourly measurement. King et al (1958) found that with sparse alfalfa cover (following cutting), the ET from a floating lysimeter given by energy balance measurement was much less for daylight hours when abundant foliage was present.

The thermal representative of the lysimeter also influences the thermal properties of the system; this can be determined by measuring the soil heat flux inside and outside the lysimeter and also by comparing the ratio of lysimeter ET to that given by micrometeorological methods where applicable.

❖ **Lysimeter Depth And Water Control**

If the lysimeter is to measure ET_a, several precautions are necessary to ensure that the root environment of the lysimeter is representative of the surrounding soil. Water distribution is the most important factor since it affects the water availability to the plants, soil aeration and the thermal regime (Thermal effect).

The effect of the lysimeter on the water regime as illustrated by Van Bavel's (1961) represents the initial water condition following rainfall or irrigation. At that time a zero plane is present at the bottom and thereby the moisture tension as well as moisture content are different from those in the surrounding soil (a rare exception would be an impervious layer or coarse layer at the same depth as the lysimeter bottom, Tanner, 1960).These two effects, firstly, more water may be available for evapotranspiration during a prolonged dry spell. Secondly, the development of the root system of crops grown in the lysimeter may differ from that in the surrounding area.

Because the surrounding soil and that inside the lysimeter must be watered in excess of ET, lysimeter must be deep enough (or have suction control) that a good root with adequate aeration develops.

❖ **Lysimeter Management** The lysimeter must be sited in identical surroundings and with representative fetch. Nearby obstructions or non-evaporating surface, including balance access structure and recording instruments, paths leading to the lysimeter, roads and exposed roofs of underground shelters should be avoided. The lysimeter and the surrounds should be planted, fertilized, watered, and otherwise managed in the same manner.

Water management should be planned to avoid unrepresentative salt accumulation, which can occur if the lysimeters drainage is re-circulated with the lysimeter irrigation water

Condensation and evaporation on walls of weighing lysimeters can cause errors .In 1961, summer and Ilroy found that the error due to variable condensation was intolerable when the gap between the lysimeter retaining tank and container was sealed but was acceptable when the gap was left open for vapor exchange to the atmosphere. Dehumidifying the air surrounding the tank is inconvenient but may prove necessary to eliminate condensation error.

2.6.2 INDIRECT MEASUREMENT OF EVAPOTRANSPIRATION

For indirect measurement of evapotranspiration, several theoretical and empirical equations relating climatological measurement were developed for computing crop evapotranspiration. These equations are used to estimate ET for crop and location where measured ET data are not available.

Basically all methods for computing crop ET involve the following equation:

$$ET = K_c * ET_0 \qquad (2.9)$$

Where, ET = evapotranspiration for a specific crop;

K_c = crop coefficient;

ET_0 = potential ET or reference crop ET

ET_0 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. Doorenbos and Pruit (1977) define reference crop ET as the "ET from an extensive surface of 8 to 15cm (3 to 6 ins) tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water. While Wright (1981) define it as being " equal to daily alfalfa ET when the crop occupies an extensive surface, is actively growing, standing erect and at least 20cm (in) tall, and is well watered so that soil water availability does not limit ET".

Reference crop ET is preferred over pOotential ET, since potential ET can varies 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.

Many methods with differing data requirement and levels of sophistication have been developed for computing ET_0. Some of these methods require daily relative humidity, solar radiation, wind and air temperature data, while others need only mean monthly temperature. Some are physically based data while others where determined empirically. These methods includes:

i. **Aerodynamic Methods:** In the aerodynamic methods vapor flux is proportional to mean wind speed and the vapor pressure differences between the evaporating surface and the surrounding air.

The DALTON equation is one of the earliest aerodynamic equations for estimating evaporation from a water surface. This equation is:

$$Eto= (es-e)f(u) \quad \text{.................................(2.10)}$$

Where: es= vapor pressure at the plant surface.(within the boundary layer surrounding the leaves);

e= vapor pressures at some height above the plant

f(u)=function of the horizontal wind velocity.

But a more common aerodynamic method of estimating ET is the one developed by Von Karman. This equation is:

$$ET_0 \alpha \frac{K^2(\overline{U_2}-\overline{U_1})(\rho V_1-\rho V_2)}{\ln(Z_1)(Z_2)^2} \quad \text{.....................................(2.11)}$$

Where k = Von Karman constant;

$\overline{U_1};\overline{U_2}$ = Mean wind velocity at heights Z_1 and Z_2;

$\rho V1;\rho V_2$= mean density of water vapor at heights Z_1 and Z_2.

ii. **Energy Balance Methods:** When a vapor pressure gradient exists and water readily available, ET is controlled by the availability of energy for vaporizing water. Hence the energy balance equation is as followed where the energy available for ET can be computed:

$$ET = Q_n - AD - S - A - C - P$$

Where Q_n= net radiation

ET= evapotranspiration

AD= advection

S= heat flux to the soil

A= heat flux to the air

C= heat storage in crop

P= photosynthesis

iii.**Combination Method** (Penman Method) In 1948, Penman combined the aerodynamic and energy budget methods to obtain an equation for computing ET. Hence the combination equations have the form:

$$ET_p = \frac{\Delta Q_m + yE_a}{\Delta + y}$$
$$\Delta = \frac{4098 e_{sa}}{(T_a + 273.3)^2}$$
$$e_{sa} = \exp\left(\frac{19.08T_a + 429.4}{T_a + 237.3}\right) \quad \text{.................................(2.13)}$$
$$y = \frac{1615 P_a}{2.48(10)^6 - 213(10)^3 T_a}$$

$P_a = 1013 - 0.1152h + 5.44(10)^{-6}h^2$

Δ= slop of the saturation vapor pressure versus temperature curve at air temperature Ta (mbar/ ^{0}C)

Qn= net radiation (mm/day);

γ= psychometric constant (mbar/ ^{0}C);

Ea= aerodynamic term = $f(e_{sa}, e_a, u_1)$(mm/ day);

e_{sa}= saturation vapor pressure of the air (mbar);

Pa= air pressure(mbar);

h= elevation above mean sea level (m).

A modification of this method, has further been proposed by Doorembos and Pruit in 1975 for estimating fairly accurately the reference crop et, which has further defined by Weis (1983). The formula is given by:

ETo= c[WRn + (1-W).F(u)(e_a-e_d)].................... (2.14)

Where: ETo= reference evapotranspiration (mm/day)

W= temperature related weighing factor.

Rn= net radiation in equivalent (mm/day)

F(u)= wind relate function

e_a= saturation vapor pressure in mbar at the mean air temperature (in mbar)

e_d= mean actual vapor pressure of the air (mbar)

c= adjustment factor to compensate for the effect of day and night weather condition.

2.6.3 EMPIRICAL METHODS:

Many simpler methods of estimating ET based on one or more of the basic parameters controlling ET have been developed. These methods are more convenient to use but are not regarded as being as accurate as the Penman-type equations for periods of less than 5 days. Empirical methods are used when all the data needed for the Penman-type are not available. These includes:

a) **Jensen-Haise Method:** It is based on the energy balance equation. Climatic data needed for this method include solar radiation; mean daily temperature, the long-term mean maximum and minimum temperatures for the month of highest mean air temperature. The elevation above sea level of the location being considered is also needed. The basic Jensen-Haise equation is:

$$ETo = Ct\ (T - Tx)\ R_S \qquad (2.15)$$

Where: Ct= air temperature coefficient for the location being considered
T= mean daily temperature

Tx= constant for the location being considered

Rs= total solar radiation for the period in inches or mm

b) **Pan Evaporation:** There are many types of evaporation Pans in use such as class A type pan used at most U.S weather station and the Colorado Sunken Pan which is sometimes preferred for crop water requirements studies, since it gives a better direct prediction of potential ET of grass than class A pans. Also ten-gallon washtubs have been successfully used as evaporation pan (Westesen and Hanson, 1981).

Reference crop evapotranspiration, ETo is related to pan evaporation Ep, by the following:

$$ETo = KpEp \qquad (2.16).$$

Where: Kp is a pan coefficient that accounts for differences in pan type and conditions up wind and for dissimilarities between plants and evaporation pans.

c) **Blaney-Criddle Approach:** One of the most used temperature based method of estimating evapotranspiration is the Blaney - Cridle equation as modified by the soil conservation services (SCS). The SCS-modified Blaney-criddle equation is as follow:

$$ET = K_{scs} K_T NP\left(\frac{\overline{T}}{K_1} + K_2\right) \qquad (2.17)$$

$$K_t = K_3 \overline{T} + K_4 \qquad (2.17a)$$

Where, ET = evapotranspiration for specific crop, mm;

K_1;K_2;K_3;K_4 = constants dependent on the units of T and ET_0 ;

K_{scs} = crop coefficient;

N = Number of days in the time period (N should not be less than 10 days or longer than 1 month);

P = Mean daily percentage of annual day-time hours for the time period;

$\overline{T}$ = Average daily temperature during the time period (^{0}C; ^{0}F)

2.6.4 BLANEY MORIN NIGERIA METHOD

In 1984, Duru.. Observed that the Blaney- Criddle model was not suitable for Nigeria because of its sole dependence on temperature as variable and since the Blaney Morin Model includes relative humidity, which is a parameter that varies over a wide range in Nigeria, both in time and in space. He found out that the later model could be applied in Nigeria given an explicit form with locally determined empirical constant h and m. He also evaluated these constant with measured temperature (T); relative humidy (R) and open water evaporation was measured with class A pans (E class A).

According to Duru;

ETp = 0.7 E class A = P(0.45T+8)(520-$R^{1..31}$)/100

i.e.

$$ET_p = 0.7classA = \frac{P(0.45T+8)(520-R^{1\ 31})}{100}$$

$$ET_p = \frac{P(0.45+8)(520-R^{1\ 31})}{100} \qquad \text{.......................................(2.18)}$$

Preliminary trials showed that the above equation predicted ETp with satisfactory results. However it was observed that ETp values for the mouth of November to January, predicted with that equation were consistently higher than the corresponding measured open-water evaporation.

Further investigation revealed this anomaly to be ascribable to percentage of daytime hours as used in Blaney-Moring formula. Therefore he replaced the ratio of sunshine hours with a radiation ratio and resulting equation becomes:

ETp = rf×(0.455T+9)(520-$R^{1.31}$)/100............. ....(2.19)

Where, ETp = potential evapotranspiration, in mm per day rf = radiation ratio or ratio of maximum possible radiation to the annual maximum

T = Summation of the mean daily temperature in °C over a month divided by the number of days in that month

R = summation of daily means relative humidity at 09^h00^{ml} GMT and 15^h00^m over a month and dividing by the number of days in that month.

2.6.5 EMPIRICAL FORMULAS CALIBRATION

The empirical methods are most reliable when calibrated for a given vegetation in a given local test and tested for the period over which estimated ETp averages are most reliable, because ETp depends on the local meteorological conditions, field size, and surroundings, and to a lesser extent upon vegetation. Particularly lysimeters are useful in calibrating empirical methods.

2.6.6 RATIO OF ACTUAL TO POTENTIAL EVAPOTRANSPIRATIONS

Several methods have been proposed for relating available soil water to ETa / ETp so that ETa can be estimated form empirical estimate of ETp.

Reason for which, Butter and Prescott (1955) established an equation for monthly measurement.

The equation is as follows

$$\frac{d\left(\frac{ETa}{ET_p}\right)}{dw} = C\left[2.4 - \left(\frac{ET_a}{ET_p}\right)\right] \qquad (2.20)$$

Where w = available water (rainfall and storage in cm)

C = crop constant

ETa and ETp = actual evapotranspiration and potential evapotranspiration respectively

2.6.7 ADVANTAGE OF EMPIRICAL FORMULA

i. They are convenient and more economical to use,
ii. Adequate accuracy can be obtained using simple empirical equation that requires less time and effort to apply.

2.6.8 DISADVANTAGE OF EMPIRICAL FORMULA

i. Most empirical formulas are not too accurate for estimating a short period ET,
ii. All empirical formulas require meteorological data which may not be readily available;
iii. They require calibration for an accurate values of evapotranspiration,
iv. Their validity is restricted to condition similar to those under which they were developed.

CHAPTER THREE

MATERIALS AND METHODOLOGY

3.1 MATERIALS:

This include the following.

Hydraulic Weighing Lysimeter:[FEL 6 Issue 3 1993]

This has following dimensions: height = 1.66m; width = 0.48m;depth = 0.43m and the polls diameter = 0.3m.

This type of lysimeter gives a simple and usually appealing method of measuring water content variations within a plant/soil system. Water weight gains and loses can be directly to related to a visual manometer scale attached to the equipment.

Vacuum Pump: This is an instrument used for extracting the air from the weighing; system.

Soil Sample: The soil used for this experiment is a sandy loamy soil(fine particle),it has a pH of 5.7 ,the % organic matter of 1.07 and the moisture content of 18.9%. It has also a hydraulic conductivity of 2.03 cm/hr, bulk density of 1.7 g / cm^3 and porosity of 29%.

The water used for this project is a borehole water (Cafeteria)

The tomato seed is Roma type. This is an early maturing among the various tomato seeds. N.P.K is used as fertilizer. **The pH meter** is used for determining the pH. **Flame Analyzer** is used for determining the Na^+ and K^+ content of the water.

