SCHOOL OF ENGINEERING AND ENGINEERING TECHNOLOGY

FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

EVAPOTRANSPIRATION OF SELECTED CEREALS IN NIGER STATE

BY

MOHAMMED .B.

DEPARTMENT OF AGRICULTURAL ENGINEERING

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submitted in partial fulfilment of the requirements for the award of the Degree of Bachelor of Engineering (Agricultural Engineering)

Approved By:

External Examiner ______ Sign/Date ______

Project Supervisor ______ Sign/Date ______ Project Co-Supervisor ______ Sign/Date ______

Head of Department ______ Sign/Date ______

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External Examiner — Sign/Date: 15/4/94

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Project Co-Supervisor — Sign/Date: 25-04-94

Head of Department — Sign/Date: 25-04-94

DEDICATION

This project is dedicated to the absolute reality, the first, the last, the hidden, the manifest and the centre of my progress.

ACKNOWLEDGEMENT

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My most sincere feelings of appreciations and thanks goes to my Project supervisor and academic adviser Engineer Nosa A. Egharevba for his dedication and assistance towards the completion of this project. Same goes to my project Co-Supervisor and Head of Department, Engineer (Dr) A. Ajisegiri for his co-operation and willingness to help throughout the project work. I have not forgetten Engineer Adekola and the rest of the department staff, whose concern and suggestions really inspired me to work.

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ABSTRACT

This Project work presents the determination of evapotranspiration for wheat, maize, sorghum and millet in Niger State. Based on grass reference evapotranspiration ETo, with the FAO Irrigation and Drainage Paper - 24 proceedure and crop coefficients (Kc), using measured data from meteorological station for a period of 15 years, and local information on the crops considered.

From the statistical analysis carried out and the data requirements of the various models used, the modified Penman method was adopted, Kc curves for each of the crops were developed. Evapotranspiration and crop water requirement at various stages of growth for the crops were determined. A computer programme for determining ETo was also developed.

The Kc curves and the crop evapotranspiration determined can be recommended for use in water management decisions throughout the State.

CHAPTER ONE

INTRODUCTION

1.1 INTRODUCTORY NOTES AND BACKGROUND

Dryland, rainfed agriculture accounts for most of the food and fibre production in Niger State. This area supports well over two million people (1991 Population Census), persistent drying trends over the last two decades points to the need for improved water management. This may involve supplementary irrigation or breeding drought tolerant varieties. In any case the water requirement of existing crops varieties need to be known.

Rapid population growth and expanding agricultural sector activities within the State are increasing the demand for water for irrigation, on the other hand, the construction of irrigation schemes, and different control structures, within and outside the State is a serious threat to the ensured and adequate availability of water. Therefore, proper understanding of the optimal crop evapotranspiration is very important for a judicious use of scarce water resources. This study aims at estimating the water requirement of the widely grown cereals in Niger State.

1.2 DEFINITION OF CROP WATER REQUIREMENT (ETc)

Crop water requirement are defined here as the depth of water needed to meet loss through evapotranspiration of a disease-free crop growing in large fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment.

1.3 DEFINITION OF REFERENCE CROP EVAPOTRANSPIRATION (ETo)

It is defined here as the evapotranspiration from an extensive surface 8 to 15cm tall, green grass cover of uniform height, actively growing, completly shading the ground and not short of water.

1.4 DEFINITION OF CROP PHYSICAL CHARACTERISTICS (Kc)

These are the characteristics of the crops that affect it rates of transpiration and evaporation from bare soils, they comprise of the leaf, its shape and features at various stages of growth.

1.5 INDIRECT MEASUREMENT OF CROP WATER REQUIREMENT

Prediction methods for determining water requirement were used owing to the difficulty of obtaining accurate field measurements. The direct methods often need to be applied under climatic and agronomic conditions very different from those under which they were originally developed. Testing the accuracy of the methods under a new set of conditions is labourious, time consuming and costly, and yet the result is required at short notice, for it to be reasonably used for project planning and development.

1.6 STAGES IN COMPUTING CROP WATER REQUIREMENT

In computing the crop water requirement a three-stage proceedure was used.

1.6.1 The effect of climate on crop water requirement. The four indirect methods presented were modified to calculate the reference crop evapotranspiration, using the daily climatic data for 30 - day periods. Primarily the choice of the method adopted was based on the climatic data available and the level of accurancy that was required in determining water needs, couple with the result of the statistical analysis in testing the various methods.

1.6.2 The effect of crop characteristics on crop water requirement. Values of the crop coefficient (Kc) which varies with the crop, its stage of growth and the growing season were computed with data obtained from local information on date of planting, harvesting, the soil surface coverage at each stage of growth.

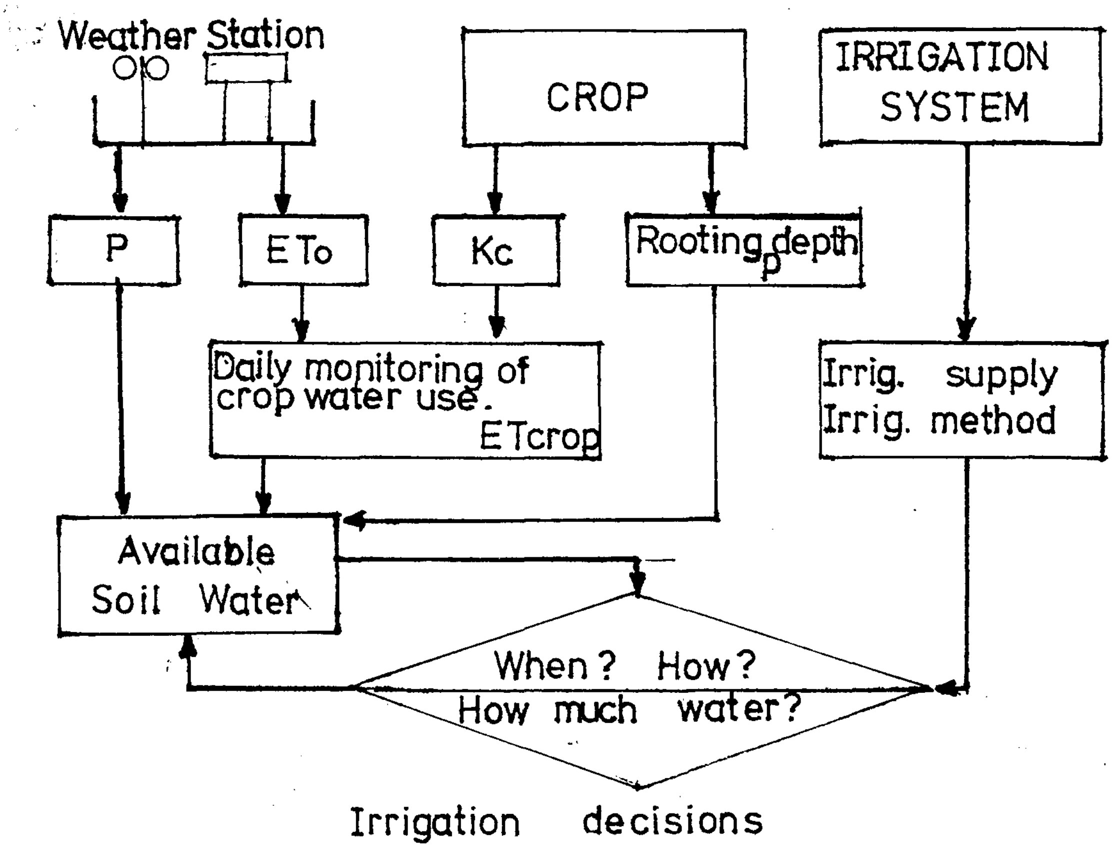


Fig. 1.0 Schematic representation of an irrigation management system.

1.6.3 Crop water requirement determination.

Computing the crop water requirement for each crop with the relationship.

ETc = ETo . Kc

1.7 LOCATION

Niger State is located within (Longitude 8^{o}- 10^{o}N; Latitude 5^{o}-7^{o}E), it is one of the State in Nigeria, within the semi arid zone.

1.8 WEATHER DATA

Weather data used represent mean values of 30 - day period, for a total period of 15 years (1979 - 1993). Individual year always have values either higher or lower than the means, with a reasonable level of standard deviation. This fact increases the level of confidence about the value of the calculated water requirement.

1.9 CLIMATE

The climate of the project area is characterised by distinct wet and dry seasons which correspond with the North South season generally lasts from april to October, approximately 200 days. The dry season, for a period is marked by harmattan condition which may prevail for a few hours or several days.

1.10 CEREAL CROPS SELECTED

The crops selected are the most widely grown, and those that have potential for greater economic benefit.

1.10.1 MAIZE (Zea Mays)

Maize is one of the most important grain crops and is geographically the most widely planted species. The maturity period is about 120 days. Maize is grown in a wide variety of soils. One essential requirement however is good drainage. It grows well in areas with rainfall between 500-600mm per annum.

1.10.2 GUINEA CORN (Sorghum guineese)

The grain Sorghum supply food for a large proportion of the population of Niger State and eaten in many different forms. It grows well in areas with rainfall between 600-1200mm per annum. It requires a dry and sunny climate for optimum growth.

1.10.3 MILLET (Pennisetum americanum)

It is a staple crop for most homes in the State, it requires temperatures above 20^{o}C if the grain is to ripen, and an annual rainfall of between 600-800mm. It will tolerate dry spells in the early stages of its growth but needs to be kept moist after the first month.

1.10.4 WHEAT (Triticum aestivum)

Though not widely grown in Niger State. It is a potential crop that can be widely grown, with improvement in irrigation facilities. The crop require a good water supply from the start of tillering until the green grain has developed. It grows well in areas with annual rainfall of between 400-500mm of rainfall, though it is considered to be less resistance to irregular rainfall.

1.11 OBJECTIVES OF THIS PROJECT

The objectives of this project were:-

i) To determine the local input parameters necessary for the computation of crop water requirement of the selected crops.

ii) To determine the effect of climate on the crop water requirement, given by the reference crop evapotranspiration (ETo).

iii) To determine the crop coefficient, for each of the selected crops (Kc).

iv) To determine the crop water requirement for each of the crops considered (ETc).

v) To obtain a water budget for the State.

vi) To determine the irrigation requirement for each of the crops considered.

vii) To determine the gross diversion requirement, for designing and constructing dams within the State.

1.12 JUSTIFICATION OF THIS PROJECT

This study was conducted to determine the water requirement of maize, sorghum, millet and wheat in Niger State, with a view to address the recent drought and a persistence drying trend over the last fifteen years which point to the need for improved water management.

The water requirement obtained will aid in determining the water balance of the rainfed crops and estimating supplementary irrigation and water conservation goals to treat this water requirement. Evaluating the suitability of cropping patterns based on estimates of water balance for the area. The information will be in maximum benefit for the entire state, as it will increase the production levels of the crops as well as justify their worth to society if properly utilized.

1.13 LIMITATION OF THIS PROJECT

Direct measurement methods were not used owing to their high installation cost, as for any reasonable level of accuracy, they must be large enough to minimize boundary effect.

The result of this study is required within a reasonable period of time, for testing the accuracy of direct measurement type is time consuming and costly, and will not represent a base value for the whole State.