The E.D.T.A. titration of Ca and Mg is used for determination of calcium and magnesium content of the water. **A Sieve Shaker** is used for particle size determination. The soil and the yield are measure by using **electronic weighing balance.**

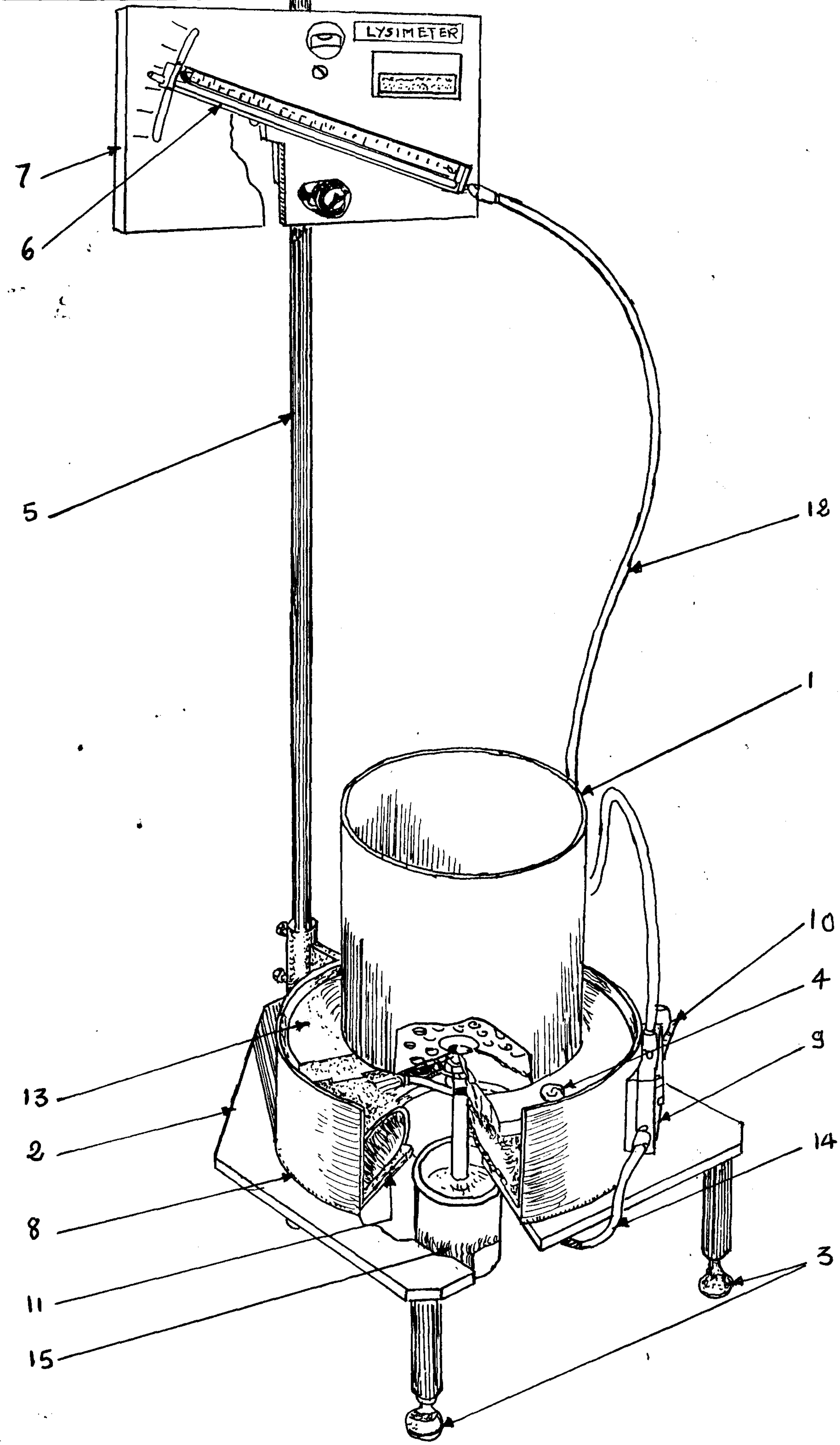


Figure 3.1: Sketch of a weighing lysimeter.

LEGEND OF FIGURE 3.1

1- Pot
2- Base Frame
3- Adjustable Feet [x 3]
4- Centre Bubble
5- Vertical Post
6- Open Ended Manometer
7- Blackboard
8- Low Walled Cylinder
9- Connection Point
10- Bleed Point
11- Rubber Tube
12- Flexible Tube
13- Circular Floating Plate
14- Drainage Tube
15- Graduated Bottle

3.2 LYSIMETER METHOD

Equipment setup: The lysimeter was setup for normal laboratory use as describe in the commissioning section. A pot was filled with soil to same desired bulk density say 15 Kg. The pot was then saturated and allowed to drain for two days to achieve field capacity. The manometer headboard was adjusted so that meniscus in the water column equilibrates toward the top quarter of the scale. The manometer was scaled to the desired angle 15°. The drainage bobble was emptied and initial manometer reading was recorded and noted before every irrigation. Considering the agronomic botany of tomato, a volume of water was added at each irrigation by observing the moisture level of the soil, which could be maintained at a conducive level for plant growth in the specific case of tomato.

The irrigation depth (mm); the drainage (mm) and the change in soil moisture were recorded during each irrigation. (See Table 4.7). Tilling of the topsoil was also carried out by time to provide a conducive medium for plant growth, by facilitating aeration and easy water infiltration. Time by time some dimensional characteristics of the tomatoes stems were recorded (see Table 4.8). Fertilizer was also added time by time to provide nutrients indispensable for plant growth 0.002g/ 0.071m^2 based on 200g/ha.

Method: At each irrigation day, before watering the plant the first reading was read from the Lysimeter and then recorded. Also at the same time the drainage water of the previous irrigation was measured and recorded. Then the water was applied and the final reading was read and recorded from the manometer. The difference between the first reading and the final reading at each irrigation day represent the depth of the irrigation.

The method used for this project was based on water balance equation given as follows:

$$ET = P_n + I - R_0 - \Delta D_0 - D_r \qquad (3.1)$$

Where; ET = evapotranspiration, mm/day

P_n = precipitation, mm

I = irrigation depth, mm

R_0 = net runoff mm

ΔD_0 = the change in soil water storage, mm

D_r = drainage, mm

But runoff is normally contained within the lysimeter and can therefore be neglected.

3.3 BLANEY-MORIN NIGERIA METHOD MODEL

Computation of crop evapotranspiration for B. M. N model, involved the following equations:

$$ET_P = \frac{rf(0.45T + 8)(520 - R^{1.31})}{100} \quad \text{.......................................(3.2)}$$

Where ETp = potential evapotranspiration, in mm per day

rf = radiation ratio or ratio of maximum possible radiation to the annual maximum

T = Summation of the mean daily temperature in °C over a month divided by the number of days in that month

R = summation of daily means relative humidity at 09^h00^m GMT over a month and dividing by the number of days in that month.

ETc = Kc × ETp..(3.3)

Where ETc = Crop evapotranspiration

Kc = crop coefficient

ETp = potential evapotranspiration

A procedure for determining Kc values for growth stage one (vegetative stage); for annual crops (as in this case of tomatoes); it is estimated from the following equation:

$$Kc = a \times ET_0^{b} \qquad (3.4)$$

Where Kc = crop coefficient for growth stage one

ETp = average daily reference (potential) crop ET during growth stage one

a = coefficient

b = exponent

a and b are read from TableX 2.

3.4 IRRIGATION WATER QUALITY TEST

The salinization / or sodification hazard posed by irrigation water can be readily predicted on the basis of the amount and types of salt contained in water.

pH determination: standardize the pH meter with pH buffer 7; 4 and 9. Then read the sample pH.

Sodium and potassium determination: Prepare Na^{+} (sodium) and K^{+} (potassium) standard in ppm (part per million) and use these to standardize the flame photometer. Then read the percentage emission of the sample and trace the concentration from the standard curve.

Calcium and magnesium determination: First use EDTA method with Erichrome black T as indicator to obtain the calcium (Ca^{2+}) and magnesium (Mg^{2+}) as a mixture. Then use EDTA method with Calcon as indicator to obtain Ca^{2+} concentration. Therefore to obtain the Mg^{2+} concentration subtracts Ca^{2+} concentration from the mixture of Ca^{2+} and Mg^{2+}.

Sodium Absorption Ratio (SAR) determination:

$$SAR = \frac{Na^{+}}{\sqrt{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)}} \quad \text{...(3.5)}$$

Where Na^{+}, Ca^{2+} and Mg^{2+} represent the concentration of these elements in the irrigation ($MeqL^{-1}$),

Exchangeable Sodium Percentage (ESP) computation:

$$ESP = \frac{100(0.015SAR)}{1 + 0.015SAR} \quad \text{...(3.6)}$$

3.5 SOIL ANALYSIS

- **Sieve analysis**:

A sample of 500 g was collected and then pound to aid in separating the soil particles. The pounded soil of 500 g was then put into the upper sieve and then on the set of 11 sieves was placed on the sieve shaker. But before this the empty sieves were weighed. Having putting the set of sieves shaker then the later was set on and start shaking the soil. After few minutes of shaking the sieves was switched off and then weigh the weight of sieves plus the soil retained in each sieve one after another. Results see Table 4.1.a

- **Soil moisture content determination**

A sample of soil was collected in a can. The empty can was first weighed then the soil wetted and the weight of can plus wetted soil was measured. This was then subjected to oven drying in an oven set at 105 ^{0}C. After 24 hour this was removed from the oven and weighed to obtain the weight of can plus dry soil. The moisture content is determined using the following equation:

$$MC = \frac{W_w - W_d}{W_d} \times 100 \quad (3.7)$$

Where MC = moisture content (%)

W_w = weight of wet soil

W_d = weight of dry soil.

Other soil properties:

Soil properties such as soil pH; Percentage organic matter (% OM); soil hydraulic conductivity (K); bulk density and porosity were also determined through laboratory test. The results of these tests are presented in Table 4.1.b....

CHAPTER FOUR

RESULTS AND DISCUSSION OF RESULTS

4.1 RESULTS

4.1.1 RESULTS FROM LYSIMETER

The Evapotranspiration rate is computed from water balance equation and the results of crop evapotranspiration of Tomatoes (ROMA) in mm/day as measured with lysimeter is presented in appendix Z.Table 4.7.

Also the cumulative E.T.C. at five days interval for tomatoes is presented in Table 4.4.

At each irrigation day, the crop evapotranspiration is calculated as follows using the water balance equation:

$$E.T = I + P_n - R_o - \Delta D_o - D_r \qquad (4.1)$$

But the experiment didn't take into account the precipitation (P_n) and with the lysimeter R_o is neglected so:

$$E.T = I - \Delta D_o - D_r \qquad (4.2)$$

Where; E.T= evapotranspiration, mm/day

I = Irrigation depth (reading after irrigation – reading before irrigation), mm

ΔD_o = Change in soil water storage (mm), which is the difference between the initial readings of two subsequent irrigation,

D_r = Drainage, mm

Hence, at first irrigation date30/03/2003, E.T was obtained as follow:

$$E.T = I - \Delta D_o - D_r$$

$$= 32.4 - 13.9 - 1.9$$

$$= 16.6 \text{mm/day}$$

So, Table 4.7 was generated based on the above procedure.

From the Table 4.3, the peak period evapotranspiration of tomatoes is 120.4mm/day, obtained during the flowering stage i.e. 64 days after sowing (planting) on 05/06/2003.

The minimum water depth, (mm), of irrigation required to cultivate tomatoes from sowing to maturity stages, during the period of 30th March to 31st August is approximated to be 3,798 × 2 = 7,596mm. This is for the five stems contained in the pot so for one stem the minimum water depth required is 1,519mm.

Therefore the average volume of water in (m^3/ha) that will be required to cultivate tomatoes during that period is estimated as follow:

$$V = AREA \times DEPTH \quad (4.3)$$

$$= 10,000 \times 1.519 = 15,192 \ m^3/ha$$

4.1.2 RESULTS FROM BLANEY MORIN NIGERIA MODEL

Computation of ET_c, using B.M.N. model, is based on meteorological data; particularly wind, temperature, relative humidity and solar radiation as presented in Appendix X.

For computing the ET_c during the first stage (vegetative stage), the K_c is computed by using the equation below :

$$K_c = aET_p^b \quad (4.4)$$

Where $ET_p = rf(0.45T + 8)(520 - R^{1.31}) / 100 \quad (4.5)$

For stage 2 and stage 3, flowering and fruiting to maturity respectively, K_c is obtained from Table X.3 knowing the wind and relative humidity.

Table 4.3 was generated (for the ET_c values for B.M.N model) using the procedure below:

For stage 1:VEGETATIVE STAGE (30^{TH} March to 30^{TH} May).

In this stage, as tomatoes is very sensitive to water response and does not need much water, the irrigation interval was scheduled to be 2 days interval based on which a and b are obtained from TableX.2:
a= 1.049 ; b= -0.119
Also from Table X.1 rf is found to be 0.0851 for month of march :

$$\text{So ETp} = \frac{0.851(0.45 \times 32.75 + 8)(520 - (42.625)^{1.31})}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(4.6)$$

ETp= 7.3965 mm/day

Hence $K_c = a \times ETp^b$

$\Rightarrow \quad K_c = 1.049(7.3965)^{-0.119}$

$\Rightarrow$

$= 0.825$

$\therefore$ The crop evapotranspiration during the first is:

ETc= K_cETp

$= 0.826 \times 7.3965$

ETc= 6.1145 mm/day

For stage 2: Flowering (June)

In this stage K_c is read from the Table X.3 base on wind and minimum relative humidity.

So for the first of the flowering stage, K_c was found to be equal to 1.100

K_c= 1.1; T= 27.45; R= RH= 79.75%; rf= 0.0851... for June

$$\text{ETp} = \frac{0.0851(0.45 \times 27.45 + 8)(520 - (79.75)^{1.31})}{100}$$

ETp= 3.64 mm/day

∴ The crop evapotranspiration for the first of the flowering stage is :

$ETc = K_c \times ETp$

$= 1.100 \times 3.64$

$ETc = 4.004$

For the stage 3: Fruiting to maturity (July to august)

As in stage 2, K_c is read from the Table X.3 base on wind and minimum relative humidity.

For the first day of the starting of fruiting, K_c was read to be equal to 0.6.

K_c= 0.66; T= 26.05; RH= 83.875%; rf= 0.0661 for July Kc values obtained from Table X.3

$$\text{So } ETp = \frac{0.0661(0.45 \times 26.05 + 8)(520 - (83.875)^{1.31})}{100}$$

ETp= 2.46 mm/day

∴ The crop evapotranspiration of the day of starting fruiting is :

$ETc = k_c \times ETp$

$= 0.6 \times 241$

ETc= 1.477 mm/day

The minimum water depth (mm) of the irrigation required to cultivate tomato, from sowing to maturity stages, during the period of match (end 30 march) to august is approximated to be = 257.57×2= 515.04 mm

Therefore the average of water in m^3/ha required is

V= 515.04×10.000= 5150.4 m^3/ha

4.1.3 IRRIGATION AND DRAINAGE WATER QUALITY ANALYSIS

- **IRRIGATION WATER**

The source of water used is borehole water Cafeteria.

Sodium Absorption (SAR) calculation:

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}} \quad \text{.......................................} (4.7)$$

$= 21.85 / [(7.2 + 4.6)]^{1/2}$

$= 8.99$

Where Na^+, Ca^{2+} and Mg^{2+} represent the concentration of these elements in the irrigation water ($MeqL^{-1}$) obtained from Table 4.2

Exchangeable Sodium Percentage (ESP) computation:

$$ESP = \frac{100(0.015SAR)}{1 + 0.015SAR} \quad \text{.......................................} (4.8)$$

ESP = 100× (0.015 × SAR) / (1 + 0.015 × SAR)

= 100× (0.015 × 8.99) / (1 + 0.015 × 8.99)

= 11.89 %

- **DRAINAGE WATER**

Sodium Absorption (SAR) calculation:

$$SAR = \frac{Na^+}{\sqrt{\frac{(Ca^{2+} + Mg^{2+})}{2}}}$$

$SAR = 368.56 / [(960 + 145.8) /2]^{1/2}$

SAR = 15.67

Exchangeable Sodium Percentage (ESP) computation:

$$ESP = \frac{100(0.015SAR)}{1 + 0.015SAR}$$

ESP = 100 × (0.015 × 15.67) / (1 + 0.015 × 15.67)

ESP =19.03 %

4.1.4 SOIL ANALYSIS RESULTS

The results obtained from sieve analysis are presented in Table 4.1.a And also other soil parameters determined from laboratory test were presented in Table 4.1.b.

The soil moisture content (MC) was found as follows:

$$MC = \frac{(Ww - Wd)}{Wd} \times 100 \quad \text{.......................(4.8)}$$

Where; Ww = 355.7g (weight of wet soil)

Wd = 299.07 (weight of dry soil)

$$\Rightarrow \quad MC = \frac{355.7 - 299.07}{299.07} \times 100$$

MC = 18.9 %

4.1.5 YIELD RESULTS

The surface area of the lysimeter is:

$$A_{lys} = \frac{\pi d^2}{4} \quad \text{... (4.9)}$$

Where d is the diameter of the pot = 0.3 m

$A_{lys} = \pi \times (0.3)^2 / 4$

$A_{lys} = 0.071\ m^2$

The yielding during the first harvest is:

$Y_1 = 12\ g / 0.071\ m^2$ or $169.16\ g / m^2$

For second stage:

$Y_2 = 47\ g / 0.071\ m^2$ or $644.9\ g / m^2$

From referential plot:

$A_{rf} = b \times a$ ....(4.10)

Where a is the width and b is the length.

$A_{rf} = 3 \times 5 = 15\ m^2$

The yielding is:

$Y_1 = 1.2\ Kg / 15\ m^2$

$Y_1 = 1200\ g / 15\ m^2$ or $80\ g / m^2$

4.2 DISCUSSION OF RESULTS

The result of the project experimentation are discussed in relation to:

4.2.1 IRRIGATION

From the project experimentation, it appears that the irrigation of tomatoes (ROMA) depends on the different stage within the length of the growing season. That is the irrigation requirement varies from stage to stages, since tomatoes are very sensitive to water response by the fact that during the early stage it does not require much water while during the flowering and fruiting stage after the vegetative stage it is very sensitive to water shortage. Therefore irrigation requirement must be scheduled by observing the soil moisture and not by observing the plant it self.

Also from irrigation water quality test (results presented in Table 4.2 which gives SAR = 8.99 and after analysis of Table 4.2 , it appear that the irrigation water,(cafeteria borehole) used contains some chemical that are toxic for sensitive crop in which tomatoes plant is included. And this may result in moderate problem. Since $3 < SAR \leq 9$ i.e. $3 < 8.99 \leq 9$. Moreover ESP = 11.89%

So 11.89% < 15% indicating that the soil is saline

4.2.2 DRAINAGE

From the experiment carried out on lysimeter, the drainage water collected varies from day to day, depending on the extent of water retained in the soil. When the soil moisture is too high, the drainage water or drainage rate is very high. Whilst when the soil moisture is low, the rate of drainage and drainage water is also very low and sometimes very negligible.

On the other hand, from the drainage water quality test (result presented in Table 4.2 which gives the SAR computed to be equal to 15.67 and in accordance with guidelines for water quality appraisal; it results that this drainage water have severe problem, when use for sensitive crop as the case of the project may be, since it contains some toxicants chemicals that are hazardous to plants like Tomato. If this water is used for irrigation it makes the soil to be a sodic soil since it's ESP >15% (19.03%. 15%) .

4.2.3 SOIL

In planning an irrigation project the soil parameters are detrimental, so the need for determining certain soil parameters is very important. After the soil analysis and test; the soil used for the project is found to be a sandy loamy soil with fine particles from (Table 4.1.a). Also more than half of material passes the sieve (200mm), so the soil is sandy soil with fine particles.

And from the soil test which gives the soil pH to be 5.7(Table 4.1.b), the soil is found to be a saline soil having appreciable quantity of soluble salt; which is also proved by the drainage water test giving an appreciable concentration of N_a^+(368.56) where as the irrigation water passes only a concentration of 21.85 pp.m of Na^+. Also the concentration of Ca^+, Mg^{++}, Ca^{++} and the pH in drainage water are larger than those contain in irrigation water, which shows that the soil has appreciable quantity of the above ions.

4.2.4 CROP

Tomatoe crop has three different stages:

i. Vegetative stage: from sowing to complete vegetative cover see figure 4.5(a; b)

ii. Flowering stage: from starting of flowering to starting of fruiting see figure 4.6.

iii. Fruiting stage: from fruit to maturity see figures 4.7(c, d, e)

4.2.5 YIELD

From this work, the yield obtained with respect to lysimeter experiment is satisfactory compare to that obtained from the referential plot. Since during the first harvest 12 g/0.071 g is obtained from lysimeter experiment while 5.65 g / 0.071 g is obtained from referential plot.

4.2.6 GRAPH INTERPRETATION

Figure 4.1 was generated base on daily crop evapotranspiration as presented in Table 4.3. This shows that:

For lysimeter – The rate of ET_c during the early stage of tomatoes (vegetative stage) increases. After this stage the rate of ET_c is becoming very high during this stage the plant attained its peak ET_c this increase in ET_c in the flowering stage is extended to the fruiting stage and during the late maturity stage the rate of ET_c decreases.

For B.M.N. model – It appears that the rate of ET_c during the early stage is higher than those computed during the flowering and fruiting stages.

Therefore after analysis of the two curves in figure 4.1 it should be noted that the rate evapotranspiration is highly influenced by the temperature, wind, relatively humidity and solar radiation but lysimeter method gives more accurate results than B.M.N. model as this later was generated based on meteorological data only.

4.2.7 RESULT INTERPRETATION

From the result presented in appendix Z, Table 4.3, it appears that the daily crop evapotranspiration value is very consistent with lysimeter measurement than that computed in B.M.N model. And the peak ET_c in lysimeter method occurs in flowering stage while the peak ET_c in B.M.N model occurs in the vegetative stage. Thus the peak ET_c for lysimeter is 24.12 mm/dayand 6.11 mm/day is obtained from B.M.N model.

The total volume required for the growing season of tomatoes crop is 15,192 m^3/ha and 5,150 m^3/ha for lysimeter and B.M.N model respectively this is over a period of five month (154 days).

From Figure 4.2 of cumulative ET_c and cumulative rainfall computed at each five days it was observed that the ET_c rate from lysimeter is higher than the rainfall which in turn is greater than ET_c rate from B.M.N model. So in view of observation in order to schedule an irrigation system for tomatoes during the rainy season, one has to supply additional water in order to meat with the tomatoes water requirement during the length of the crop growth.

From figure 4.3 it appears that there is no significant similarity for the drainage water collected during the season. Thus it varies day to day.

4.2.8 INTERPRETATION OF K_C ESTIMATE

The Kc estimate from the crop evapotranspiration (lysimeter) and potential evapotranspiration (B.M.N model) is shown in Table 4.5 generated from equation (2.20). The analysis of this table shows that the average K_c for the vegetative stage is found to be equal to 0.23 while K_c = 0.7 was found for flowering stage and 1.6 represented the K_c value for fruiting to maturity stage.

Comparison of these K_c values with the FAO standard K_c values shows that:

- For the vegetative stage the K_c obtained match the interval gave by the FAO standard since K_c equals to 0.23 is included in 0.2 to 1.0. And 0.2-1.0 is the range of K_c values during the vegetative stage as given by FAO standard.
- For the flowering stage the K_c value estimated is higher than that of the FAO standard. K_c equals to 0.7 is approximately half of that gave by FAO standard (1.1).
- For fruit to maturity stage: here the K_c estimate obtained is also higher than that from the FAO standard. It is about 2 times that given by the FAO standard, i.e. K_c = 1.6 estimated and K_c = 0.66 from FAO standard, hence 1.6 is greater than 0.66.

Figure 4.4 shows that the crop coefficient estimated varies that is there is no similarity between the Kc values within each stage of growth.

The results also show that there is no uniformity between the values of the same stage

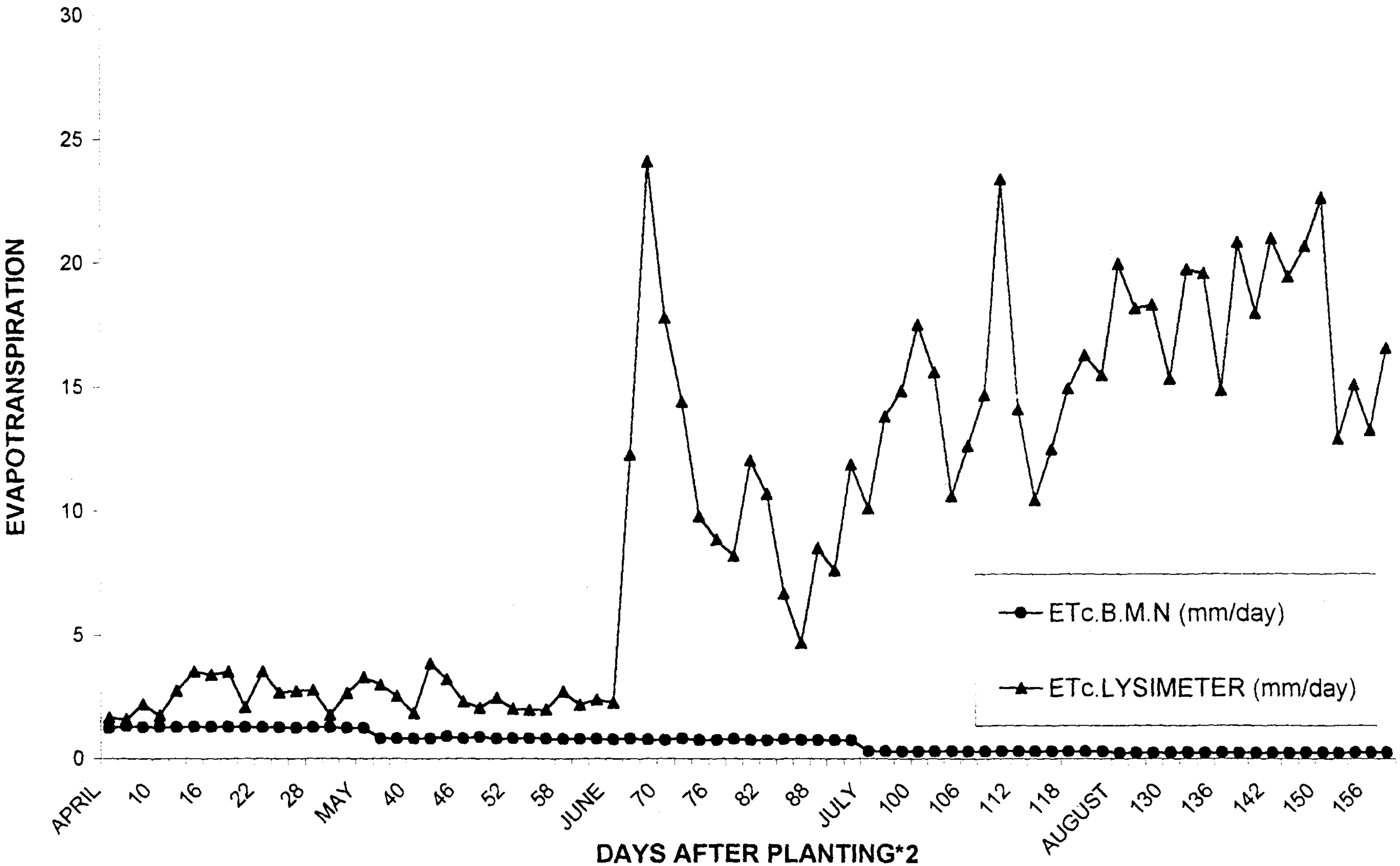


FIGURE 4.1: DAILY CROP EVAPOTRANSPIRATION FOR TOMATOES [ROMA] FOR ONE STEM.

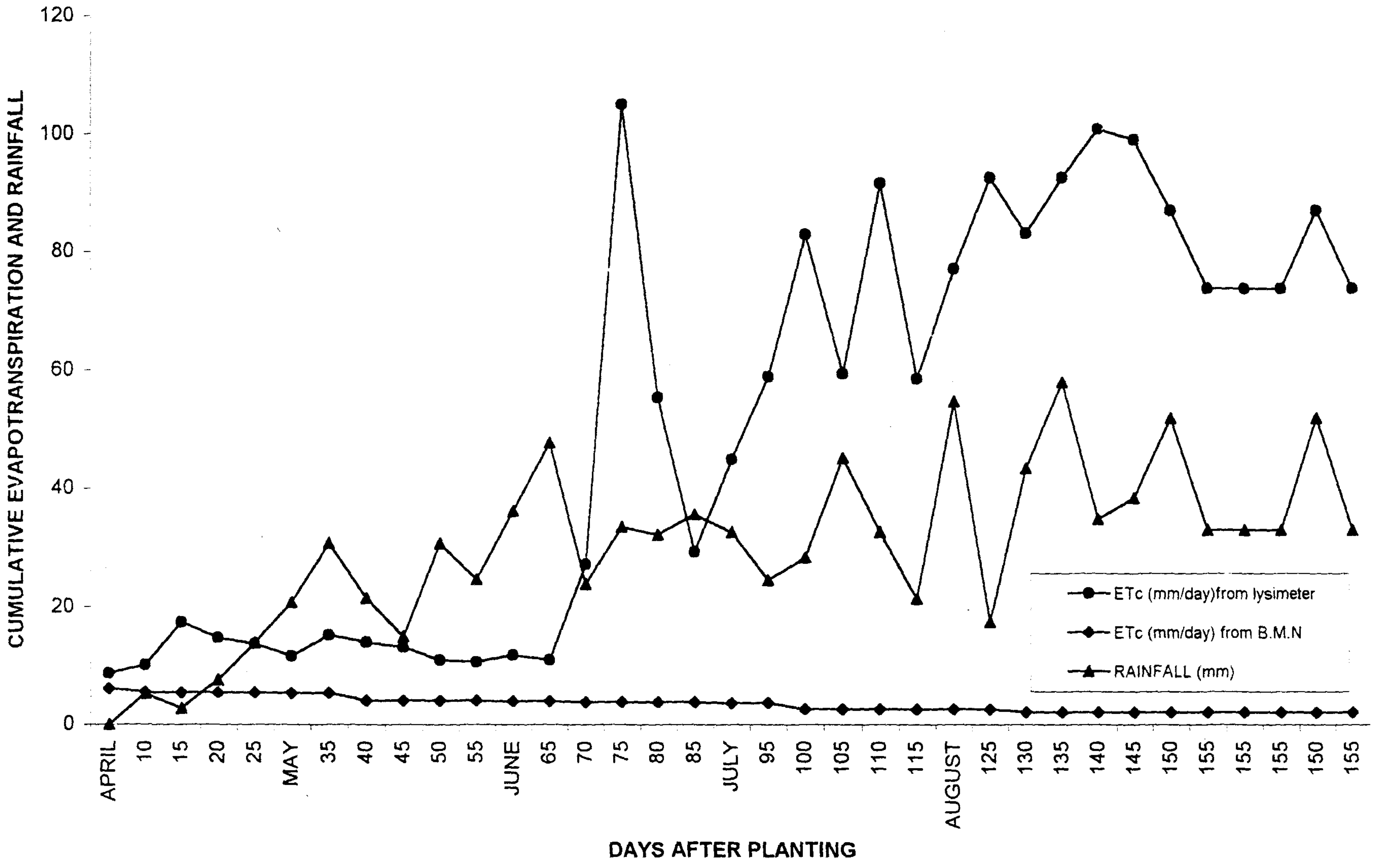


FIGURE 4.2 : CUMULATIVE CROP EVAPOTRANSPIRATION AND RANIFALL AT 5 DAYS INTERVAL [FOR ONE STEM]