1.14 BASIC ASSUMPTIONS

i) Precipitation (P). This is defined as cumulative rainfall during a standard monthly period. It is assumed that falls less than 0.01mm do not contribute to the soil water storage and are evaporated almost immediately from the soil surface.

ii) A reflection coefficient of 0.25 was used for the modified penman calculation of reference crop evapotranspiration.

iii) Growing season. It is assumed that the cereals crops can mature without ill effect after the end of the rains.

iv) It is assumed that the whole state has a homogenous soil type.

CHAPTER TWO

LITERATURE REVIEW

2.0 PLANT WATER RELATIONSHIPS

Almost every plant process is affected directly or indirectly by water supply. Water constitutes about 80 to 90 percent of most plant cells and tissues in which there is active metabolism. It forms a continuous liquid phase through the plant from the root hairs to the leaf epidermis. Plant roots take up water and transfer it through the root tissues to the conducting vessels of the plant . These conducting vessels pass it on to the mesophyll tissues of the leaves. After moving through these tissues , the water reaches the evaporation sites which are primarily the walls of the sub-stomatal cavities. All these flows are in the liquid phase along a potential gradient. The final transfer of water from the sub-stomatal cavities through the stomata of the leaves is a process of molecular diffusion of water vapour (Michael 1978).

The factors influencing the water relations of plants and thus their growth and yield responses, may be grouped into the followings:-

i) Soil factors -Soil moisture content, texture, structure, density, salinity, fertility, aeration, temperature and drainage.

ii) Plant factors - type of crop, density and depth of rooting, rate of root growth, aerodynamic roughness of the crops, drought tolerance and varietal effects.

iii) Weather factors- sunshine, temperature, humidity, wind and rainfall.

iv) Miscellaneous factors- soil volume and plant spacing, soil fertility, crop and soil management.

2.1 ABSORPTION OF WATER IN SOIL-PLANT-ATMOSPHERE SYSTEM

The root system is extremely variable in different crop plants. The variability exists in rooting depth, root length and horizontal distribution of roots. These are further influenced by environmental factors and the genetic constitution. Singh (1976), discovered that the root of cereals, apparently, occupy more surface area of the soil than other crops. He shows that cereal roots extend to 200-400cm^2 soil surface as against 150-200cm^2 for non-graminaceous plants.

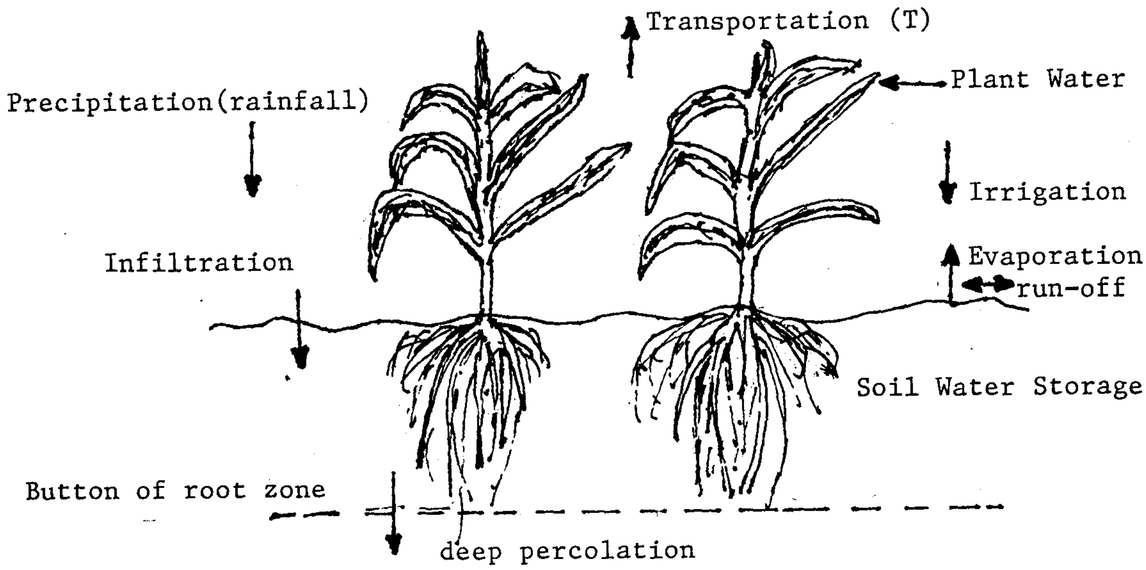


Fig. 2.0 Schematic sketch illustrating soil - plant - atmosphere system.

It is desiderable to consider water absorption in the total soil-plant-atmosphere system instead of the roots alone. In this system, one can partition the system in such a manner so that the involvement of different plant parts is taken into acount. The flow rate of water in this system is given by the equation below.

$$\text{Flow rate} = \frac{V\ \text{xylem} - V\ \text{leaf}}{r\ \text{xylem} + r\ \text{leaf}} = \frac{V\ \text{leaf} - V\text{air}}{r\ \text{leaf} + r\ \text{air}}$$

in which, V is the water potential at various sites of the system and r is the corresponding resistance.

2.2 EVAPORATION, TRANSPIRATION AND REFERENCE EVAPOTRANSPIRATION

Evaporation, transpiration and water requirement are important factors in estimating irrigation requirement and planning irrigation system.

2.2.1 EVAPORATION

Evaporation is the process during which a liquid changes into gas. The process of evaporation in nature is one of the fundamental components of the hydrological cycle by which water changes to vapour through the absorption of heat energy.

Evaporation from natural surfaces, such as open water, bare soil or vegetation cover is a diffusive process, by which water in the form of vapour is transferred from the underlying surface to the atmosphere.

The fundamental principle of evaporation from a free surface was enunciated by Dalton in the year 1882. Dalton stated that evaporation is a function of the difference in the vapour pressure of the water and the vapour pressure of the air. Several empirical equations for estimating evaporation are based on Dalton law, which may be written as follows:-

$$E = (es - ed)\ f\ (u) \qquad 2.2.1$$

Where

E = Evaporation

es = saturation vapour pressure at the temperature of evaporation surface, mm Hg

ed = saturation vapour pressure at the dew point temperature of the atmosphere, mm Hg

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

2.2.2 TRANSPIRATION

Transpiration is the process by which water vapour leaves the living plant body and enters the atmosphere. It occurs when the vapour pressure within the leaf exceeds that of surrounding air and stomata are open to allow carbon dioxide into the plant for photosynthesis.

The rate at which water vapour escapes the leaf, that is, the transpiration rate is given by Larry (1988)

$$T = e\ leaf - e\ air \qquad 2.2.2$$

Where T = Transpiration rate

e leaf = vapour pressure within the leaf
e air = vapour pressure of air
r leaf = resistance to vapour flow through the stomata
r air = resistance to vapour flow through the air boundary layers around the leaf.

Transpiration generally occurs whenever stomata are open, since e leaf usually exceeds e air. It is commonly assumed that e leaf equals the saturation vapour pressure for the temperature within the leaf, since there is usually at least some water in the leaf even if it is wetted.

2.3 REFERENCE EVAPOTRANSPIRATION

Evapotranspiration, or consumptive use, denotes the quantity of water transpired by plants during growth, or retained in the plant tissues. plus the moisture evaporated from the surface of the soil and the vegetation.

The concept of reference evapotranspiration (ETo) was suggested by Thornthwaite (1978) who defined it as the evapotranspiration from a large vegetation covered land surface with adequate moisture at all times. He felt that since the moisture supply was not restricted the ETo depended solely on available moisture. Penman (1948) defined ETo as the ET from an actively growing short green vegetation completely shadding the ground and never short of moisture availability. Though Penman's definition is complete it does not specify the name of the vegetation. Jensen (1968) assumed ETo as the upper limit of ET that would occur with a well watered crop having an aerodynamically rough surface such as lucern with 30-50cm of top growth.

Apparently, the concept of ETo can be visualized as the evapotranspiration process. It may be defined as the upper limit of ET that occurs when the ground is completely covered by actively growing vegetation and where there is no limitation in the soil moisture. It may be considered as the upper limit of ET for a crop in a given climate.

2.3 DETERMINING EVAPOTRANSPIRATION

Crop evapotranspiration is determined by direct measurement or calculated from crop and climate data. Direct measurement techniques involves isolating a portion of the crop from its surrounding and determining evapotranspiration by measurement.

2.3.1 DIRECT MEASUREMENT OF EVAPOTRANSPIRATION

The most widely used direct measurement techniques are based on the conservation of mass principle. Equation 2.3 defined the conservation of mass principle (James 1988) in control volume as

$$Ds = Drz\ (0_f - 0_i) = \text{Inflow} - \text{outflow} \qquad 2.3$$

Where

Inflow, outflow = total flow into and out of the control volume during the time interval being considered, respectively (cm)

Drz = Depth of root zone (below soil surface) (cm)

0_f, 0_i = Soil moisture content by volume at end (final) and beginning (initial) of the time interval being considered, respectively (decimal).

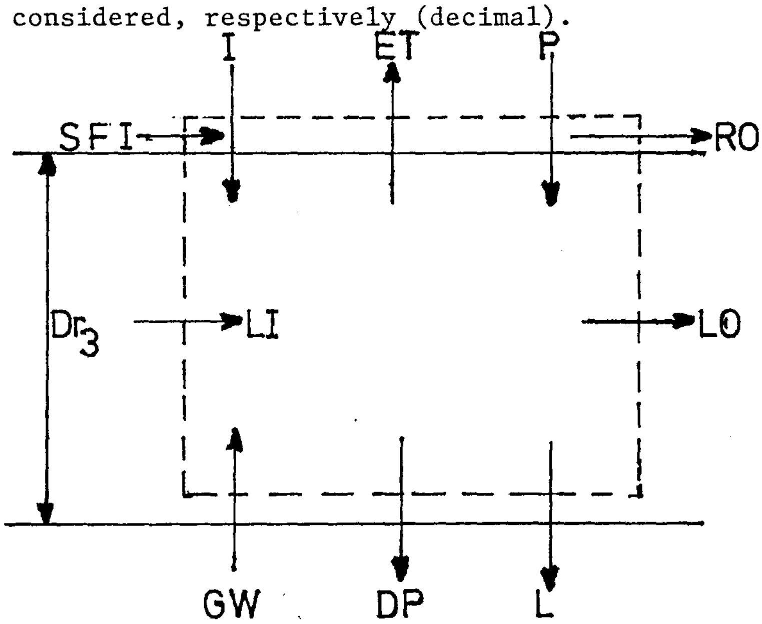


Fig. 2.3 Definition sketch for equation 2.3

Where, I = irrigation (cm)

P = precipitation (rain) (cm)

SFI = surface flow into the control volume (cm)

LI = subsurface lateral flow into the control volume (cm)

GW = groundwater seepage into the control volume (cm)

ET = evapotranspiration (cm)

RO = surface flow out of the control volume (cm)

LO = sub surface lateral flow out of the control valume(cm)

L = leaching requirement (amount of water that must flow

DP = deep percolation (downward movement of water from the control volume in excess of that needed for leaching (cm).