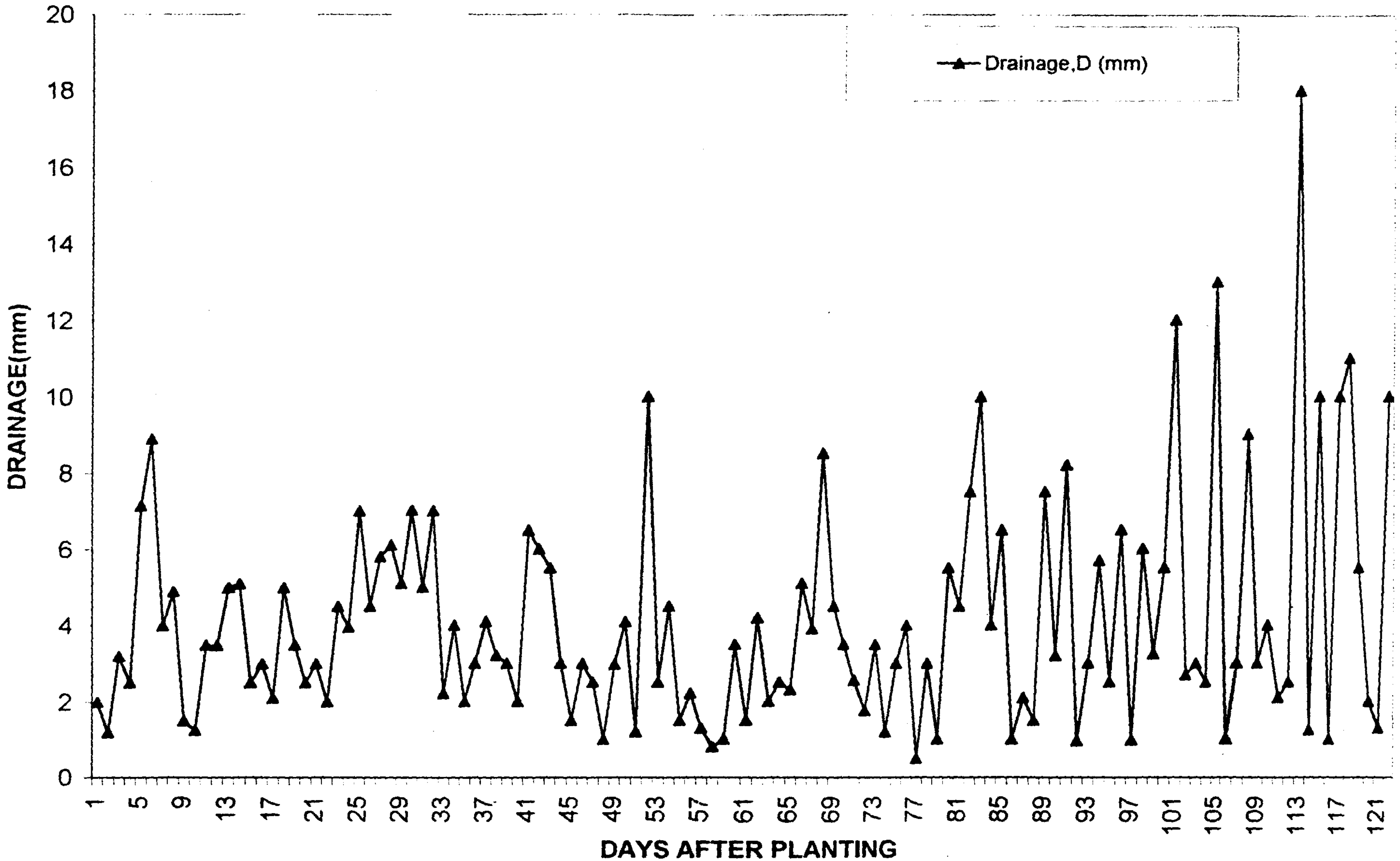


FIGURE 4.3 DRAINAGE ,D (mm)

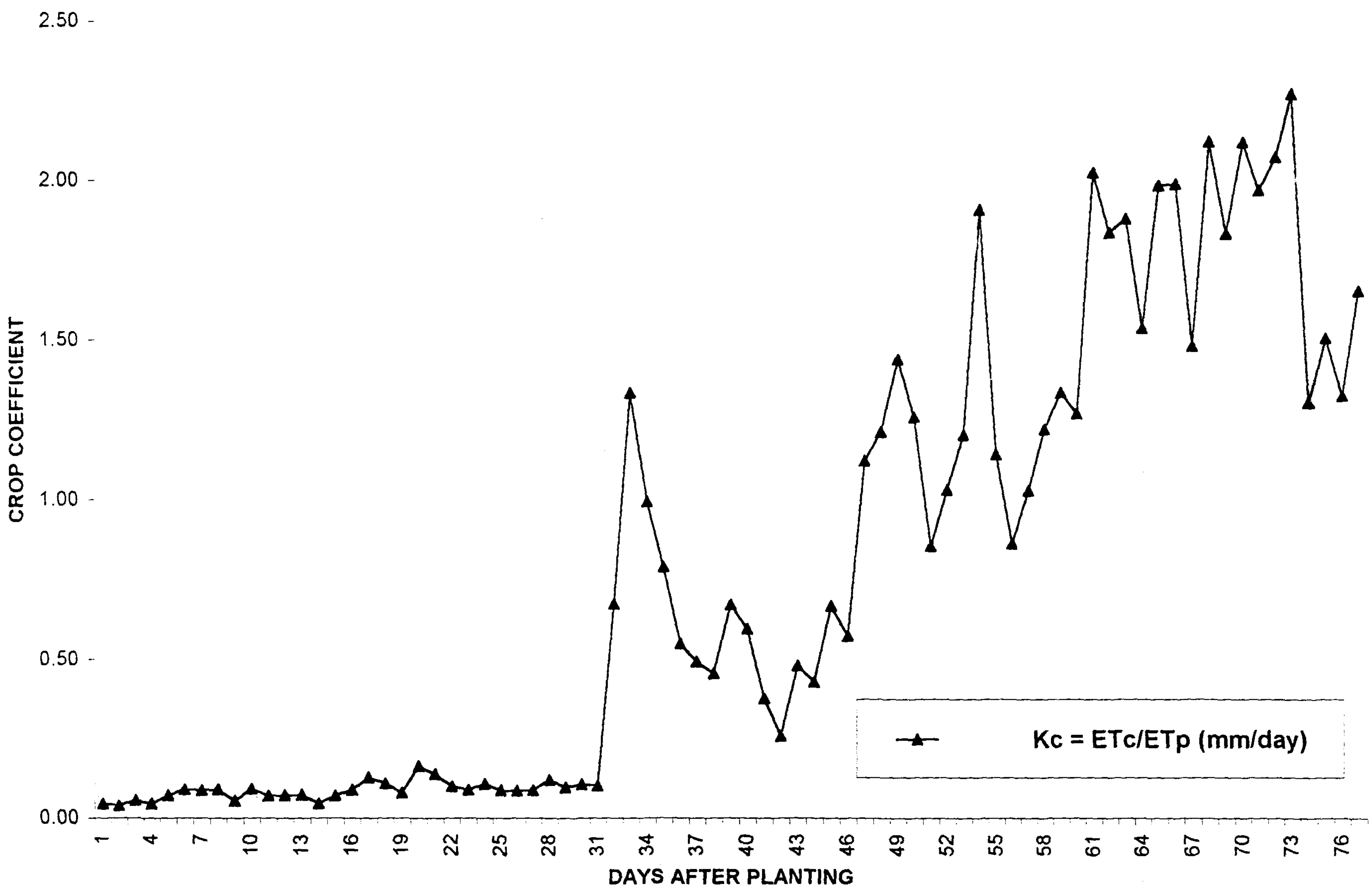
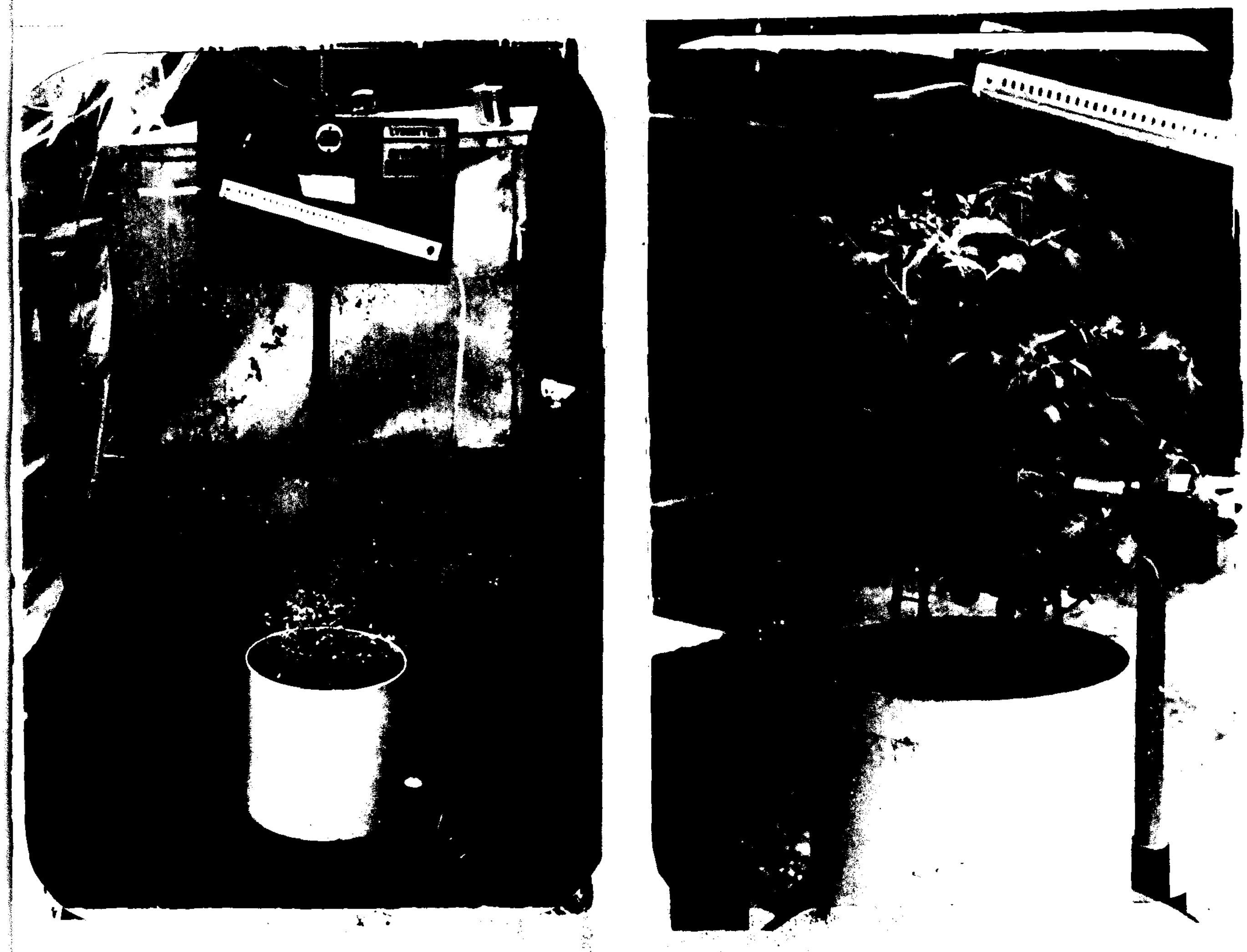


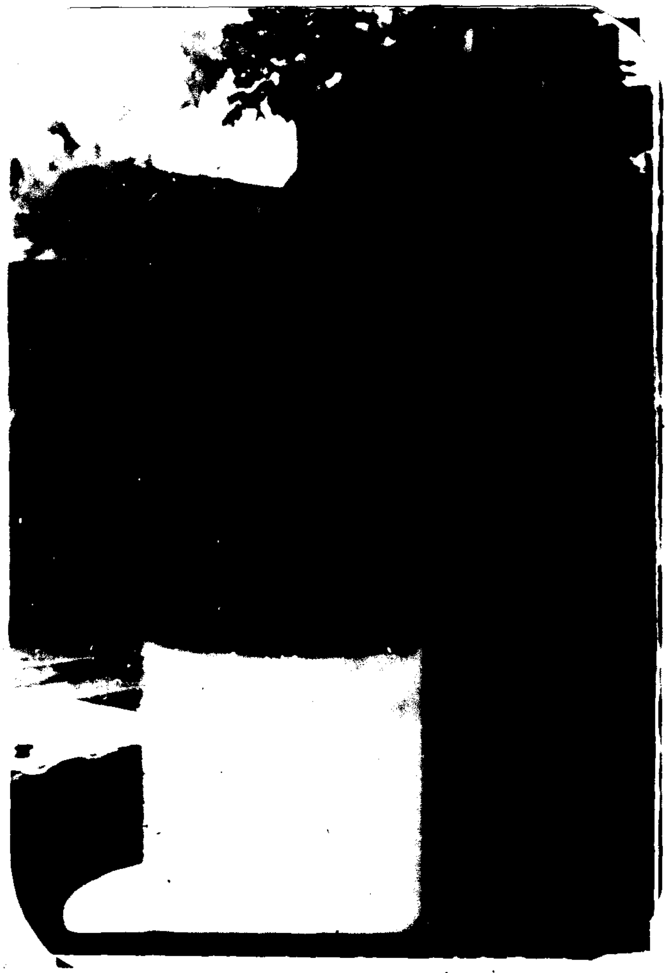
FIGURE 4.4 CROP COEFFICIENT, Kc= ETc/ETp (mm/day) FOR ONE STEM



a) Three (3) Weeks After Planting

b) Six (6) Weeks After Planting

FIGURE 4.5: VEGETATIVE STAGE OF TOMATOES CROP[ROMA]