From figure 2.3

$$\text{Inflow} = I + P + SFT + GW \qquad 2.3.1$$

and

$$\text{Outflow} = ET + RO + LO + L + DP \qquad 2.3.2$$

All terms in equation 2.3, 2.3.1, 2.3.2 are depth and have dimenstions of length. Substitution of equation 2.3.1 and 2.3.2 into equation 2.3 and solving for ET yield equation 2.3.3.

$$ET = I + P + SFI + LI + GW + RO - L - DP + Drz\,(0_f - 0_i) \qquad 2.3.3$$

2.3.1.1 LYSIMETERS

Crops are often grown in soil-filled tanks called lysimeter, to facilitate application of equation 2.3.3. Lysimeters hydrologically isolate soil within them from surrounding soil and make it possible to eliminate SFI, LI and LO, while GW, RO, L and DP are either eliminated or measured. ET can be calculated when I, P, D, 0_i, 0_f have been measured.

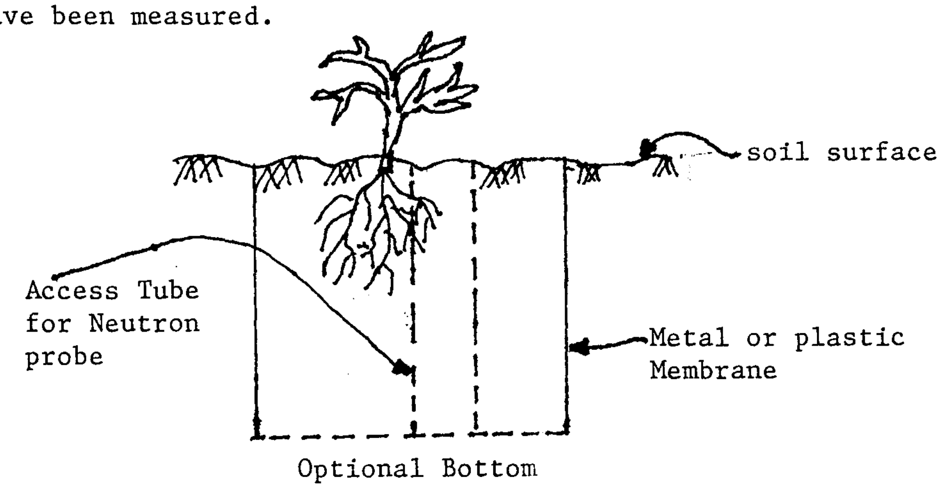


Fig. 2.3.1 A non - weghing Lysimeter.

Lysimeters differ in the way in which Ds is determined. Weighing lysimeters are constructed so that Ds is determined by weighing. Various techniques for measuring or infering changes in soil moisture are used to determine Ds in non-weighing lysimeters. Figures 2.3.1 and 2.3.2 show the primary differences in the construction of weighing and non-weighing lysimeters. Weighing lysimeters have a second tank that retain surrounding soil so ... container is free for weighing. They also

Non-weighing lysimeters may or may not have this capability.

James (1988) found that the reliability of evapotranspiration data collected with the lysimeters depends on how well the conditions within the lysimeters (i.e. soil structure and density, drainage characteristics, temperature, desity, height etc of the crops) match conditions surrounding the lysimeter. Lysimeters must be large enough to minimize boundary effects and to avoid restricting root development. High installation costs and the immobility of lysimeters preclude their use as routine field instruments.

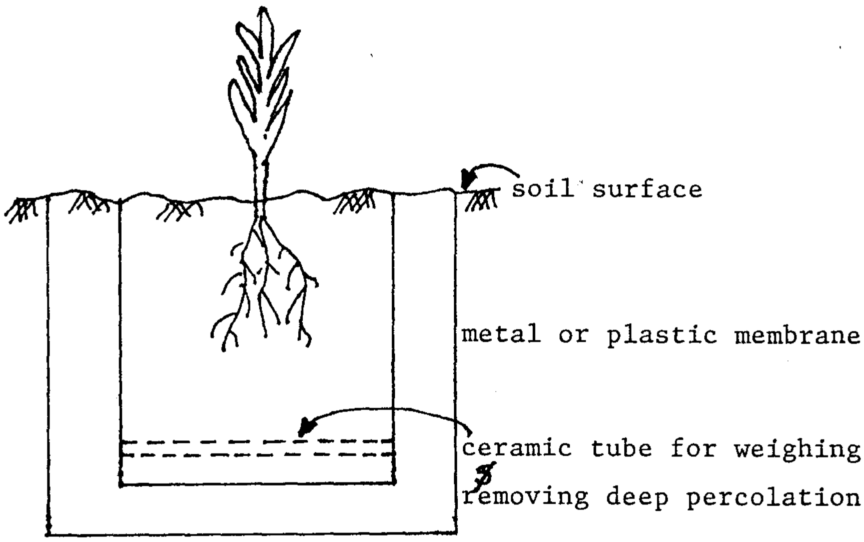


Fig. 2.3.2 A weighing lysimeter.

2.3.1.2 FIELD WATER BALANCES

Equation 2.3.3 can also be used to determine evapotranspiration in irrigation fields by field water balancing (without the use of lysimeter). The accuracy of evapotranspiration estimates obtained in this manner is usually reduced because it is normally more difficult to control and or measure one or more of the terms in equation 2.3.3. The terms 0_f and 0_i (Hansen 1979).

2.3.1.3 EVAPOTRANSPIRATION CHAMBERS

Another direct measurement technique uses an above ground chamber to enclose a vegeted area was developed by Reicosky and Peters (1977). The chamber is transparent to radiation and prevents water exchange with the atmosphere.

Though useful for many studies, the space inside the chamber is not representative of conditions outside the chambers since

All the above direct measurement approach have the advantage that all the parameters of the hydraulic equation are being considered. However, the following disadvantages limit their use:-

i) They must be large enough to minimize boundary effects and to avoid restricting root development.

ii) High installation cost, because of their size, if there if going to be any reasonable level of accuracy

iii) The immobility of the instrument makes them to be applied under climatic and agronomic conditions very different from those which they were originally developed.

iv) Testing the accuracy of the methods under a new set of conditions is laborious, time consuming and costly.

2.3.2 COMPUTING EVAPOTRANSPIRATION

Because evapotranspiration is not easy to measure either in the atmosphere or in the soil Tanner (1967), it is often estimated in relation to indicators of atmospheric evaporative demand. Many methods with differing data requirements and level of sophistication have been developed for computing evapotranspiration Some of these methods require daily relative humidity, solar radiation, wind and air temperature data, which others needed only mean monthly temperatures. Some are physically or physiologically based while others are determined empirically. The more commonly used formulae in estimating evapotranspiration are:-

(a) Blaney - Criddle (Temperature) method;

(b) Radiation method;

(c) Penman method;

(d) Pan evaporation method.

2.3.2.1 TEMPERATURE METHOD

Blaney and Criddle (1950) observed that the amount of water consumptively used by crops during their growing seasons was closely correlated with mean monthly temperatures and daylight hours. In order to adjust the method to various adjective factor, C, has been introduced. The equation is given by

$ET = C\ [P\ (0.46\ T + 8]$mm/day

where

C=adjustment factor which depends on mean humidity and wind condition.

ET=Evapotranspiration in mm/day.

P=mean daily percentage of total annul day time hours for a given month and latitude.

T=Mean daily temparature in °C.

Table 2.3.2 Climatic data needs of the various methods of computing evapotranspiration.

		CLIMATIC VARIABLES				
Methods	Temperature	Relative Humidity	Wind	Sunshin	Radia tion	Evapora tion
Blanney-Criddle (Temperature)	*	o	o	o		
Radiation	*	o	o	*	[*]	
Penman	*	*	*	*	[*]	
Pan evaporation		o	o			*

* Measured data

(*) If available

o estimated data

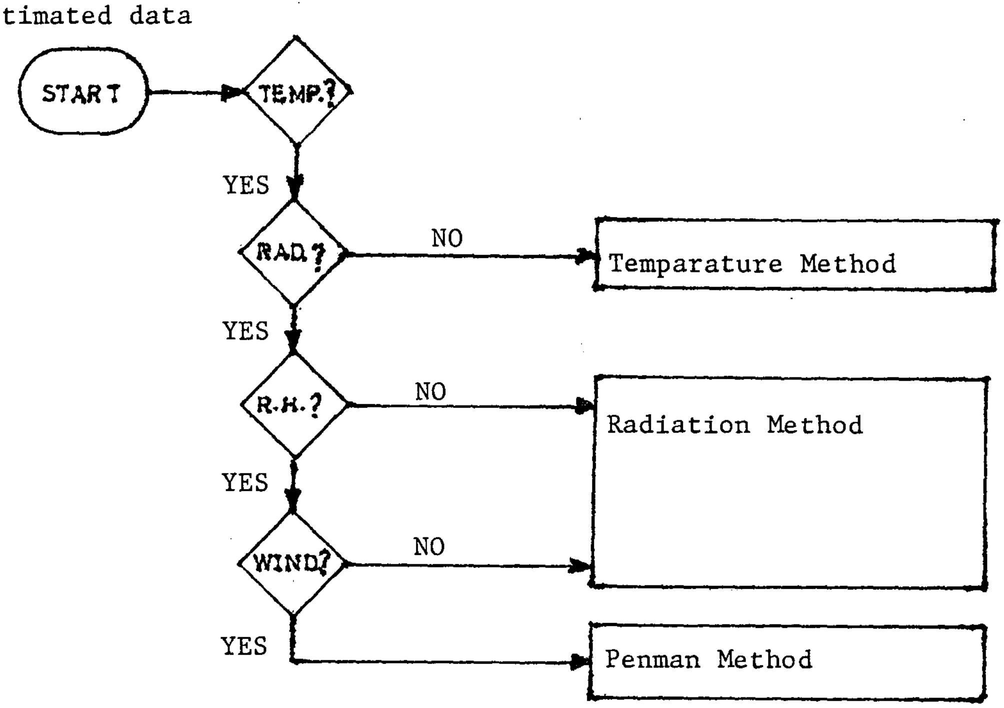


Fig. 2.3.2 Flow chart for the choice of computing evapotranspiration

2.3.2.2 RADIATION METHOD

The strong dependence of evapotranspiration on the radiation term has given rise to a formular based upon solar radiation measurements. This formular eliminate the effect of the surface albedo (reflectivity) and minimize the contribution of the aerodynamic term. The radiation method is essentially an adaptation of the Makkink formular (1957). This method require measured air temperature and sunshine, cloudiness or radiation, but not measured wind and humidity.

The relationship is given by

$$ET = C \; (W.Rs) \text{ mm/day} \qquad 2.3.2.3$$

Where

ET = evapotranspiration in mm/day for the period considered.

Rs = solar radiation in equivalent evaporation in mm/day

W = weighing factor which depends on temperature and altitude.

2.3.2.3 PENMAN METHOD

Penman (1948) proposed an equation for evaporation from open water surface, based on a combination of energy balance and sink strength which is given by

$$E = \frac{DQn + YE_a}{D + Y} \qquad 2.3.2.3$$

Where E_o = Evaporation from open water surface, mm/day

D = Scope of saturarion vapour pressure

Q_n = Net radiation, mm of water

Y = Psychrometric Constant

E_a = Aerodynamic component

Based on intensive studies of the climatic and measured grass evapotranspiration data from various research stations in the world and the available literature on prediction of evapotranspiration, Doorenbos and Pruit (1977) proposed a modified Penman method to facilitate the computation of evapotranspiration.