Two Months After Planting

FIGURE 4.6: FLOWERING STAGE OF TOMATOES [ROMA]CROP

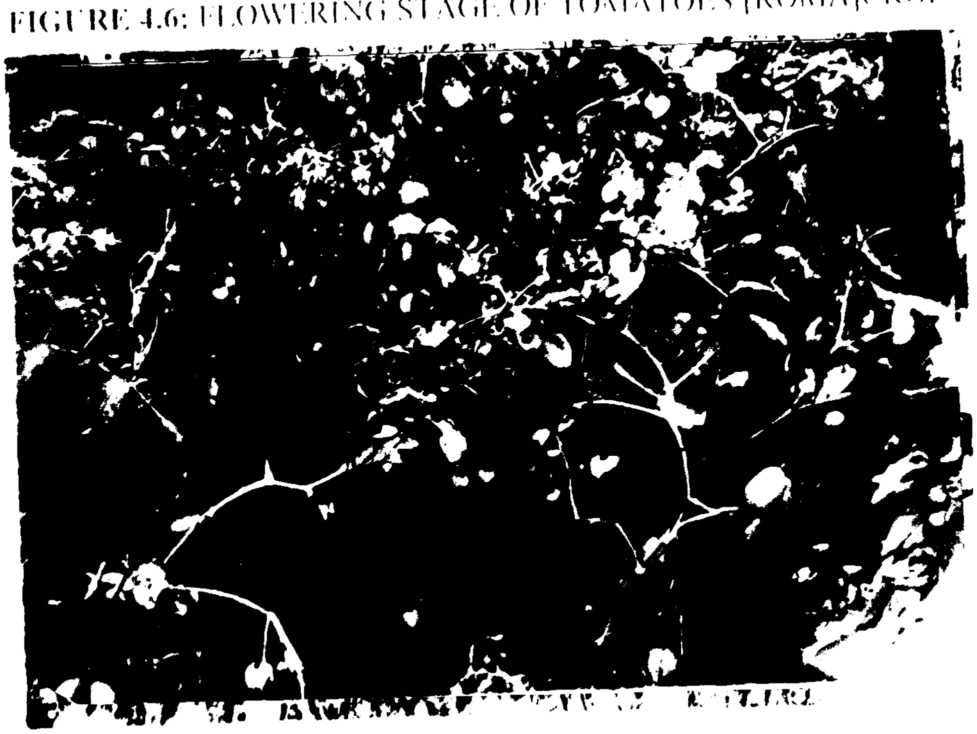


FIGURE A: REFERENCIAL PLOT

a) 130 Days After Planting

c) 140 Days After Planting

b) 137 Days After Planting

FIGURE 4.7 FRUITING TO MATURITY STAGE OF TOMATOES [ROMA]

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

After the completion of this project experimentation, it should be noted that either the lysimeter measurement and the B.M.N. model used are in one way or another influenced by the climatic factors such as temperature, wind, sunshine radiation and relative humidity. Hence the hotter the day, the higher the ETc rate. The ETc rate is also influenced by the rate at which leaves spreads within the growing season.

A delay in growing of the crop was observed during this project experimentation, and this is due to some limitation of the project such as the restriction of the soil layer resulting from the size of the lysimeter pot or tank. Thus the length of growing season took five (5) months instead of three (3) months as known for this tomato variety (Roma).

On the other hand a cumulative ETc 7,596 mm/season for five stems (i.e. 1,519 for one stem) and 515.04 mm/season were measured and computed from lysimeter and B.M.N. model within the limit of experimental errors respectively, during the growing season. Moreover, when planning and scheduling an agricultural irrigation scheme for tomato the peak ETc of 24.12 mm/day most taking into consideration. Therefore a minimum of 24.12mm depth of water per day must be supplied (for one stem). If the water supply does not meet this limit; it may result some effect that may be harmful to the tomato plant inhibiting its growth.

The yielding obtained for the experiment is found satisfactory compare to that obtained from referential plot of 15 m^2 it was found that the yielding of 12 g / 0.071 m^2 for lysimeter is greater than that of reference plot (5.65 g / 0.071 m^2) this is base on area.

The Kc values estimate show that the values varies independently from the stage.

5.2 RECOMMANDATION

For future work relative to this project the recommendation that I proposed are as follows:

i. The soil must be sterilized in order to make it free from disease because when the soil contents some diseases such as nematodes it delays the implementation of the work.

ii. The soil must be tilt time be time in order to provide good aeration and enhance infiltration of water into the soil.

iii. The equipment must be sited at one specific place (provision of a green house for the lysimeter) to avoid obstruction due to the fact of moving the instrument or touching it, because obstruction affect readings and enhance falling of flowers and fruits.

iv. The result of this work must be made available and accessible to both the public and private irrigation scheme planners and schedulers and also farmer in the country.

v. If the soil is sterilized, addition of NPK has to be made according to 200 Kg / ha recommendation.

vi. The pound water should be used for irrigation because of their nutrients content.

vii. The plant must be treated regularly to avoid insect infection using ordinary sulfur or any other insecticide recommended for that specific plant.

viii. Other works must be carried out to compare lysimeter method with other meteorological based methods apart from B.M.N. model in order to determine the degree of accuracy of such methods.

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APPENDIX X

TABLE X.1: Mean Monthly Sunshine Radiation And Radiation Factor Of Minna; Nigeria [1993-2003]

TABLE X.2: Values Of Constant "a "And "b"

TABLE X.3: Typical Crop Coefficient Kc For Crops At Different Growth Stage

TABLE X.4: Mean Monthly Relative Humidity Of Minna; Nigeria [993-2003]

TABLE X. 5: Mean Daily Wind Velocity Of Minna; Nigeria [1993-2003]

TABLE X. 6 : Mean Daily Temperature Of Minna ; Nigeria [1993-2003]

TABLE X.7: Daily Temperature Of Minna; Nigeria [2003]

TABLE X.8: Daily Wind Velocity Of Minna [2003]

N.B: All Meteorological Data are **Collected From Minna Airport {Maikunkele Local Government]**

APPENDIX Z

TABLE 4.1; Soil Analysis[Sieve Analysis Of The Soil And Other Soil Properties Determination]

TABLE 4.2: Chemical Parameters From Water Quality Test

TABLE 4.3: Daily Crop Evapotranspiration For Tomatoes [Roma]

TABLE 4.4: Cumulative Crop Evapotranspiration For Tomatoes And Cumulative Rainfall At 5 Days Interval

TABLE 4.5: Estimated Values Of Kc From Lysimeter And B.M.M. Model

TABLE 4.6; Drainage Recorded During The Growing Season Of Tomatoes

TABLE 4.7: Worksheet[Recorded Evapotranspiration Of The Tomatoes Growing Season]

TABLE 4.8: Dimensional Characteristics Of The Crop [Tomatoes]

TABLE X1: MEAN MONTHLY SUNSHINE RADIATION AND RADIATION FACTOR OF MINNA;NIGERIA;[1979-1999]

MONTH	SUNSHINE RADIATION	RADIATION FACTOR
JANUARY	7.3	0.0914
FEBRUARY	7.7	0.09634
MARCH	6.8	0.0851
APRIL	7.3	0.0914
MAY	7.1	0.0888
JUNE	6.8	0.0851
JULY	4.9	0.0661
AUGUST	4.6	0.0575
SEPTEMBER	5.5	0.0688
OCTOBER	6.4	0.0801
NOVEMBER	8.9	0.1114
DECEMBER	7.1	0.088

TABLE X2: VALUES OF CONSTANTS "a" AND "b".

	UNITS OF ET			
Average interval of irriga	mm/day		in/day	
or Rainfall[Days]	a	b	a	b
1	1.122	-0.287	0.846	-0.287
2	1.049	-0.119	0.714	-0.119
4	0.904	-0.216	0.450	-0.216
7	0.742	-0.319	0.264	-0.319
10	0.550	-0.408	0.155	-0.408
20	0.438	-0.455	0.101	-0.455

TABLE X4: MEAN MONTHLY RELATIVE HUMIDITY OF MINNA NIGERIA[1993-2002],(%)

	RELATIVE HUMIDITY[%]	
MONTH	Mean minimumR.H.(%)	Mean maximum R.H. (%)
JANUARY	20.03	59.06
FEBRUARY	15.5	51.37
MARCH	18.37	66.87
APRIL	29.5	84.12
MAY	54.25	91.25
JUNE	65.75	93.75
JULY	71.37	96.375
AUGUST	75.62	96.5
SEPTEMBER	75.3	89.5
OCTOBER	60.9	96.6
NOVEMBER	34	76
DECEMBER	22	70

BLE X.3: TYPICAL CROP COEFFICIENT K_c FOR CROPS AT DIFFERENT GROWTH STAGES AND PREAVALING CLIMATIC CONDITION OF SOME SELECTED CROPS					
op	humidity	R H >70%		R H <20%	
	wind, m/sec	*0-5*	*5.-8*	*0-5*	*5.-8*
1	2	3	4	5	6
	crop stages				
arley	M	1.05	1.1	1.15	1.2
	H	0.25	0.25	0.2	0.2
arrot	M	1	1.05	1.1	1.15
	H	0.5	0.5	0.5	0.5
naize (grain)	M	1.05	1.1	1.15	1.2
	H	0.55	0.55	0.6	0.6
otton	M	1.05	1.15	1.2	1.25
	H	0.65	0.65	0.65	0.7
abbage, coliflower	M	0.95	1	1.05	1.1
	H	0.8	0.85	0.9	0.95
rain	M	1.05	1.1	1.15	1.2
	H	0.3	0.3	0.25	0.25
ettuce	M	0.95	0.95	1	1.05
	H	0.9	0.9	0.9	1
nelons	M	0.95	0.95	1	1.05
	H	0.65	0.65	0.75	0.75
nillet	M	1	0.05	1.1	1.15
	H	0.3	0.3	0.25	0.2
onion(dry)	M	0.95	0.95	1.05	1.1
	H	0.75	0.75	0.8	0.85
onion(green)	M	0.95	0.95	1	1.05
	H	0.95	0.95	1	1.05
groundnut	M	0.95	1	1.05	1.1
	H	0.55	0.55	0.6	0.6
patato	M	1.05	1.1	1.15	1.2
	H	0.7	0.7	0.75	0.75
sorghum	M	1	1.05	1.1	1.15
	H	0.5	0.5	0.55	0.55
soybeans	M	1	1.05	1.1	1.15
	H	0.45	0.45	0.45	0.45
tomato	M	1.05	1.1	1.2	1.25
	H	0.6	0.6	0.65	0.65
wheat	M	1.05	1.1	1.15	1.2
	H	0.25	0.25	0.2	0.2

M- mid-season (from attainment of full ground cover to star of maturing)
H- late season (from end of mid season to full maturity or harvest).

NB: note that Kc values ranges between 0.2 and 1.0 as given by FAO.
[Based on Doorenbos and Pruitt, 1975;Irr. and Drainage paper 24.FAO]

TABLE X5: MEAN DAILY WIND VELOCITY OF MINNA;NIGERIA [1993-2003] ,m/s

DAY	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	4	5	5	4	6	5	4	4	5	4	4	4
2	4	5	5	5	4	6	5	4	4	5	4	4
3	5	5	5	4	4	5	5	5	4	5	4	4
4	5	5	5	5	5	4	5	4	5	5	4	4
5	5	5	5	5	6	5	4	4	5	6	5	5
6	5	5	4	5	5	4	5	5	5	5	4	4
7	5	5	5	5	5	5	5	4	4	5	4	4
8	5	5	5	5	6	6	5	5	5	5	4	4
9	5	5	5	5	5	5	5	4	4	6	4	4
10	5	5	5	5	5	5	4	4	4	5	5	4
11	5	5	4	4	5	5	4	4	4	4	4	5
12	5	5	4	5	6	5	5	4	5	5	4	5
13	4	5	5	4	5	5	4	5	4	4	4	4
14	4	5	4	5	5	6	4	4	5	4	4	4
15	4	5	4	6	6	5	6	4	4	5	4	5
16	5	5	4	5	5	5	4	4	5	4	4	5
17	5	5	4	5	6	4	5	5	5	4	4	5
18	5	5	5	5	5	5	4	4	4	5	4	4
19	5	5	4	6	5	5	4	4	5	5	4	4
20	5	5	5	5	5	4	4	4	5	4	4	4
21	5	5	4	5	5	5	5	4	5	4	4	4
22	5	5	5	5	5	5	4	4	5	4	4	4
23	5	5	5	5	5	5	4	4	5	4	4	5
24	5	5	5	5	6	5	4	4	6	4	4	5
25	5	4	5	4	6	5	4	4	5	4	4	5
26	5	5	4	5	5	5	4	4	6	3	4	5
27	5	5	4	5	6	5	4	4	5	4	4	5
28	5	4	5	5	6	5	4	4	6	4	4	5
29	5		4	5	5	5	5	4	4	4	4	4
30	5		4	5	5	4	4	4	5	4	4	5
31	5		4		5		5	5		4		4

TABLE X.6 MEAN DAILY TEMPERATURE OF MINNA ;NIGERIA [1993-2003]

DAYS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	27.25	27.15	31.2	32.1	30.75	27.1	25.55	24.9	28.5	26.1	27.15	27.8
2	27.5	29.85	30.7	32.6	29.8	27.3	25.95	25.75	25.7	25.95	27.3	27.6
3	27.6	28.6	30.6	31.1	29.45	26.9	25.85	25.2	25.8	26.35	27.6	27.55
4	27.8	28.95	31.8	31.5	29.05	27.2	26.2	24.2	25.8	26.25	27.85	27.05
5	26.5	26.6	31.4	31.6	29.55	26.2	26.1	24.85	25.7	26.45	27.25	27.5
6	26.4	29.35	31.1	31.1	29.7	27.5	24.9	25.9	25.9	26	27.7	27.9
7	26.65	28.65	31.4	31.7	29.65	27.6	26.25	25.7	25.6	26	27.05	26.9
8	26.1	28.3	30.9	29.6	30.3	26.1	26.05	25.4	25.6	25.75	27.2	26.75
9	26.95	29.05	31.5	31.6	29.35	27	26.6	24.7	25.7	26.45	27.3	27.45
10	26.8	29.1	30.9	32	29.5	27.1	26.85	25.45	25.9	26.45	27.3	27.25
11	26.45	29.25	30.9	31.9	29.1	26.7	25.9	25.9	23.5	26.6	27.25	27.2
12	26.6	29.1	31.5	32.1	29.75	26.9	25.7	25.95	25.5	26.7	27.25	27.45
13	26.3	29	32.2	31.3	29.55	27	25.95	25	25.2	26.8	27.4	26.8
14	25.75	29.3	32	31.9	29	27	25.35	25	26.1	26.7	26.95	26.85
15	26.4	29.65	31.7	30.2	28.9	26.6	26.1	25.4	26.2	26.7	26.85	26.05
16	26.9	30.8	32	30.9	28.65	26.8	25.75	24.55	26.2	26.45	26.94	27.5
17	27.9	29.9	31.6	30.9	28.95	27.1	26.05	25.3	24.5	26.55	27.33	26.95
18	27.55	29.95	32	30.9	29.3	26.2	25.65	25.35	25.4	26.7	27.16	27.3
19	28.55	30	31.5	31.2	28.95	26.6	25.9	25.3	26.4	26.3	27.44	27.45
20	28.2	30.2	31.6	30.6	29.05	27.5	25.2	25.15	36.1	26.75	27.38	27.45
21	27.85	29.85	32.1	30.3	28.85	26.7	25.45	25.85	25.5	27.1	27.78	27.2
22	27.8	30.25	32.4	30.4	28.7	26.3	25.65	25.45	26	26.95	27.35	27.45
23	27.9	30.4	31.8	30.7	28.7	26.3	25.4	25.3	26.4	26.9	27.35	27.5
24	28.2	30.3	32	30.3	27.3	26.1	26.2	25.9	25.2	27	27.3	27.4
25	27.95	30.1	32.2	31	28.55	26.9	25.6	25.15	25.8	27.3	27.65	26.8
26	28.5	30.1	32.3	30.4	28.35	26.7	25.75	25.5	26.1	27.1	27.6	26.85
27	29.1	30.45	32.2	29.9	38.7	26.3	25.6	25.9	26.7	27.4	27.35	27.1
28	29.4	30.85	32.2	29.9	26.95	26	25.45	25.9	26.1	27.75	27.45	2670
29	28.45	29.75	32.1	29.3	26.9	26.2	25.8	26	26.3	27.35	27.75	27.05
30	28.75		32.4	29.9	27.45	26.6	25.2	25.55	26.4	27.3	27.44	26.9
31	28.45		32.8		27.85		25.1	25.85		27.25		26.95