The formular is given by

$$ET = c[WRn + (1-w). F(u). (ea - ed)] \qquad 2.3.2.4$$

Where

ET = evapotranspiration in mm/day

W = temperature-related weighing factor

Rn = net radiation in equivalent mm/day

f(u) = wind related function

$(e_a - e_d)$ = difference between the saturation vapour pressure at mean air temperature and the mean actual vapour pressure of the air, both in Mbar.

C = adjustment factor to compensate for the effect of day and night weather conditions.

2.3.2.4 PAN EVAPORATION METHOD

Pan evaporation data can be used to calculate evapotranspiration because evaporation from the pan is an integral of the effects of radiation, wind, temperature and humidity on the pan.

However physical differences between pan and grass make adjustments necessary. These differences are:-

(a) Albedo (reflectivity) of water in the pan is 5-8%, where as for grass it is 20-25%;

(b) Pans can store heat which can be used to evaporate water even at night where as crops transpire only during day time;

(c) There are differences in micro climate (wind turbulence, humidity and temperature) around the pan compare to a crop;

(d) Some heat can be transfered from the environment to the pan especially in Sunken pan. This can enhance evaporation;

(e) Local condition of heat depending on where pan is sited, can affect measured evaporation.

From these reasons an adjustment factor is necessary to relate evapotranspiration to pan evaporation, the relation is expressed as

$$ET = Kp \cdot Epan \qquad 2.3.2.5$$

Where

ET = Evaporation in mm/day

Kp = Pan Coefficient

Epan = Measured daily pan evaporation in mm/day for the period considered.

2.4 CROP EVAPOTRANSPIRATION STUDIES IN THE PROJECT AREA

There have been very few studies on water requirement or evapotranspiration of crops in the area. In such studies Kowal and Knabe (1970) used the original Penman equation (1948) in estimating evapotranspiration for the whole of Northern Nigeria of which Niger State was included. Kasam et. al (1975), measured

In the feasibility report by Minco Nig Ltd(1981) for the design of Kontangora Dam Project, the original penman equation was also used. However, with the modifications made to the original equation, this project became necessary.

CHAPTER THREE

3.0 PHYSICAL VARIABLES:

Several proceedures have been assesed to estimate evapotranspiration in the previous chapter in relation to these physical variables. Accuracy of the estimate depends largely on the accurancy of the measurements of the variables involved. This accuracy in turn depends on proper siting of weather stations, installation and maintainance of recording instruments and making of observations. In this chpater the definition, units, measurement and recording of the key physical variables of temparature, humidity wind and solar radiation are discussed. The objective is to:-

(a) Review the physical variables relevant for the calculation of crop water requirement in Niger State.

(b) To be acquinted with the available meteorological data;

(c) To prepare basic summaries and statistics of meteorological data relevant for computing crop water requirement of the selected crops (Maize, Surghum, Millet and Wheat) in Niger State.

3.1 WEATHER STATIONS:

Most meteorological data relevant to irrigation planning and operation are collected at meteorological stations. However, there are differences in weather stations depending on the purpose for which they were established. There are aeronautic (general use), hydrometeorological stations. Aeronautic stations are normally sited at airports, hydrometeorological stations are sited in hydrological watershed and dams. They collect mainly precipitation data for use in hydrological analysis. Agrometeorological stations are sited in cropped area where instruments are exposed to atmospheric conditions very much the same as surrounding crops

In addition to the three types of weather stations mentioned above, there are stations sited at schools for teaching purposes, and by individuals at locations such as farms and large agricultural projects. One of the functions of National meteorological service is to guide the establishment of all stations in a country, collect

For this project the meteorological data used are from the Minna meteorological office. The data are of aeronautic origin, as there are no agrometeorological stations in the project area.

3.2. TEMPARATURE:

In agrometeorological we are concerned with the temparature of the air at the level of the canopy. Daily minimum temparature (Tmin) and maximum (Tmax) are available at the station. From there an estimate of daily mean is going to be computed.

Tmean = (Tmin & Tmax)/2 $\quad$ 3.2

The unit of temparature adopted is the degree centrigrade (^{o}C), however for older records degree Fahrenheit were used, they are converted to centigrade, using the relationship.

$T(^{o}C) = [(^{o}F) - 32] \times 5/9$ $\quad$ 3.3.1

3.2.1 TEMPARATURE MEASUREMENTS:

Thermometers are the instrument used to measure temparature. The types available at this station are liquid in glass thermometers, minimum and maximum thermometers and combined maximum and minimum thermometers. The monthly minimum and maximum temparature for the Minna station for the years 1979-1993 were collected and analysed to give mean base condition for the State. The result with the standard deviation are presented in Appendix A Table A.1.

3.3 HAMIDITY:

Humidity generally refers to an expression of the moisture content of the air. Air contains molecules of various gaseous constituents in addition to other foreign particles, when water evaporates from land surfaces, the gaseous water (water vapour) so formed mixes with air.

3.3.1 DEFINITION AND UNITS:

Of the various ways of expressing the moisture content of air, the most common are:

3.3.1.1 Actual vapour pressure (ed);-pressure exerted by water vapour in the air (units: millibars)

3.3.1.2 Saturation vapour pressure (ea):- maximum possible pressure at a given temparature at which vapour starts to condense (units: millibars).

3.3.1.3 SATURATION DEFICIT (ea-ed)- Difference between saturation and actual vapour pressure. This indicates the evaporative demand of

3.3.1.4 RELATIVE HUMIDITY (RH):- Ratio of actual amount of water vapour contained in the air to the amount the air would hold if it were saturated at the same temparature (express in percentage).

3.3.2 MEASUREMENT OF ATMOSPHERE HUMIDITY:

The instruments at the station are used to measure relative humidity (RH), RH is measured with hair hygrometer and psychrometer readings. The mean monthly relative humidity for the station for a period of 15 years was collected and analysed. And a base relative humidity for each month for the State was determined. This is presented in Appendix A Table A.3.

3.3.3 COMPUTING VAPOUR PRESSURE:

It is difficult to measure ea and ed directly. However saturation pressure (ea) is related to air temparature. This relationship is given in Table 3.3. saturation vapour pressure is, therefore, estimated from the dry bulb temparature. On the other hand, the difference in reading between the dry and wet bulb thermometers is related to the water vapour content of the air and the nature of ventilation of the psychrometer.

Table 3.3.3 saturation vapour pressure (ea) in millibars as a function of mean air remparature (T) in (oC).

Temp (oC)	ea (Mbar)	Temp (oC)	ea (Mbar)	Temp (oC)	ea (Mbar)	Temp (oC)	ea (Mbar)
0	6.1	10	12.3	20	23.4	30	42.4
1	6.6	11	13.1	21	24.9	31	44.9
2	7.1	12	14.0	22	26.4	32	47.6
3	7.6	13	15.0	23	28.1	33	50.3
4	8.1	14	16.1	24	29.8	34	53.2
5	8.7	15	17.0	25	31.7	35	56.2
6	9.3	16	18.2	26	33.6	36	59.4
7	10.0	17	19.4	27	35.7	37	62.8
8	10.7	18	20.6	28	37.8	38	66.3
9	1.15	19	22.0	29	40.1	39	69.9

Source: AbdulMumin (1988), Crop coefficients of selected crops in Nigeria Semi-arid zones.

Wet bulb depression, is used to determine the actual vapour pressure (ed), the relationship is presented in Table 3.3.4 and 3.3.5, Appendix B.

3.4 WIND:

Wind turbulence near the ground causes the transport of water vapour away from an evaporating surface and helps to maintain the gradient of water vapour between the surface and the air.

3.4.1 DEFINITION AND UNITS:

In simpler term wind is a two dimentional quantity expressed by its speed and direction. In this sense it is termed as wind velocity. Wind speed is recorded as average in meters per second (m/s) or as total run in (km/day). The conversion from one unit to another is given by the relation.

$1 m/s \doteq 86.4 Km/day$.

Wind direction is given in degrees and refers to the direction from which wind is blowing.

3.4.2 MEASURING WIND SPEED:

Wind speed is measured with cup-anemomemter in the station. Surface friction tends to show down wind passing over it, in other words, wind speed is slowest at the surface, and increases with height until a constant, main stream, value is reached at a certain height above the surface. For this reason the anenometer is placed at a choosen standard height in the open field location. In the station the height used is one meters. In agrometeorology the standard height is 2m. The height was therefore converted to the standard 2m height by multiptying with a correction factor.

Table 3.4.2 correction factor for different measurement heights.

Measurement Height (m)	0.5	1.0	1.5	2.0	3.0	4.0	5.0	6.0	7.0	8.0
Multiplier	1.35	1.15	1.06	1.0	0.93	0.88	0.85	0.83	0.80	0.78

Source:- AbdulMumin (1988), Crop coefficients of selected crops in Nigeria semi-arid zones.

With multiplying factor of 1.15, the mean monthly wind run was estimated for the area for a 15 years records, these are presented in Appendix A Table A.45.

3.5 SOLAR RADIATION:

Radiation from the sun is the most important energy source for the earth atmosphere system. Plant capture solar energy and use it in the production of primary substances from which plant dry matter and yield are formed. Solar energy is also used in plant canopies to

3.5.1 MEASUREMENT OF GLOBAL SHORT WAVE RADIATION:

Global shortwave radiation is direct and diffused radiation received on a horizontal surface. It is either measured directly with pyranometers, or indirectly from measurement of sunshine hours and cloudiness observations. The Minna station do not have a pyranometer, the indirect measurement was used in the calculations.

3.5.2 INDIRECT MEASUREMENT OF SOLAR RADIATION:

Solar radiation is estimated from measured duration of bright sunshine hours, or cloud observations and known extraterrestial radiation and day lenth, according to the following relationship.

$Rs = [a + b\ (n/N]Ra$

where

Rs = Daily estimate of global solar radiation.

Ra = extra terrestial radiation for the latitudes.

n = observed period of bright sunshine.

N = maximum possible sunshine period for the latitude

a,b = correlation constants.

Values of Ra and N are given for each latitude in Table 3.5.1 and 3.5.2 in appendix B respectively the value of Rn are given in mm.

Values of a and b are taken from the recommended values of world meteorological organization (WMO) a= 0.25,b=0.50 as a reference.

The campbell stokes sunshine recorder is the instrument commonly used to measure sunshine hours. The campbell stokes is available at the Minna station. The monthly mean for a period of 15 years are analysed to draw a mean value for Niger State.

3.5.3 NET RADIATION:

Net radiation Rn is the difference between all radiation received at the surface of the earth and all radiation emitted by surface.

$Rn = R\ (\text{recieved}) - R\ (\text{emitted})$ 3.5.3.1

The radiation of Rs absorbed by the surface is the net shortwave radiation Rns given by

$Rns = (1-\&)\ Rs$ 3.5.3.2

The longwave balance at the surface is given as

$Rnl=Rl\ (\text{absorbed}) - Rl\ (\text{radiated})$ 3.5.3.3

The net radiation is therefore given by

$Rn = Rns-Rnl$ 3.5.3.4

3.6 PRECIPITATION:

Precipitation is the most important source of water to the soil, and so to the crops. In the project area precipitation is mainly in the form of liquid rainfall. Rainfall effectively stores in the soil

3.6.1 DEFINITION AND UNITS:

Precipitation occurs when water vapour condenses in the air and falls as liquid or solid to the surface. It is expressed in units of depth (mm). A rainfall of 25mm means that if all the rain fell on a unit area (say, $1m^2$) were to stand on the surface without run-off, evaporating or infilterating into the soil profile, it will be 25mm deep representing on 1m2 a volume of 25 litres ($25x10^3m^3$).

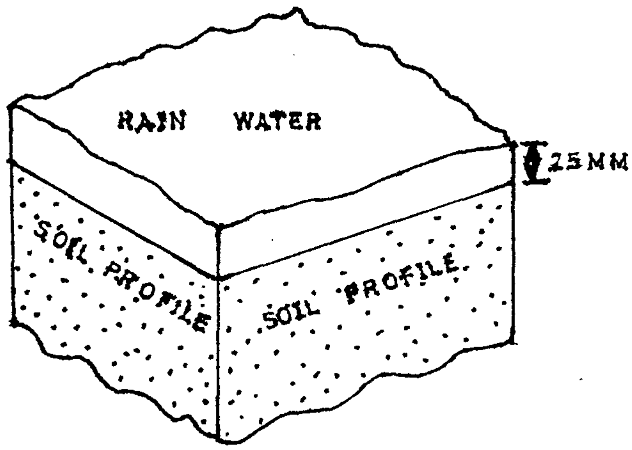


Fig. 3.6 Illustration of the depth of rainfall.

3.6.2 MEASURING PRECIPITATION:

Precipitation within the project area is measured with gauges. The great variability of precipitation in time and space means that particular care was given to rainfall records. Rainfall records for a period of 15 years were collected and analysed with a mean value taken for the State. These are represented in Appendix A Table A.4.

3.7 EVAPORATION:

Evaporation is the major process by which water in the soil, lakes, rivers is returned to the atmosphere to sustain precipitation process. The evaporation records for 15 years period was collected and analysed and presented in Appendix A Table A.7.

CHAPTER FOUR

PROCEDURE AND METHODS

Crop water requirement over the period of time, was estimated by the equation.

$$ETc=Kc. \quad .ETo \qquad .....4.0$$

Where ETc is the actual crop evapotranspiration or crop water requirement in mm/day, ETo is the reference crop evapotranspiration in mm/day, and Kc is the crop coefficient.

To establish the values of ETc at various stages of crop growth, ETo and Kc were determined.

4.1 DETERMINATION OF ETo:

ETo for each month of crop growth was determined with quantified forms of the four methods in the previous chapter, Blaney-criddle (temparature), Radiation, Penman and Pan evaporation methods.

4.1.1 TEMPARATURE METHOD:

The equation used is expressed as

$$ETo=C[P\ (0.46T + 8],\ mm/day$$

where

ETo is reference crop evapotranspiration in mm/day for the month considered.

T=mean daily temparature in oC over the month.

P=mean daily percentage of total annual daytime hours for a given month and latitude.

C=adjustment factor which depends on minimum relative humidity, sunshine hours and daytime wind estimate.

Values of P are obtained from Appendix b Table 4.1.1, the T Values are obtained from local mean monthly temparature for the month, computed from local data over a period of 15 years (1979-1993). The original Blaney-Criddle ETo estimate is given by the factor $f=p\ (0{,}46T + 8)$. To better account for local climatic condition, an estimate of humidity, sunshine and wind was made based on the local data from Appendix B. Figure 4.1.1. was used to read off corrected values of ETo on the Y-axis from the calculated values of f on the X-axis. The correct curve to use was determine from information on the general levels of minimum daytime relative humidity (RHmin), the ratio of actual (n) to maximum possible (N) sunshine hours (n/N), and day time wind speed. The result of this method is presented in Appendix C, worksheet No.1

4.1.2 RADIATION METHOD:

The equation used is expressed as

ETo=C (W.Rs) mm/day.

where

ETo=reference crop evapotranspiration in mm/day for the month considered.

Rs=solar radiation in equivalent evaporation in mm/day.

W=weighing factor which depends on temparature and altitude.

C=adjustment factor which depends on mean humidity and daytime wind conditions. The components of the equation were determine as follows:-

i) Solar Radiation (Rs)

The solar radiation (Rs) was determined using the equation.

Rs=[a + b (n/N)] Ra

where

Rs=daily estimate of global solar radiation.

Ra=extra terrestial radiation for the latitude.

n=observed hours of bright sunshine recorded with the campbell stokes.

N=maximum possible sunshine hours for the latitude.

a,b=correlation constant.

Values of Ra and N are determined from Appendix B Table 4.1.2.1 and 4.1.2.2. respectively.

Values of a = 0.25 and b=0.50 was used, as a global reference recommended by WMO.

Value of n was obtained from local data recorded with the campbell stokes, for a period of 15 years.

ii) The weighing factor (W).

The radiation method actually assumes that ETo is largely correlated with solar radiation - (Rs). As relationship between ETo and Rs is influenced by the temparature and altitude, a wighing factor W, based on temparature and altitude is introduced to make Rs a better estimate of ETo. W was read from Appendix B Table 4.1.2.3, using the mean temparature data and altitude of the location.

iii) The adjustment factor C.

To take into account local conditions an adjustment factor C is used. The variable considered are general levels of mean relative humidity (RHmean) and daytime wind (Uday) from Appendix B. Figure 4.1.2 was used with the calculated radiation term (W.Rs) on the X-axis to read off ETo on the Y-axis. The correct curve to read was determined with estimates of RHmean and Uday. The result of this method is presented in Appendix C worksheet No.2.

4.1.3 PAN EVAPORATION METHOD:

The relation for estimating ETo from pan evaporation is expressed as

ETo=KP. Epan

where

Epan=daily pan evaporation in mm/day for the month considered.

Kp=Pan Coefficient

iv) Epan

They are collected from measured data in the Minna station and the mean for each month derived from a record for a period of 15 years.

v) Kp

Is read from Appendix B Table 4.1.3.1 and 4.1.3.2, depending on pan exposure, and general levels of winds and humidity.

The following steps were followed:-

(a) RHmean was collected from local data over a period of 15 years, and a mean value for each month determined.

(b) The general level of daily wind speed classified as light, moderate and strong was made the criteria used as displayed in Table 4.1.3.1.

(c) The description of the pan location was made.

(d) The value of Kp was read from Table 4.1.3.1. using the above information.

The result of this method is presented in worksheet number 4 in Appendix C.

4.1.4 PENMAN METHOD:

The equation used is the modified penman formular by Doorenbos and prutt (1975), and further defined by Weis (1983) the formular is given by

ETo=C[WRn + (1-W). f(u). (ea-ed]

where

ETo=reference evapo transpiration in mm/day.

W=temparature related weighing factor.

Rn=net radiation in equivalent mm/day.

f(u)=wind related function.

(ea-ed)=difference between the saturation vapour pressure at mean air temparature and the mean actual vapour pressure of the air, both in mbar.

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

consists of a wind function f(u), a vapour pressure deficit (ea-ed) term and a correction factor (1-W) for the effect of wind and humidity on ETo. The sum of the two terms, which gives a first estimate of ETo is then corrected by a factor C for effects of differences in day and night weather conditions. Calculation of the various component of the equation proceeded in the following order.

i) The vapour pressure term (ea-ed)

ea was determined from Table 3.3.3. using the mean temparature values obtained from the 15 years records.

and ed was determined by

ea-ed (RH/100)

and estimate from Appendix B Table 3.3.3.1 and 3.3.3.2 by using the dry and wet bulb thermometer readings the depression of the wet bulb temparature was calculated as

Tdepr. = Tdry - Twet

Therefore (ea-ed) was computed.

ii) Calculation of the wind function f(u)

The equation

$$f(u) = 0.27\ (1 + u/100) \text{ was used}$$

where

u=24 hour wind run in km/day, measured at 1.0m height and corrected to standard 2m height using Table 3.4.2 and Table 4.1.4.1.

iii) Calculation of the weighing factor (W) and (1-W) .

Values of W was read off from Appendix B Table 4.1.2.3 corresponding to Tmean and mean altitude of the location.

iv) Determination of the longwave radiation radiation (Rnl)

The net longwave radiation was estimated by $Rnl = (\sigma\, Tmean^4)$ $(a + b\ [n/N]) \times (c + d\ \sqrt{ed})$

where

σ = Bolozman constant (4.9 x 10 - 3 Jm - 3 day - 1 K- 4)

Tmean = the mean air temparature

a,b,c,d = empirical constants general values of the constant used are a=0.1, b=o.9, c=0.34 and d=0.44

ed=actual vapour pressure (mb).

The three terms on the right hand side of the equation represent the effects of temparature f(T), sunshine hours f(n/N) and vapour pressure f(ed) on net longwave radiation.

vi) Determination of the net shortwave radiation (Rns)

Rns was determined using

Rns = (1 - &) Rs

vii) Determination of net radiation (Rn)

Rn was determined by

$Rn = Rns - Rnl$

Viii) Determination of the adjustment factor C

Since the penman equation assumes ideal conditions of medium to high levels radiation and RHmax, and moderate wind condition, a correction factor C is used to account for the local condition of the project area. The correction factor was determined using the subroutine in Appendix III Doorenbos and Pruit (1977). The subroutine requires an estimate of Rs, mean day wind speed Uday, (m/s), the ratio Uday/Unight and RHmax from the local data was used to determine C. The result of this method presented in worksheet number 3 of Appendix C.

4.2 STATISTICAL COMPARISON OF THE METHODS USED:

A statistical comparison of the four methods was made with a view to choosing the best method from these result. A two-way analysis of variance (ANOVA) was used to:-

1. determine whether ETo varies among the various methods used in computation.
2. determine wehther ETo varies with different month.

The mean square deviation for the methods and months was computed, this was divided by the mean residual error. This statistic was used to test the hypothesis at a signficant level of 5%. After the variations where determined, the best method was choosed based on the result of the deviation that each method shows from the standard calculated. These are presented in Appendix C Table 4.2.

4.3 DETERMINATION OF ETo Per decade (10-days values):

Mean ETo values determined were computed from mean monthly climatic data. However, for the calculation of crop water requirement, shorter periods of 10 days (decades) are required. To convert monthly results to 10-day values a graphical inter polation procedure was used.

(a) Using a graph sheet of paper, the monthly mean daily ETo values are plotted, and a smooth curve are drawn through them.

(b) The length of each monthly period on the x-axis were divided into three 10-day intervals. These result are presented in Table 4.31 Appendix C.

4.4 DETERMINATION OF WATER BUDGET:

4.4.1 WATER DEFICIT AND SURPLUS:

Water deficit and surplus was computed with

WS/WD = ETo - P

where

ETo = reference evapotranspiration in mm/day.

ETo - P is positive = WS

ETo - P is negative = WD

The result are presented in Table 4.4.1 in Appendix C.

4.5 DETERMINATION OF GROSS DIVERSION REQUIREMENT:

Diversion requirements was determined for the whole state as a guide for designing Dams and control structures in the State.

The diversion requirements was determined by:-

i) Ignoring distribution and system losses;

ii) Including for 45% of distribution and system losses.

The results are presented in Table 4.5 of Appendix C.

4.6 DETERMINATION OF CROP COEFFICIENT (KC):

For a given crop Kc is not constant throughout its growth period. Average value of Kc at any time depends on the crop growth stage. The rate of change of Kc within a growth stage depends on the length of the stage. The proceedure below was used for determing Kc.

i) Determination of the crop growth stage.

For all the crops considered the growing period was devided into.