TABLE X.7 DAILY TEMPERATURE OF MINNA ;NIGERIA [2003]													
January		february		march		april		may		june		jully	
Tmax	*Tmin*	*Tmax*	*Tmin*	*Tmax*	*Tmin*	*Tmax*	*Tmin*	*Tmax*	*Tmin*	*Tmax*	*Tmin*	*Tmax*	*Tmin*
34	20	37	22	40	23	40	23	36	27	26	22	30	21
33	19	39	23	40	24	41	26	39	25	31	21	30	24
34	21	39	22	39	26	38	26	39	25	32	24	28	19
35	20	38	24	39	24	37	217	39	25	32	23	30	22
33	19	38	22	39	25	38	27	38	25	33	24	31	23
35	18	37	23	37	25	35	23	37	27	31	23	31	23
35	17	40	22	38	28	39	25	38	27	31	25	28	23
36	19	40	21	39	27	40	28	40	26	30	22	30	23
35	18	37	22	39	27	38	28	38	28	33	24	29	22
36	18	39	23	38	24	36	28	38	28	31	24	30	22
35	20	37	22	39	27	37	25	38	28	29	23	29	22
35	22	37	23	39	26	32	27	38	26	32	25	30	23
35	23	37	24	38	27	38	24	38	25	30	22	29	23
36	22	38	25	38	25	36	27	37	27	33	24	31	23
37	21	36	24	38	26	36	25	38	27	33	22	32	24
35	23	39	24	38	24	38	26	36	28	31	22	30	22
36	24	36	27	39	24	37	27	32	24	31	25	30	23
35	22	39	26	40	27	37	26	36	24	30	21	27	24
37	23	40	26	42	27	33	26	35	26	31	25	28	22
36	23	37	25	39	27	35	25	33	23	31	21	30	23
36	21	38	27	39	27	37	26	37	25	29	23	30	22
34	24	38	25	38	27	38	27	35	26	30	22	29	23
35	23	39	25	38	27	36	24	34	27	31	24	30	23
35	20	40	20	38	26	36	26	36	25	27	22	30	23
36	22	37	28	42	29	38	25	34	24	31	23	32	23
36	20	39	27	39	27	36	27	30	22	29	23	28	22
36	19	39	26	39	28	36	23	34	25	32	22	31	23
36	23	40	24	38	26	37	27	30	22	32	24	29	24
34	22			40	25	38	27	29	22	29	21	32	23
35	20			39	25	38	26	33	24	29	23	31	24
37	22			40	25			33	26			28	24

TABLEX.8 DAILY WIND VELOCITY OF MINNA [2003]						
january	february	march	april	may	june	jully
5	5	4	3	4	7	4
6	4	6	4	3	4	4
6	6	6	4	3	4	8
6	5	5	4	3	3	4
5	5	5	6	3	7	3
4	6	4	4	4	9	3
3	5	4	4	5	8	4
4	5	4	3	3	3	4
4	4	5	4	4	4	3
3	5	4	6	4	5	4
3	3	5	5	5	4	4
4	4	5	5	6	5	4
4	5	6	4	4	3	3
4	4	5	4	4	3	3
5	4	5	5	4	7	3
4	4	4	6	5	5	3
4	5	4	4	3	5	3
4	4	3	4	4	3	5
3	5	3	4	9	5	5
4	4	4	3	5	3	4
4	9	3	5	6	5	3
4	4	3	7	4	4	3
5	4	4	4	4	3	4
4	5	4	4	7	4	3
4	4	4	4	5	3	4
4	4	4	8	4	3	4
4	5	4	4	6	3	4
4	4	4	4	7	6	3
6		4	3	3	7	4
4		3	4	3	3	3
5		3		4		3

TABLE 4.1 SOIL ANALYSIS

Table 4.1.a. SIEVE ANALYSIS RESULTS TABLE

Sieve No	Sieve diam	Weight of sieve(g)	Weight of sieve+sample(g)	Material retained(g)	Material passing(g)	% Retained	%Passing
1	5.00 mm	479.5	485.16	5.66	494.34	1.13	98.87
2	3.35 mm	468.4	470.12	1.72	492.62	0.34	98.53
3	2.00 mm	420.1	425.52	5.42	487.2	1.08	97.44
4	1.18 mm	391.1	410.08	18.98	468.22	3.79	93.64
5	850 um	358.7	387.08	38.38	429.84	7.67	85.97
6	600 um	336	386.29	50.29	379.55	10.06	75.91
7	425 um	329.5	391.48	61.98	317.57	12.39	63.514
8	300 um	316.2	374.88	57.68	259.89	11.53	51.98
9	150 um	295.7	422.24	126.54	133.35	25.3	26.67
10	75 um	296.2	390.73	94.53	38.82	18.9	7.66
11	pan	304.3	343.12	38.82	0	7.64	0

Table 4.1.b Properties of the soil used for the project

Properties	Soil sample
pH	5.7
% Organic matter	1.07
hydraulic conductiv	2.03 cm/hr
Moisture content	18.90%
Bulk density	1.7 cm^2
Porosity	29%

Table 4.1.c; chemical composition of soil

Parameters	Composition
Sodium (ppm of Na^+)	346.71 mg/l
Potassium (ppm of K^+)	3.87 mg/l
Calcium (ppm of Ca^{++})	952.8 mg/l
Magnesium(ppm Mn^{++})	141.2 mg/l

TABLE 4.2 CHEMICAL PARAMETERS DETERMINED FROM WATER QUALITY TEST

Chemical	Irrigation w	Drainage water
ph	6.03	6.8
ppm N+	21.85	368.56
ppm K+	1.68	5.55
mg/l C++	7.2	960
mg/l Mg+	4.6	145.8

TABLE 4.3 DAILY CROP EVAPOTRANSPIRATION FOR TOMATOES(ROMA) FOR ONE STEM

	BLANY MORIN NIGERIA METHODS				LYSIMETER METHOD
MONTHS	DAYS	TEMP	ETp	ET_c.B.M.N (mm/day)	ET_c.LYSIMETER (mm/day)
	2	32.575	7.396	1.2229	1.66
APRIL	4	32.3	7.9	1.296	1.57
	6	31.25	7.735	1.272	2.19
	8	31.325	7.747	1.274	1.73
	10	30.6	7.6325	1.256	2.734
	12	31.8	7.822	1.2846	3.52
	14	31.975	7.85	1.288	3.4
	16	31.575	7.786	1.2796	3.51
	18	30.555	7.625	1.259	2.074
	20	30.9	7.68	1.264	3.526
	22	30.85	7.672	1.263	2.68
	24	30.3	7.585	1.2504	2.732
	26	30.45	7.61	1.254	2.78
	28	30.675	7.644	1.259	1.75
	30	29.85	7.514	1.24	2.65
	32	29.55	7.467	1.234	3.3
MAY	34	29.775	4.659	0.814	2.99
	36	29.25	4.608	0.806	2.52
	38	29.625	4.645	0.8116	1.85
	40	29.975	4.679	0.8172	3.85
	42	29.425	4.625	0.886	3.2
	44	29.425	4.6252	0.817	2.3
	46	29.275	4.61	0.864	2.05
	48	28.775	4.561	0.7988	2.46
	50	29.125	4.596	0.8042	2
	52	29	4.583	0.8022	1.962
	54	28.775	4.561	0.8064	1.986
	56	28	4.485	0.787	2.708
	58	28.45	4.53	0.794	2.18
	60	27.825	4.468	0.784	2.374
	62	27.175	4.405	0.774	2.25

JUNE	64	27.45	3.64	0.808	12.28
	66	27.075	3.61	0.7581	24.12
	68	26.675	3.576	0.75096	17.8
	70	27.525	3.644	0.80168	14.42
	72	26.526	3.564	0.7484	9.8
	74	26.925	3.595	0.755	8.862
	76	26.775	3.596	0.7912	8.2
	78	26.95	3.58	0.7518	12.05
	80	26.375	3.59	0.7556	10.7
	82	27.05	3.55	0.782	6.692
	84	26.275	3.61	0.744	4.68
	86	26.5	3.54	0.748	8.5
	88	26.45	3.56	0.746	7.629
	90	26.1	3.558	0.7412	11.89
	92	26.05	3.53	0.2954	10.1
JULY	94	25.9	2.46	0.2946	13.81
	96	26.15	2.45	0.2962	14.85
	98	25.575	2.436	0.292	17.54
	100	26.325	2.478	0.2974	15.602
	102	26.375	2.48	0.2976	10.6
	104	25.825	2.449	0.294	12.629
	106	25.725	2.44	0.2932	14.68
	108	25.9	2.45	0.2944	23.4
	110	25.775	2.47	0.2936	14.105
	112	25.325	2.42	0.2906	10.45
	114	25.525	2.43	0.2918	12.5
	116	25.85	2.451	0.2942	14.95
	118	25.675	2.441	0.293	16.3
	120	25.625	2.438	0.2926	15.478
	122	25.15	1.972	0.2366	19.98
AUGUST	124	25.325	1.98	0.2376	18.185
	126	24.7	1.95	0.2342	18.332
	128	25.375	1.997	0.2396	15.35
	130	25.55	1.99	0.2388	19.752
	132	25.075	1.97	0.2362	19.596
	134	25.925	2.008	0.241	14.87
	136	25	1.965	0.2358	20.85

	138	24.975	1.964	0.2356	18
	140	25.325	1.9802	0.2376	21
	142	25.225	1.975	0.23708	19.45
	146	25.65	1.995	0.2394	20.69
	148	25.6	1.992	0.23914	22.625
	150	25.325	1.9802	0.2376	12.9
	152	25.9	2.006	0.2408	15.1
	154	25.775	2.0009	0.2401	13.25
	156	25.85	2.004	0.24052	16.57

N.B: These values are obtained by dividing the Etc values in Table 4.9(for five stems) by five. This is for one stem.

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TABLE4.4: CUMULATIVE CROP EVAPOTRANSPIRATION FOR TOMATOES [ROMA] AND CUMULATIVE RAINFALL AT FIVE DAYS INTERVAL [FOR ONE STEM]

Months	D.A.P.[1]	ET_c (mm/day)from lysimeter	ET_c (mm/day) from B.M.N	RAINFALL (mm)
APRIL	5	8.65	6.117	0
10	10	10.027	5.486	5.28
15	15	17.35	5.437	2.78
20	20	14.71	5.461	7.56
25	25	13.72	5.42	13.86
MAY	30	11.58	5.368	20.72
35	35	15.1	5.301	30.68
40	40	13.92	4.047	21.46
45	45	13.05	4.062	14.9
50	50	10.96	4.031	30.74
55	55	10.586	4.008	24.64
JUNE	60	11.8	3.97	36.2
65	65	10.89	3.916	47.74
70	70	27.2	3.775	23.84
75	75	105.14	3.78	33.5
80	80	55.4	3.767	32.2
85	85	29.25	3.766	35.58
JULY	90	44.9	3.627	32.62
95	95	58.96	3.725	24.48
100	100	83	2.578	28.32
105	105	59.46	2.59	45.2
110	110	91.68	2.57	32.64
115	115	58.59	2.571	21.36
AUGUST	120	77.172	2.562	54.74
125	125	92.61	2.551	17.36
130	130	83.164	2.0621	43.34
135	135	92.632	2.084	57.96
140	140	100.9	2.085	34.78

145	145	99.08	2.069	38.4
150	150	87.07	2.088	51.88
155	155	73.84	2.101	32.94
155	155	73.84	2.101	32.94
155	155	73.84	2.101	32.94
150	150	87.07	2.088	51.88
155	155	73.84	2.101	32.94

N.B:These values of ETc for lysimeter are obtained by dividing the values of ETc for lysimeter able 4.10 by five. This is for one stem.