1. Initial stage: From germination through establishment show increase in vegetative cover, with crop cover less than 10%.
2. Crop development stage: From end of initial stage to full ground cover. Rapid increase in vegetative cover until full cover is attained.
3. Mid-season stage: From full cover to start of maturity when leaves starts to yellow and fall.
4. Late season stage: From start of maturity to harvest.

Average planting date was collected from local information from farmers for the crops, the average duration of the growth stages was also collected.

ii) Determination of Kc Values:
Kc values were obtained from Kc values suggested by AbdulMumin 1989 for the selected crops for Northern regions.

iii) Drawing of the Kc Curves:
Kc curve for each crop was drawn, and the mean Kc values for each 10-day period was obtained. These are presented in

4.7 COMPUTATION OF ETc:

The ETc was determined for each 10-day period with equation 4.0, for each of the selected crops, the result are presented in Table 4.6.1, 4.6.2., 4.6.3., 4.6.4 in Appendix C.

4.8 COMPUTER PROGRAMMING FOR DETERMINATION OF ETo:

The computer programme is based on the modified penman method to calculate reference crop evapotranspiration (ETo) as presented in part 4.1.4. The programme can be used to calculate on a routinue basis the monthly ETo data for several locations in development projects. Since large amounts of computations are involved, the programme will provide an efficient means to perform these calculations at reasonable cost.

4.8.1 Capabilities of the computer Programme:

The programme determines the values of reference crop evapotranspiration (ETo), conversion to evapotranspiration for different crops must be done manually using technique described in part 4.6.

4.8.2 Description of the Programme:

The programme consists of one main programme, five subroutines and a function subprogramme. All climatological data are read in the main programme and if no error in input data from a given station occurs, estimation of ETo by use of various subroutines is done. A macro flow-chart of the programme function is shown in Figure 4.8.2. the programme itself is shown in Appendix D.

CHAPTER FIVE

RESULTS AND DISCUSSION OF RESULTS :

5.1. RESULTS OF REFERENCE CROP EVAPOTRANSPIRATION ETo):

Results of each of the models used are presented in Appendix C worksheet 1-4. ETo are presented for each month mm per day. A graphical comparison of the methods are presented in figure 5.1.

5.1.1. Temparature Method:

The result of this method seems consistence throughout the year with the maximum ETo of 5.3mm/day in February, and a minimum of 3.0mm/day in September.

5.1.2. Radiation Method:

The result is also consistence throughout the year with maximum ETo of 5.2mm/day in april and minimum ETo of 3.1mm/day in August.

5.1.3. Evaporation Method:

The result for the method is not consistence throughout the year, with maximum ETo of 4.69mm/day in January and minimum of 1.02mm/day in September.

5.1.4. Penman Method:

The result are consistence over the year, with maximum ETo of 5.25mm/day in April, and a minimum of 2.74mm/day in August.

5.1.5. Result of Statistical Analysis:

The results are presented in Appendix C, Table4.2The standard mean ETo was found to be 3.88mm/day, the deviation for each model were o.21,0.378, 0.207 and 1.208 for the temparature, radiation, penman and Pan A evaporation respectively. From the ANOVA Table Fet = 4.41 and Fmt = 2.77.

5.2 GROSS DIVERSION REQUIREMENT:

The diversion requirement for different 10-day periods (decades) were computed, they are presented in Appendix C, Table 4.5. The maximum requirement occuring in April, with 647m^3/ha in second decade, and the minimum of 448m^3/ha in the first decade

9218m^3/ha without distribution and system losses and 13359m^3/ha including 45% distribution losses. A graphical evaluation of the diversion requirement is presented in figure 5.2.

5.3 WATER BUDGET FOR THE STATE:

The water budget for the State for each decade were determined, with period of water deficit and surplus. Surplus clearly indicated. The results shows that there is a deficit of 82.10mm, and surplus of 38.02mm. A graphical evaluation of the water budget for the State is presented in figure 5.3.

5.4 CROP COEFFICIENTS:

The values of the crop coefficients for each crop is presented in Appendix C Tables 4.6.1, 4.6.2, 4.6.3, 4.6.4. Crop Coefficient (Kc) curves for the four crops are given in figure 5.4.1, 5.4.2, 5.4.3, 5.4.4.

The X-axis is expressed in months, with days of maturity of 105, 125, 130 and 120 days for millet, maize, sorghum and wheat respectively. The fitted curves were drawn by hand, keeping in mind the typical shape of such curves.

5.5. Evapotranspiration:

The result of the evapotranspiration of each crop are presented in Appendix C., Tables 4.6.1, 4.6.2, 4.6.3, 4.6.4.

The result are presented in mm/day for each decade.

5.5.1. Maize:

The result for maize shows a maximum evapotranspiration (ETo) of 3.11mm/day in the third decade of June and a minimum of 1.76mm/day in the second decade of May. The total water required per hectare of maize was found to be 3214m^3 throughout its growing season.

5.5.2. Sorghum:

The maximum ETc was obtained during the first decade of September, 3.03mm/day and a minimum of 1.56mm/day in second decade of June. The total water required per hectare of

5.5.3. Millet:

The maximum ETc of 2.78mm/day occured in the third week of July, and a minimum of 0.96mm/day during the first decade of September, with a water requirement of 2425m^3/ha/annum.

5.5.4. Wheat:

The maximum ETc of 5.23mm/day was obtained during the first decade of February, and the minimum during the third week of March, 1.27mm/day. The total water required per hectare of wheat was found to be 4002m^3/ha.

5.6. DISCUSSION OF RESULTS:

In discussing the result, the following limitations are firstly enumerated.

i) Ideally, ETo of the reference crop should have been experimentally measured with a lysimeter to correlate the values obtained from the months;

ii) The soils in different part of the State should have been classified and tested.

All the aforementioned limitation will no doubt affect the results obtained. Neverthe-less the effect are of little significance.

5.6.1. ETo Results Obtained:

From the results of graphical evaluation of the ETo models, it is clearly seen that there is a correlation between the values obtained for temparature, radiation, and penman methods (Doorenbus and Pruitt 1977). However the Pan A evaporation significantly vary from the results, this is basically due to the unreliability of the data obtained from the evaporation pan in the Minna Airport, as the evaporation pan are not constantly watered.

5.6.2. Statistical Analysis:

From the analysis of variance carried out, there was a significant variation at 5% significant level between the various models, further analysis with deviation suggest that the modified penman model is most appropriate for the calculation of ETo in Niger State, Kassam et. al (1977), Weiss (1988). However the temparature method is still very accurate.

5.6.3. Kc Curves:

Major deviations of the estimated Kc points from the Curves

5.6.4. Crop Evapotranspiration (ETo):

The alternative proceedure of determining ETc used in this report is similar to that obtained for Samaru, near Zaria (AbdulMumin 1988). The FAO-24 (Penman) was developed and tested by Doorenbos and Pruith (1977) with data from different climate around the world, and is adjustable to local climatic condition through the adjustment factor C. They estimated the accuracy of the method to within 10%.

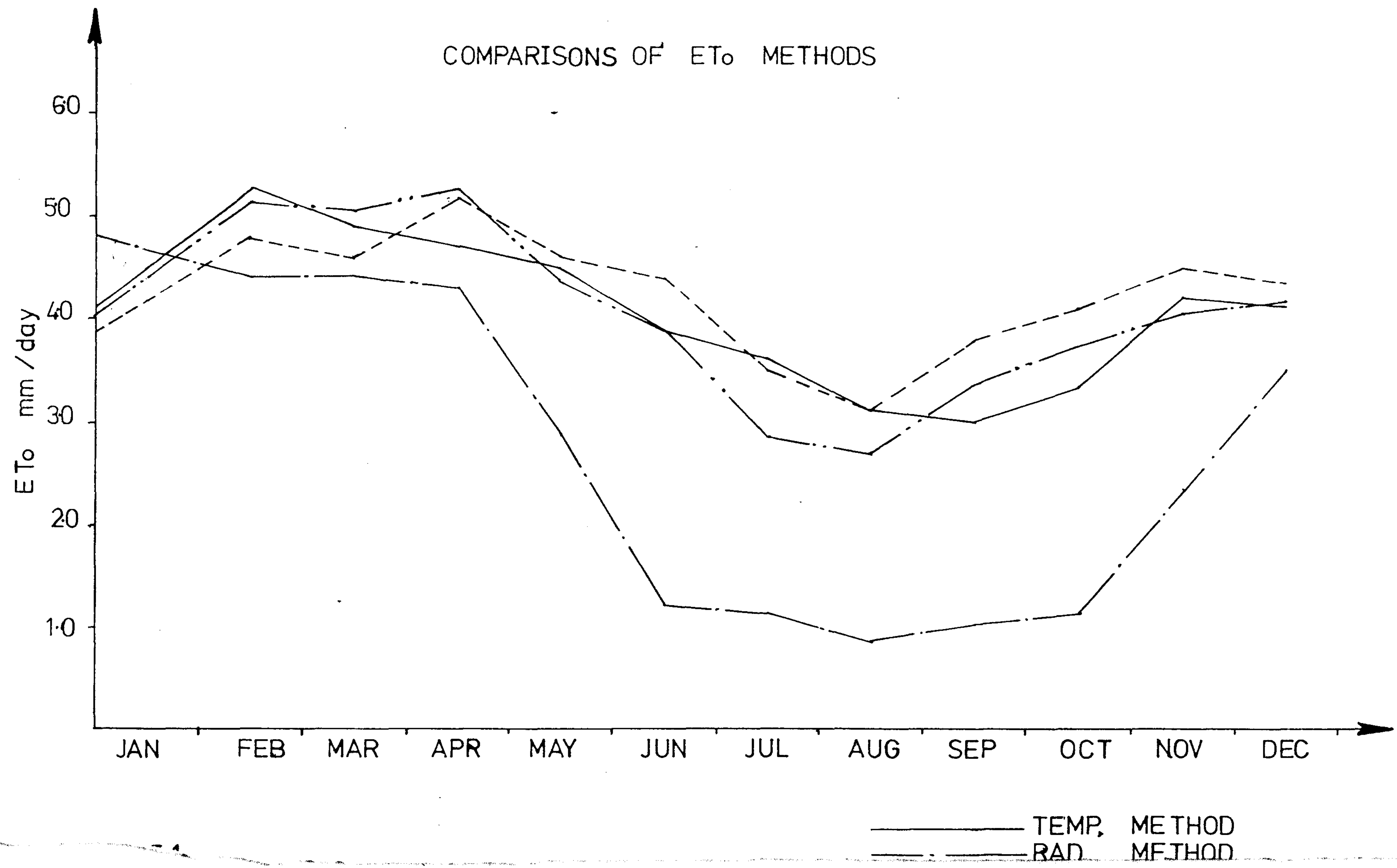
The fact that the ETo and Kc were locally caliberated, they should be accurate enough for the purpose of estimating water requirements in the study area.

5.6.4. Water Requirements:

The water requirements of 2425, 3214, 3292 and 4002m^3/ha/annum determined conforms with those obtained for rough estimations recommended for millet, maize, sorghum and wheat respectively (Kowal et. al, 1973).

5.6.5. Gross Diversion Requirement:

The diversion requirement of 13359m^3/ha obtained is highly less than 21,104m^3/ha obtained by Minco Nig. Ltd (1981) in the design and construction of Kontagora Dam Project. This is due to the use of original penman (1948) model in their assessment.



COMPARISONS OF ETo METHODS
ETo mm / day
60
50
40
30
20
1·0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
TEMP. METHOD
RAD METHOD

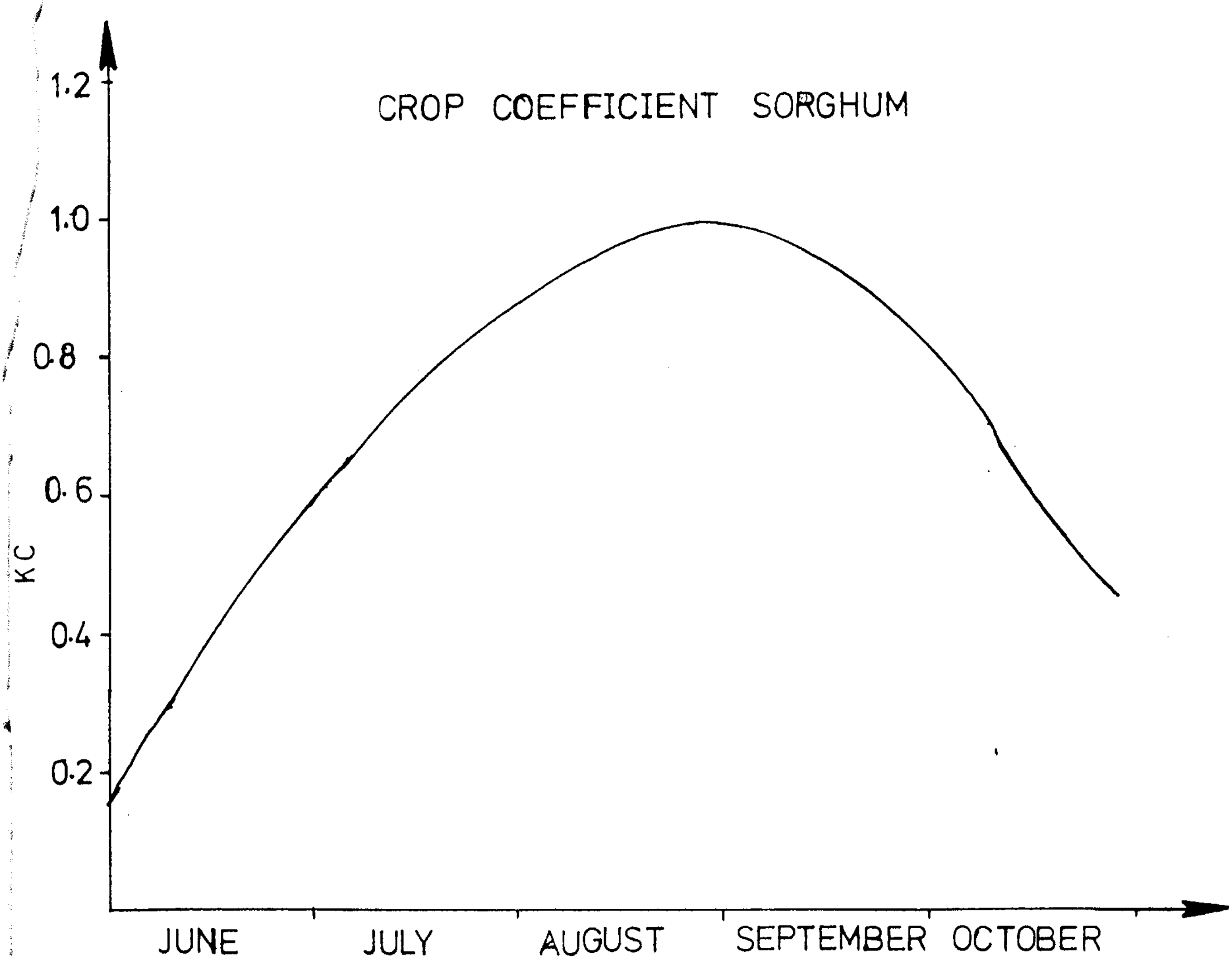
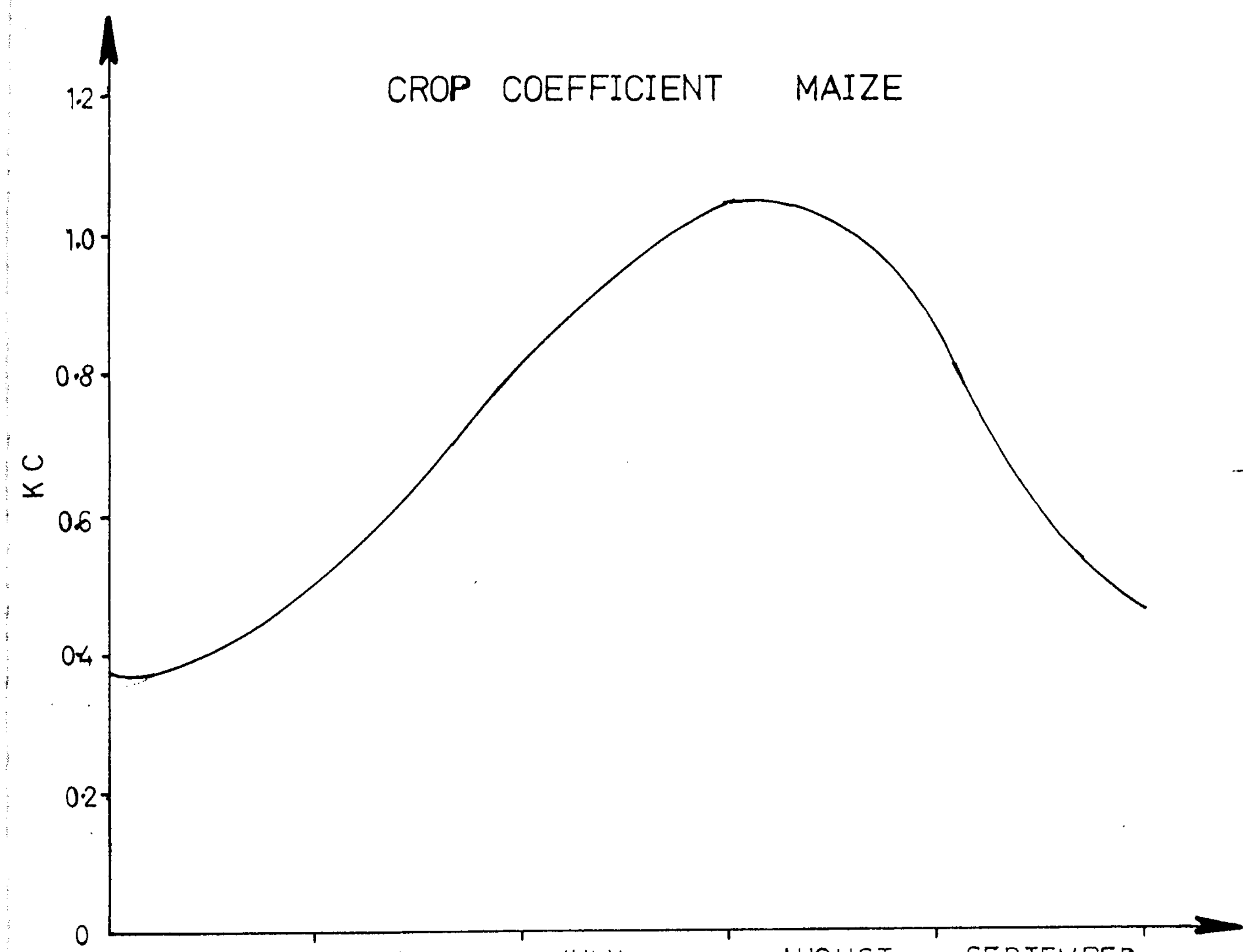