TABLE 4.5 VALUES OF Kc ESTIMATED FROM LYSIIMETER AND BLANEY MORIN NIGERIA MODEL [FOR ONE STEM]

DAYS	$E.T_p$ (mm/day)	$E.T_c$ (mm/day)=ETc.lys / 5	$K_c = ET_c/ET_p$ (mm/day)
2	7.396	1.66	0.04
4	7.9	1.57	0.04
6	7.735	2.19	0.06
8	7.747	1.73	0.04
10	7.6325	2.734	0.07
12	7.822	3.52	0.09
14	7.85	3.4	0.09
16	7.786	3.51	0.09
18	7.625	2.074	0.05
20	7.68	3.526	0.09
22	7.672	2.68	0.07
24	7.585	2.732	0.07
26	7.61	2.78	0.07
28	7.644	1.75	0.05
30	7.514	2.65	0.07
32	7.467	3.3	0.09
34	4.659	2.99	0.13
36	4.608	2.52	0.11
38	4.645	1.85	0.08
40	4.679	3.85	0.16
42	4.625	3.2	0.14
44	4.6252	2.3	0.10
46	4.61	2.05	0.09
48	4.561	2.46	0.11
50	4.596	2	0.09
52	4.583	1.962	0.09
54	4.561	1.986	0.09
56	4.485	2.708	0.12
58	4.53	2.18	0.10
60	4.468	2.374	0.11

62	4.405	2.25	0.10
64	3.64	12.28	0.67
66	3.61	24.12	1.34
68	3.576	17.8	1.00
70	3.644	14.42	0.79
72	3.564	9.8	0.55
74	3.595	8.862	0.49
76	3.596	8.2	0.46
78	3.58	12.05	0.67
80	3.59	10.7	0.60
82	3.55	6.692	0.38
84	3.61	4.68	0.26
86	3.54	8.5	0.48
88	3.56	7.629	0.43
90	3.558	11.89	0.67
92	3.53	10.1	0.57
94	2.46	13.81	1.12
96	2.45	14.85	1.21
98	2.436	17.54	1.44
100	2.478	15.602	1.26
102	2.48	10.6	0.85
104	2.449	12.629	1.03
106	2.44	14.68	1.20
108	2.45	23.4	1.91
110	2.47	14.105	1.14
112	2.42	10.45	0.86
114	2.43	12.5	1.03
116	2.451	14.95	1.22
118	2.441	16.3	1.34
120	2.438	15.478	1.27
122	1.972	19.98	2.03
124	1.98	18.185	1.84
126	1.95	18.332	1.88
128	1.997	15.35	1.54
130	1.99	19.752	1.99
132	1.97	19.596	1.99
134	2.008	14.87	1.48

136	1.965	20.85	2.12
138	1.964	18	1.83
140	1.9802	21	2.12
142	1.975	19.45	1.97
146	1.995	20.69	2.07
148	1.992	22.625	2.27
150	1.9802	12.9	1.30
152	2.006	15.1	1.51
154	2.0009	13.25	1.32
156	2.004	16.57	1.65

NB:Here ETc = ETc.lys / 5 ; [FOR ONE STEM]
ETp is obtained from B.M.N.
These Kc values for one stem are obtained by dividing the Kc values in Table 4.11(for five stems) by five

TABLE 4.6 : DRAINAGE RECORDED DURING THE GROWING SEASON OF TOMATO

D.A.P	Drainage,D (mm)
2	2
4	1.2
6	3.21
8	2.5
10	7.15
12	8.9
14	4
16	4.9
18	1.5
20	1.25
22	3.5
24	3.49
26	5
28	5.1
30	2.5
32	3
34	2.1
36	5
38	3.5
40	2.5
42	3
44	2
46	4.5
48	3.95
50	7
52	4.5
54	5.8
56	6.1
58	5.1
60	7.02
62	5
63	7
64	2.21
65	4
66	2
67	3
68	4.1
69	3.2
70	3
71	2
72	6.5
73	6
74	5.5
75	3
76	1.5
77	3
78	2.5
79	1

TABLE 4.6 CONTINUATION

DAP	D
80	2.98
81	4.1
82	1.2
873	10
84	2.5
85	4.5
86	1.5
87	2.21
89	1.3
90	0.8
91	1
92	3.5
93	1.5
94	4.2
95	2
96	2.5
97	2.3
98	5.1
99	3.9
100	8.5
101	4.5
102	3.5
103	2.56
104	1.75
105	3.5
106	1.2
107	3
108	4
109	0.5
110	3
111	1
112	5.5
113	4.5
114	7.5
115	10
116	4
117	6.5
118	1
119	2.1
120	1.5
121	7.5
122	3.2
123	8.2
124	0.95
125	3
126	5.7
127	2.5
128	6.5

DAP	D
129	0.98
130	6
131	3.24
132	5.5
134	12
135	2.7
136	3
137	2.5
138	13
139	1
140	3
141	9
142	3
143	4
144	2.1
145	2.5
146	18
147	1.25
148	10
149	1
150	10
151	11
152	5.5
153	2
154	1.3
155	10

TABLE 4.7: Worksheet:recorded Evapotranspiration of the tomato growing season.

STATE: NIGER	LATITUDE: 09^0 37'N
PLACE: MINNA	ELEVATIO:848M
CROP TYPE: TOMATOES(ROMA)	
SEASON: 30/03/2003 TO 31/08/2003	
SOIL TEXTURED CLASS: SANDY SOIL	
DEVELOPMENT OF COMPLETE VEGETATIVE COVER STAGE:	

Irrigation days	Irrigation depth ,I (mm)	Change in soil noisture, ΔS (mm)	Drainage,D (mm)	Evapotranspiration,E.T (mm/days)
Sunday- 30/ 03/ 2003	220.0 - 187.6 = 32.4	201.5 - 187.6 = 13.9	2	32.4 -13.8 - 2 = 16.6
Tuesday- 01/ 04 /2003	235.2 - 201.5 = 33.7	201.5 - 185.0 = 16.8	1.2	33.7 - 16.8 -1.2 = 15.7
Thursday- 03/04/2003	220-185=35	185-175.1=9.9	3.21	35-9.9-3.21=21.89
sat- 5/04	210-175.1=34.9	175.1-160=15.1	2.5	34.9-15.1-2.5=17.3
mond- 7/04	204.5-160=44.5	160-150=10	7.15	44.5-10-7.15=27.35
wed- 9/04	202.1-150=52.1	150-142=8	8.9	52.1-8-8.9=35.2
frid- 11/04	200-142=58	162-142=20	4	58-20-4=34
sund- 13/04	218-162=56	178-162=16	4.9	56-16-4.9=35.1
tuesd- 15/04	220-178=42	178-158.25= 19.75	1.5	42-19.75-1.5=20.75
Thurs- 17/04	205- 158.25=46.75	168.5-158.25=10.25	1.25	46.75-10.25-1.25=35.25
sat- 19/04	201-168.5=32.6	170.2-168.5=1.7	3.5	32.5-1.7-3.5=27.4
mond- 21/04	215.1-170.2=44.9	170.2-156.1=14.1	3.49	44.9-14.1-3.49=27.31
wed- 23/04	205-156.1=48 . 9	156.1-140=16.1	5	48.9-16.1-5=27.8
frid- 25/04	200.6-140=60.6	178-140=38	5.1	60.6-38-5.1=17.5
sund- 27/04	217 -178 =39.0	178 -168 = 10	2.5	39 - 10 -2.5 = 26.5
tuesd- 29/04	213 - 168 = 45.0	177 - 168 = 9.0	3	45 - 9 - 3 = 33
Thurs- 01/05/2003	220 - 177 = 43	177 - 166 = 11	2.1	43 - 11 - 2.1 = 29.9
Sat- 03/05	215.2 - 166 = 49.2	185 - 166 = 19	5	49.2 - 19 - 5.0 = 25.2
Mond- 05/05	220 - 185 = 35	185 - 172 = 13	3.5	35 - 13 - 3.5 = 18.5
Wed- 07/05	225 - 172 = 53	172 - 160 = 12	2.5	53 - 12 - 2.5 = 38.5
Frid- 09/05	210 - 160 = 50	160 - 145 = 15	3	50 - 15 - 3.0 = 32
Sund- 11/05	205 - 145 = 60	180 - 145 = 35	2	60 - 35 - 2.0 = 23
Tuesd- 13/05	215 - 180 = 35	180 - 170 = 10	4.5	35 - 10 - 4.5 = 20.5
Thurs- 15/05	208 - 170 = 38	170 - 160.5 = 9.5	3.95	38 - 9.5 - 3.95 = 24.45
Sat- 17/05	203 - 160.5 = 42.5	176 - 160.5 = 15.5	7	42.5 - 15.5 - 7 = 20

Mond- 19/05	210 - 176 = 34	176 - 166.12 = 9.88	4.5	34 - 9.88 - 4.5 = 19.62
Wed- 21/05	202.9 -166.12 = 36.78	166.12 - 155 = 11.12	5.8	36.78 - 11.12 - 5.8 = 19.86
Frid- 23/05	205 - 155 = 50	172 - 155 = 17	6.1	50 - 17 - 6.1 = 26.9
Sund- 25/05	210 - 172 = 38	172 - 160.9 = 11.10	5.1	38 - 11.10 - 5.10 = 21.8
Tues- 27/05	204 - 160.9 = 43.10	173.25 - 160.9 = 12.35	7.02	43.1 - 12.35 - 7.02 = 23.73
Thurs- 29/05	209 - 173.25 = 35.75	173.25 - 165 = 8.25	5	35.75 - 8.25 - 5 = 22.5
FLOURING STAGE				
Irrigation days	**Irrigation depth ,I (mm)**	**Change in soil noisture, ΔS (mm)**	**Drainage,D (mm)**	**Evapotranspiration,E.T (mm/days)**
Sat- 31/05	300 - 165 = 135	165.0 - 159.8 = 5.2	7	135 - 5.2 - 7 = 122.8
Mond- 02/06/2003	305 - 159.8 =145.2	169.5 - 159.8 = 9.7	2.21	145.2 - 9.7 - 2.21 = 133.29
Tues- 03/06	299 - 169.5 = 129.5	187.0 - 169.5 = 17.5	4	129.5 - 17.5 - 4.0 = 108
Wed- 04/06	290 - 187 = 103	187 - 180 = 7	2	103 - 7 - 2 = 94
Thurs- 05/06	302 - 180 = 122	180 - 145 = 35	3	122 - 35 - 3 = 84
Frid- 06/06	290 - 145 = 145	179.5 - 145 = 34.5	4.1	145 - 34.5 - 4.1 = 106.4
Sat- 07/06	230 - 179.5 = 50.5	179.5 - 170 = 9.5	3.2	50.5 - 9.5 - 3.2 = 37.8
Sund- 08/06	240 - 170 = 70	170 - 162 = 8	3	70 - 8 - 3 = 59
Mond- 09/06	225 - 162 = 63	162 - 140 = 22	2	63 - 22 - 2 = 39
Tues- 10/06	215 - 140 = 75	172.81 - 140 = 32.81	6.5	75 - 32.81 - 6.5 = 35.69
Wed- 11/06	240 - 172.81 =67.12	181 - 172.81 = 8.19	6	67.12 - 8.19 - 6 = 52.93
Thurs- 12/06	245 - 181 = 64	181 - 170.5 = 10.5	5.5	64 - 10.5 - 5.5 = 48
Frid- 13/06	240 - 170.5 = 69.5	170.5 - 138 = 32.5	3	69.5 - 32.5 - 3 = 34
Sat- 14/06	230 - 138 = 92	175 - 138 = 37	1.5	92 - 37 - 1.5 = 53.5
Sund- 15/06	260 - 175 = 85	175 - 160 = 15	3	85 - 15 - 3.0 = 67
Mond- 16/06	255 - 160 = 95	178 - 160 = 18	2.5	95 - 18 - 2.5 = 74.5
Tues- 17/06	245 - 178 = 67	211.5 - 178 = 33.5	1	67 - 33.5 - 1 = 32.5
Wed- 18/06	262 - 211.5 = 50.5	211.5 - 187 = 24.5	2.98	50.5 - 24.5 - 2.98 = 23.02
Thurs- 19/06	260 - 187 = 73	212 - 187 = 25	4.1	73 - 25 - 4.1 = 43.9
Frid- 20/06	265 - 212 = 53	212 - 173 = 39	1.2	53 - 39 - 1.2 = 12.8
Sat- 21/06	260 - 173 = 87	216 - 173 = 43	10	87 - 43 - 10 = 34
Sund- 22/06	280 - 216 = 64	216 - 171 = 45	2.5	64 - 45 - 2.5 = 16.4
Mond- 23/06	265 - 171 = 94	192 - 171 = 21	4.5	94 - 21 - 4.5 = 68.5
Tues- 24/06	270 - 192 = 78	220 - 192 = 28	1.5	78 - 28 - 1.5 = 48.5
Wed- 25/06	290 - 220 = 70	220 - 180 = 40	2.21	70 - 40 - 2.21 = 27.79
Thurs- 26/06	275 - 180 = 95	180 - 149.5 = 30.5	1.3	95 - 30.5 - 1.3 = 63.2

Frid- 27/06	250 - 149.5 = 100.5	193.5 - 149.5 = 44	0.8	100.5 - 44 - 0.8 = 55.7
Sat- 28/06	270 - 193.5 = 76.5	193.5 - 144.5 = 49	1	76.5 - 49 - 1 = 26.5
Sund- 29/06	280 - 144.5 = 135.5	202 - 144.5 = 57.5	3.5	135.5 - 57.5 - 3.5 = 74.5
Mond- 30/06	298 - 202 = 96	202 - 180 = 22	1.5	96 - 22 - 1.5 = 72.5
FRUITING STAGE				
Irrigation days	**Irrigation depth ,I (mm)**	**Change in soil noisture, ΔS (mm)**	**Drainage,D (mm)**	**Evapotranspiration,E.T (mm/days)**
Tuesd- 01/07/2003	268.5 - 180 = 88.5	180 - 161.5 = 18.5	4.2	88.5 - 18.5 - 4.2 = 65.6
Wed- 02/07	245 - 161.5 = 83.5	161.5 - 156 = 5.5	2	83.5 - 5.5 - 2 = 76
Thurs- 03/07	260 - 156 = 104	185 - 156 = 29	2.5	104 - 29 - 2.5 = 72.5
Frid- 04/07	285 - 185 = 100	185 - 164.2 = 20.8	2.3	100 - 20.8 - 2.3 = 76.9
Sat- 05/07	280 - 164.2 = 115.8	164.2 - 152 = 12.2	5.1	115.8 - 12.2 - 5.1 = 98.5
Sund- 06/07	270 - 152 = 118	175 - 152 = 23	3.9	118 - 23 - 3.9 = 91.1
Mond- 07/07	265 - 175 = 90	191.5 - 175 = 16.5	8.5	90 - 16.5 - 8.5 = 75
Tuesd- 08/07	280 - 191.5 = 88.5	191.5 - 162 = 29.5	4.5	88.5 - 29.5 - 4.5 = 54.5
Wed- 09/07	260 - 162 = 98	205 - 162 = 43	3.5	98 - 43 - 3.5 = 51.5
Thurs- 10/07	296 - 205 = 91	205 - 150 = 55	2.56	91- 55 - 2.56 = 33.44
Frid- 11/07	258.5 - 150 = 108.5	164.9 - 150 = 14.9	1.75	108.5 - 14.9 - 1.75 = 92.85
Sat- 12/07	255 - 164.9 = 90.1	174.5 - 164.9 = 9.6	3.5	90.1 - 9.6 - 3.5 = 77
Sund- 13/07	260 - 174.5 = 85.5	174.5 - 160 = 14.5	1.2	85.5 - 14.5 - 1.2 = 69.8
Mond- 14/07	298 - 160 = 138	160 - 144 = 16	3	138 - 16 - 3 = 119
Tuesd- 15/07	280 - 144 = 136	144 - 127 = 17	4	136 - 17 - 4 = 115
Wed- 16/07	265 - 127 = 138	186.9 - 127 = 59.9	0.5	138 - 59.5 - 0.5 = 77.6
Thurs- 17/07	305 - 186.9 = 118.1	186.9 - 135.25 = 51.65	3	118.1 - 51.65 - 3 = 63.45
Frid- 18/07	280 - 135.25 = 144.75	215 - 135.25 = 79.75	1	144.75 - 79.75 - 1 = 64
Sat- 19/07	290 - 215 = 75	215 - 186 = 29	5.5	75 - 29 - 5.5 = 40.5
Sund- 20/07	265 - 185 = 80	186 - 160 = 26	4.5	80 - 26 - 4.5 = 49.5
Mond- 21/07	278 - 160 = 118	160 - 125 = 35	7.5	118 - 35 - 7.5 = 75.5
Tuesd- 22/07	270 - 125 = 145	182.5 - 125 = 57.5	10	145 - 57.5 - 10 = 77.5
Wed- 23/07	173 - 182.5 = 90.5	182.5 - 168 = 14.5	4	90.5 - 14.5 - 4 = 72
Thurs- 24/07	270 - 168 = 102	168 - 144 = 24	6.5	102 - 24 - 6.5 = 71.5
Frid- 25/07	250 - 144 = 106	144 - 130.5 = 13.5	1	106 - 13.5 - 1 = 91.5
Sat- 26/07	265 - 130.5 = 134.5	189.54 - 130.5 = 59.04	2.1	134.5 - 59.04 - 2.1 = 73.36
Sund- 27/07	290 - 189.54 = 100.46	189.54 - 172 = 17.54	1.5	100.46 - 17.54 - 1.5 = 81.42
Mond- 28/07	295 - 172 = 123	172 - 137 = 35	7.5	123 - 35 - 7.5 = 80.5

Tuesd- 29/07	275 - 137 = 138	152.5 - 137 = 15.5	3.2	138 - 15.5 - 3.2 = 119.3
Wed- 30/07	280 - 152.5 = 127.5	152.5 - 128 = 24.5	8.2	127.5 - 24.5 - 8.2 = 94.8
Thurs- 31/07	273 - 128 = 145	185 - 128 = 57	0.95	145 - 57 - 0.95 = 87.05
Frid- 01/08/2003	307 - 185 = 122	185 - 132 = 53	3	122 - 53 - 3 = 66
Sat- 02/08	263 - 132 = 131	140 - 132 = 8	5.7	131 - 8 - 5.7 = 117.3
Sund- 03/08	255 - 140 = 115	184 - 140 = 44	2.5	115 - 44 - 2.5 = 68.5
Mond- 04/08	300 - 184 = 116	184 - 159.5 = 24.5	6.5	116 - 24.5 - 6.5 = 85
Tuesd- 05/08	275 - 159.5 = 115.5	159.5 - 124 = 35.5	0.98	115.5 - 35.5 - 0.98 = 79.02
Wed- 06/08	270 - 124 = 146	145.5 - 124 =- 21.5	6	146 - 21.5 - 6 = 118.5
Thurs- 07/08	278 - 145.5 = 132.5	145.5 - 123.7 = 21.8	3.24	132.5 - 21.8 - 3.24 = 107.46
Frid- 08/08	284 - 123.7 = 160.3	190 - 123.7 = 66.3	5.5	160.3 - 66.3 - 5.5 = 88.5
Sat- 09/08	295 - 190 = 105	190 - 155 = 35	12	105 - 35 - 12 = 58
Sund- 10/08	275.4 - 155 = 120.4	155 - 128 = 27	2.7	120.4 - 27 - 2.7 = 90.7
Mond- 11/08	275 - 128 = 147	128 - 87 = 41	3	147 - 41 - 3 = 103
Tues 12/08	280 - 87 = 193	172 - 87 = 85	2.5	193 - 85 -2.5 = 105.5
Wed 13/08	290 - 172 = 118	172 - 132 = 40	13	118 - 40 - 13 = 65
Thurs- 14/08	260 - 132 = 128	132 - 120 = 12	1	128 - 12 - 1 = 115
Frid- 15/08	252 - 120 = 132	133 - 120 = 13	3	132 - 13 - 3 = 116
Sat- 16/08	267 - 133 = 134	133 - 102 = 31	9	134 - 31 - 9 = 94
Sund- 17/08	260 - 102 = 158	151 - 102 = 49	3	158 - 49 - 3 = 106
Mond- 18/08	254 - 151 = 103	151 - 140.5 = 10.5	4	103 - 10.5 - 4 = 88.5
Tuesd- 19/08	260 - 140.5 = 119.5	149.5 - 140.5 = 9	2.1	119.5 - 9 - 2.1 = 108.4
Wed- 20/08	280 - 149.5 = 130.5	149.5 - 120 = 29.5	2.5	130.5 - 29.5 - 2.5 = 98.5
Thurs- 21/08	290 - 120 = 170	128.9 - 120 = 8.9	18	170 - 8.9 - 18 = 143.1
Frid- 22/08	260 - 128.9 = 131.1	175.5 - 128.9 = 46.6	1.25	131.1 - 46.6 - 1.25 = 83.25
Sat- 23/08	285 - 175.5 = 109.5	175.5 - 130 = 45.5	10	109.5 - 45.5 - 10 = 54
Sund- 24/08	230 - 130 = 100	154 -130 = 24	1	100 - 24 - 1 = 75
Mond- 25/08	265 - 154 = 111	175 - 154 = 21	10	111 - 21 - 10 = 80
Tuesd- 26/08	270 - 175 = 95	175 - 162 = 13	11	95 - 13 - 11 = 71
Wed- 27/08	255 - 162 = 93	162 - 124 = 38	5.5	93 - 38 - 5.5 = 49.5
Thurs- 28/08	225 - 124 = 101	140 - 124 = 16	2	101 - 16 - 2 = 83
Frid- 29/08	245 - 140 = 105	158 - 140 = 18	1.3	105 - 18 - 1.3 = 85.7
Sat- 30/08	260 - 158 = 102	170 - 158 = 12	10	102 - 12 - 10 = 80

TABLE 4.8 DIMENSIONAL CHARACTERISTICS OF THE CROP{TOMATO]

DATE	STEM LENGTH	BRANCH LENGTH	N° OFLEAVES FOR TOP BRANCH	N° OF TRUSSES
12/4/03	6cm	0cm	3	1
30/04/03	18cm	8cm	5	1
15/05/03	25cm	10cm	5	2
3/6/03	33cm	12cm	10	2
19/06/03	47cm	21cm	11	3
26/06/03	58cm	20 cm	9	3
6/7/03	74cm	18cm	7	8
20/06/03	79cm	16cm	5	11
7/8/03	85cm	17.5cm	5	13

	TABLE 4.9 DAILY CROP EVAPOTRANSPIRATION FOR TOMATOES(ROMA) [FOR FIVE STEMS]				
	BLANY MORIN NIGERIA METHODS				LYSIMETER METHOD
MONT	DAYS	TEMP	Etp	ETc.B.M.N (mm	ETc.LYSIMETER (mm/day)
	2	32.575	7.396	6.1145	8.3
APRIL	4	32.3	7.9	6.48	7.85
	6	31.25	7.735	6.36	10.95
	8	31.325	7.747	6.37	8.65
	10	30.6	7.6325	6.28	13.67
	12	31.8	7.822	6.423	17.6
	14	31.975	7.85	6.44	17
	16	31.575	7.786	6.398	17.55
	18	30.555	7.625	6.295	10.37
	20	30.9	7.68	6.32	17.63
	22	30.85	7.672	6.315	13.4
	24	30.3	7.585	6.252	13.66
	26	30.45	7.61	6.27	13.9
	28	30.675	7.644	6.295	8.75
	30	29.85	7.514	6.2	13.25
	32	29.55	7.467	6.17	16.5
MAY	34	29.775	4.659	4.07	14.95
	36	29.25	4.608	4.03	12.6
	38	29.625	4.645	4.058	9.25
	40	29.975	4.679	4.086	19.25
	42	29.425	4.625	4.43	16
	44	29.425	4.6252	4.085	11.5
	46	29.275	4.61	4.32	10.25
	48	28.775	4.561	3.994	12.3

	50	29.125	4.596	4.021	10
	52	29	4.583	4.011	9.81
	54	28.775	4.561	4.032	9.93
	56	28	4.485	3.935	13.54
	58	28.45	4.53	3.97	10.9
	60	27.825	4.468	3.92	11.87
	62	27.175	4.405	3.87	11.25
JUNE	64	27.45	3.64	4.04	61.4
	66	27.075	3.61	3.7905	120.6
	68	26.675	3.576	3.7548	89
	70	27.525	3.644	4.0084	72.1
	72	26.526	3.564	3.742	49
	74	26.925	3.595	3.775	44.31
	76	26.775	3.596	3.956	41
	78	26.95	3.58	3.759	60.25
	80	26.375	3.59	3.778	53.5
	82	27.05	3.55	3.91	33.46
	84	26.275	3.61	3.72	23.4
	86	26.5	3.54	3.74	42.5
	88	26.45	3.56	3.73	38.145
	90	26.1	3.558	3.706	59.45
	92	26.05	3.53	1.477	50.5
JULY	94	25.9	2.46	1.473	69.05
	96	26.15	2.45	1.481	74.25
	98	25.575	2.436	1.46	87.7
	100	26.325	2.478	1.487	78.01
	102	26.375	2.48	1.488	53
	104	25.825	2.449	1.47	63.145
	106	25.725	2.44	1.466	73.4
	108	25.9	2.45	1.472	117

	110	25.775	2.47	1.468	70.525
	112	25.325	2.42	1.453	52.25
	114	25.525	2.43	1.459	62.5
	116	25.85	2.451	1.471	74.75
	118	25.675	2.441	1.465	81.5
	120	25.625	2.438	1.463	77.39
	122	25.15	1.972	1.183	99.9
AUGU	124	25.325	1.98	1.188	90.925
	126	24.7	1.95	1.171	91.66
	128	25.375	1.997	1.198	76.75
	130	25.55	1.99	1.194	98.76
	132	25.075	1.97	1.181	97.98
	134	25.925	2.008	1.205	74.35
	136	25	1.965	1.179	104.25
	138	24.975	1.964	1.178	90
	140	25.325	1.9802	1.188	105
	142	25.225	1.975	1.1854	97.25
	146	25.65	1.995	1.197	103.45
	148	25.6	1.992	1.1957	113.125
	150	25.325	1.9802	1.188	64.5
	152	25.9	2.006	1.204	75.5
	154	25.775	2.0009	1.2005	66.25
	156	25.85	2.004	1.2026	82.85

0

TABLE :4.10

TABLE4.10 CUMULATIVE CROP EVAPOTRANSPIRATION FOR TOMATOES [ROMA] AND CUMULATIVE RAINFALL AT FIVE DAYS INTERVAL [FOR FIVE STEMS]

Months	D.A.P.[1]	ET_c (mm/day)from lysimeter	ET_c (mm/day) from B.M.N	RAINFALL (mm)
APRIL	5	43.25	30.585	0
10	10	50.135	27.43	5.28
15	15	86.75	27.185	2.78
20	20	73.55	27.305	7.56
25	25	68.6	27.1	13.86
MAY	30	57.9	26.84	20.72
35	35	75.5	26.505	30.68
40	40	69.6	20.235	21.46
45	45	65.25	20.31	14.9
50	50	54.8	20.155	30.74
55	55	52.93	20.04	24.64
JUNE	60	59	19.85	36.2
65	65	54.45	19.58	47.74
70	70	136	18.875	23.84
75	75	525.7	18.9	
80	80	277	18.835	32.2
85	85	146.25	18.83	35.58
JULY	90	224.5	18.135	32.62
95	95	294.8	18.625	24.48
100	100	415	12.89	28.32
105	105	297.3	12.95	45.2
110	110	458.4	12.85	32.64
115	115	292.95	12.855	21.36
AUGUST	120	385.86	12.81	54.74
125	125	463.05	12.755	17.36
130	130	415.82	10.3105	43.34
135	135	463.16	10.42	57.96
140	140	504.5	10.425	34.78
145	145	495.4	10.345	38.4

150	150	435.35	10.44	51.88
155	155	369.2	10.505	32.94
155	155	369.2	10.505	32.94
155	155	369.2	10.505	32.94
150	150	435.35	10.44	51.88
155	155	369.2	10.505	32.94

TABLE: 4.11

TABLE 4.[illegible] VALUES OF Kc ESTIMATED FROM LYSIIMETER AND BLANEY MORIN NIGERIA MODEL			
		[FOR. FIVE. STEMS]	
DAYS	$E.T_p$ (mm/day)	$E.T_c$ (mm/day)=ETc.lys / 5	$K_c = ET_c/ET_p$ (mm/day)
2	7.396	1.66	0.224445646
4	7.9	1.57	0.198734177
6	7.735	2.19	0.283128636
8	7.747	1.73	0.22331225
10	7.6325	2.734	0.358205044
12	7.822	3.52	0.450012784
14	7.85	3.4	0.433121019
16	7.786	3.51	0.450809145
18	7.625	2.074	0.272
20	7.68	3.526	0.459114583
22	7.672	2.68	0.349322211
24	7.585	2.732	0.360184575
26	7.61	2.78	0.365308804
28	7.644	1.75	0.228937729
30	7.514	2.65	0.352675007
32	7.467	3.3	0.441944556
34	4.659	2.99	0.64176862
36	4.608	2.52	0.546875
38	4.645	1.85	0.398277718
40	4.679	3.85	0.82282539
42	4.625	3.2	0.691891892
44	4.6252	2.3	0.497275793
46	4.61	2.05	0.444685466
48	4.561	2.46	0.539355405
50	4.596	2	0.43516101
52	4.583	1.962	0.428103862
54	4.561	1.986	0.435430827
56	4.485	2.708	0.603790412
58	4.53	2.18	0.481236203
60	4.468	2.374	0.53133393

62	4.405	2.25	0.510783201
64	3.64	12.28	3.373626374
66	3.61	24.12	6.681440443
68	3.576	17.8	4.977628635
70	3.644	14.42	3.957189901
72	3.564	9.8	2.749719416
74	3.595	8.862	2.465090403
76	3.596	8.2	2.280311457
78	3.58	12.05	3.365921788
80	3.59	10.7	2.980501393
82	3.55	6.692	1.885070423
84	3.61	4.68	1.296398892
86	3.54	8.5	2.401129944
88	3.56	7.629	2.142977528
90	3.558	11.89	3.341765037
92	3.53	10.1	2.861189802
94	2.46	13.81	5.613821138
96	2.45	14.85	6.06122449
98	2.436	17.54	7.200328407
100	2.478	15.602	6.296206618
102	2.48	10.6	4.274193548
104	2.449	12.629	5.156798693
106	2.44	14.68	6.016393443
108	2.45	23.4	9.551020408
110	2.47	14.105	5.710526316
112	2.42	10.45	4.318181818
114	2.43	12.5	5.144032922
116	2.451	14.95	6.099551204
118	2.441	16.3	6.677591151
120	2.438	15.478	6.348646432
122	1.972	19.98	10.13184584
124	1.98	18.185	9.184343434
126	1.95	18.332	9.401025641
128	1.997	15.35	7.686529795
130	1.99	19.752	9.925628141
132	1.97	19.596	9.947208122
134	2.008	14.87	7.405378486

136	1.965	20.85	10.61068702
138	1.964	18	9.16496945
140	1.9802	21	10.6049894
142	1.975	19.45	9.848101266
146	1.995	20.69	10.37092732
148	1.992	22.625	11.35793173
150	1.9802	12.9	6.514493486
152	2.006	15.1	7.527417747
154	2.0009	13.25	6.622020091
156	2.004	16.57	8.268463074

NB:Here ETc = ETc.lys / 5 ; [FOR ONE STEM]
ETp is obtained from B.M.N.