CROP COEFFICIENT SORGHUM
1.2
1.0
0.8
0.6
0.4
0.2
KC
JUNE
JULY
AUGUST
SEPTEMBER
OCTOBER

FIGURE 4.5.1


CROP COEFFICIENT MAIZE
1.2
1.0
0.8
0.6
0.4
0.2
0
KC

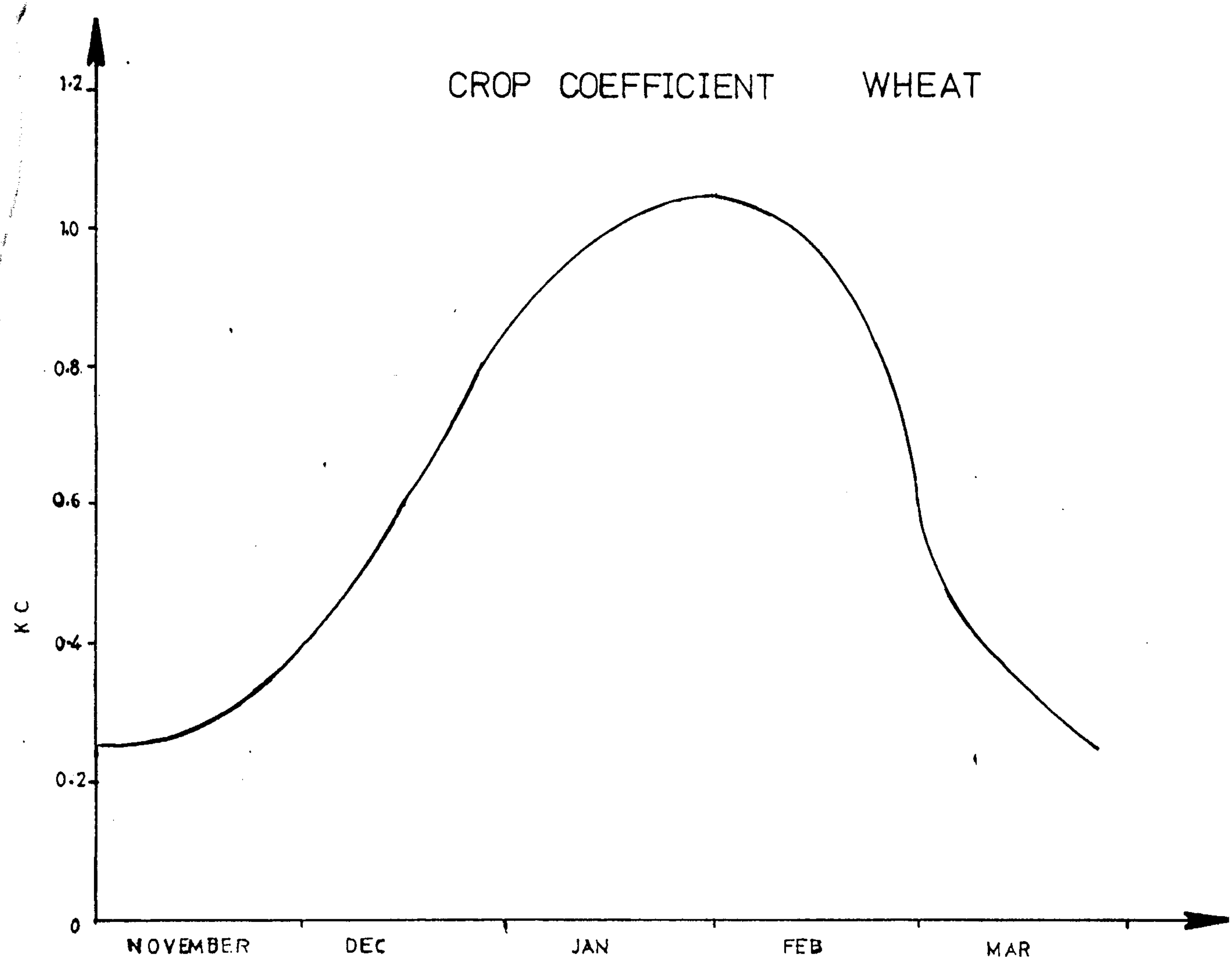
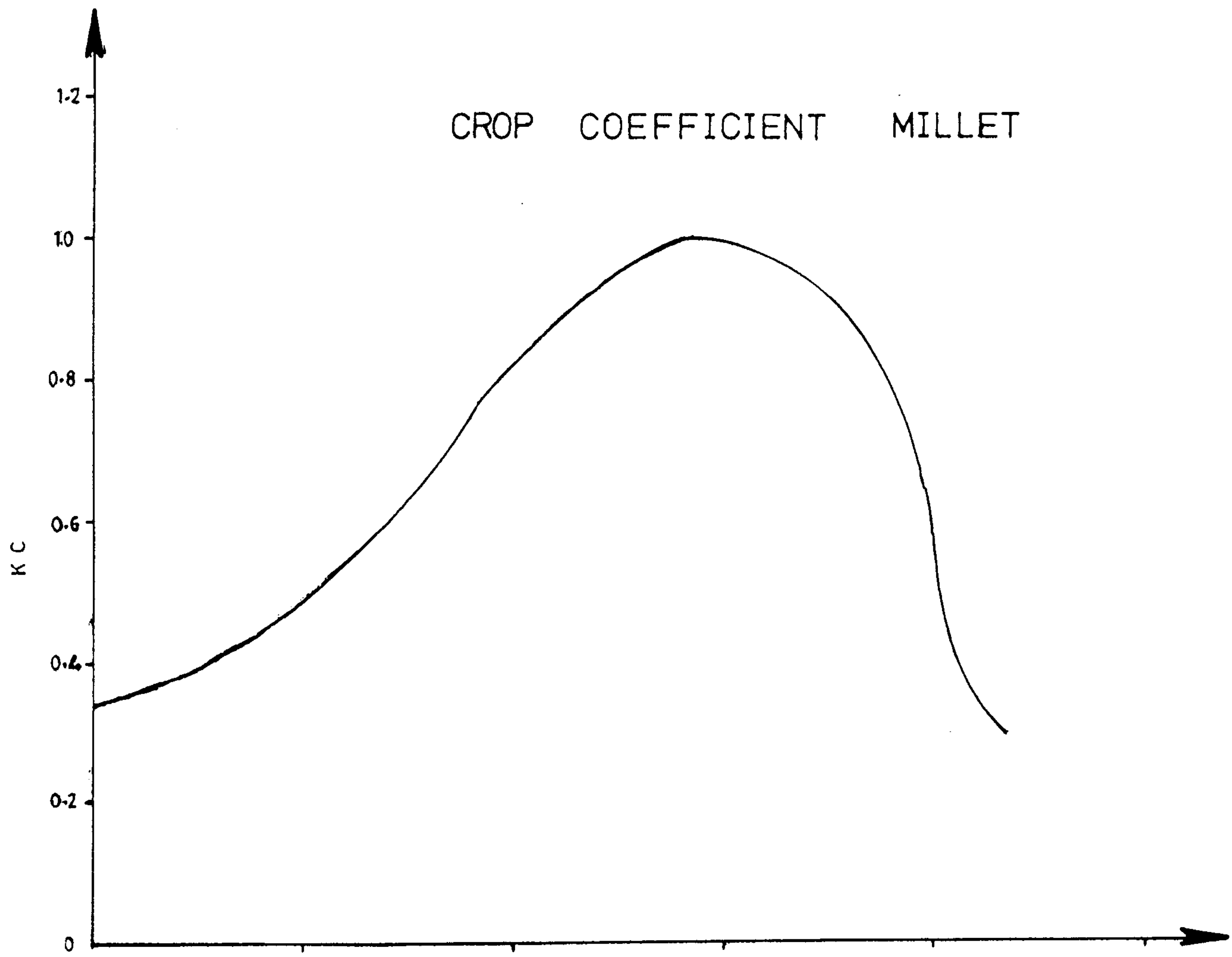

CROP COEFFICIENT WHEAT
KC
1·2
1.0
0·8
0·6
0·4
0·2
0
NOVEMBER
DEC
JAN
FEB
MAR

FIGURE 4·5·3


CROP COEFFICIENT MILLET
KC
1·2
1.0
0·8
0·6
0·4
0·2
0

CHAPTER SIX

RECOMMENDATIONS AND CONCLUSION:

6.1. RECOMMENDATIONS:

The following recommendations are made with the experience gained from this work.

*The department should undertake another research on evapotranspiration of the selected cereals using one or two of the direct measurement methods, the result should be compared and correlated with the ones obtained here, from where a conclusion can be drawn.

*The result of this project should be tested and made available to farmers, water resources planners and managers to improve, the use of the scarce water resource in the State.

*The computer programme developed is recommended for use on the farm for irrigation management, by farmers who will find it easier to estimate the amount of water they need to apply to their crops once they have information from the weather station and the available soil moisture.

*The modified penman method of computing reference evapotranspiration is recommended for use in the State, However the temparature method can be used where the farmer is accesible to a thermometer and weather station report is not available.

*The water budget prepared for the state can be used by farmers in preparing their cropping schedule.

*The gross diversion requirement obtained can be use by engineers in designing dams for the irrigation of cereal crops.

*The Kc curves obtained is recommended for use, with slight modification to be made during dry spells.

*In view of the result of the evapotranspiration obtained for wheat, it is recommended that the planting of the crop should commence ealier (October) to allow the crop to withstand the short spells.

6.2. CONCLUSION:

Of all the model of evaluating reference evapotranspirations considered, the modified penman and the temparature methods were found to be most appropriate for the computation of evapotranspiration in Niger State. The modified penman is adjudged the best, because of it level of data requirement, however the temparature model is valuable where these data are not accessible. The Kc curves developed are represenrative of each of the selected cereals, and is recommended for use. The computer programme can aid to the scientific management of scarce water resources in the farms. The evapotranspiration determined for each crop can be use by water resources managers and planners, farmers and crop breeders, in controlling the persistance dryingtrends recently noticed.

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APPENDIX 'A'

ANALYSED CLIMATIC VARIABLES

TABLE A. 1:

MONTHLY MEAN OF TEMPARATURES: AIR TEMPARATURE IN DEGEE CENTIGRADE MINNA, 1979 - 1993.

MONTH	MAXIMUM		MINIMUM		MEAN
	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION	
JANUARY	34.5	1.24	20.3	1.25	27.4
FEBRUARY	36.7	0.84	22.9	0.94	29.8
MARCH	37.1	0.96	24.3	1.33	30.7
APRIL	36.3	1.17	25.2	1.05	30.8
MAY	33.7	1.96	24.0	0.92	28.9
JUNE	30.8	0.77	22.6	0.66	26.7
JULY	29.4	0.79	21.9	0.37	25.7
AUGUST	29.0	0.79	21.6	0.59	25.3
SEPTEMBER	29.9	0.87	21.4	0.40	25.6
OCTOBER	31.8	0.56	21.7	0.67	26.8
NOVEMBER	34.5	1.23	19.8	1.14	27.1
DECEMBER	34.5	1.63	19.9	1.04	27.3

TABLE A. 2

MONTHLY BULB TEMPARATURE: WET BULB, DRY BULB, BULB DEPRESSION IN DEGEREE CENTIGRADE MINNA 1979 - 1993.

MONTH	WET BULB		DRY BULB		DEPRESSION
	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION	
JANUARY	17.0	1.34	27.0	1.42	10.0
FEBRUARY	18.0	1.02	30.0	0.61	12.0
MARCH	21.0	1.14	31.0	1.21	10.0
APRIL	20.0	0.34	31.0	1.24	11.0
MAY	23.0	0.68	29.0	0.41	6.0
JUNE	23.0	1.21	26.0	0.98	3.0
JULY	24.0	0.94	25.0	1.03	1.0
AUGUST	23.0	0.81	25.0	1.04	2.0
SEPTEMBER	22.0	0.76	24.0	2.11	2.0
OCTOBER	22.0	1.22	25.0	1.14	3.0
NOVEMBER	19.0	0.81	24.0	0.45	5.0
DECEMBER	17.0	0.38	24.0	1.01	7.0

TABLE A. 5: MEAN MONTHLY WIND RUN - MINNA 1979 - 1993

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	D
MEAN WIND RUN (KM DAY-1)	121.1	130.2	124.5	118.8	113.4	86.9	73.1	73.1	65.2	68.6	103.1	108
STANDARD DEVIATION	1.8	2.3	2.1	2.7	1.2	0.8	0.3	1.6	2.4	2.0	0.8	1.

TABLE A 6: MEAN UDAY UNIGHT MINNA - 1979 - 1993

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
MEAN UDAY UNIGHT	3	3	4	4	4	4	4	4	4	4	3	3
STANDARD DEVIATION	0.1	0.5	1.0	0.4	0.5	0.2	0.4	0.6	0.3	0.1	0.4	0.[illegible]

TABLE A. 7: MEAN MONTHLY PAN CLASS A EVAPORATION - MINNA - 1979 - 1993

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
EVAPORATION (MM)	207	196	174	163	104	46	41	31	35	42	89	15[illegible]
STANDARD DEVIATION	7.3	9.1	11.2	21.3	0.5	2.5	6.3	8.1	7.4	11.6	2.9	3.[illegible]

TABLE A. 3:

MONTHLY RELATIVE HUMIDITY: MAXIMUM, MINIMUM, MEAN

RELATIVE HUMIDITY IN PERCENTAGE MINNA 1979 - 1993

MONTH	MAXIMUM		MINIMUM		MEAN
	MEAN	STANDARD DEVIATION	MEAN	STANDARD DEVIATION	
JANUARY	31.0	1.25	17.0	1.12	27.0
FEBRUARY	47.0	0.96	21.0	1.21	33.0
MARCH	62.0	0.54	25.0	1.23	53.0
APRIL	69.0	0.21	35.0	0.78	61.0
MAY	77.0	1.11	61.0	0.81	73.0
JUNE	83.0	1.25	64.0	0.52	82.0
JULY	87.0	1.34	70.0	0.82	84.0
AUGUST	90.0	0.81	72.0	0.92	87.0
SEPTEMBER	88.0	0.79	57.0	1.21	86.0
OCTOBER	79.0	0.82	51.0	1.12	76.0
NOVEMBER	57.0	0.91	21.0	1.73	44.0
DECEMBER	44.0	1.31	21.0	1.01	39.0

MEAN RAINFALL - MINNA 1979 - 1993

MONTH	DECADES/ 10 - DAY	MEAN MONTHLY RAINFALL (MM)	MEAN DECADE RAINFALL (MM)	RAINFALL MM/DAY	STANDARD DEVIATION
JANUARY	1 - 10		-	-	
	11 - 20		-	-	
	21 - 31		-	-	0.00
FEBRUARY	1 - 10		-	-	
	11 - 20		-	-	
	21 - 28	-	-	-	0.00
MARCH	1 - 10		2.7	0.27	
	11 - 20		10.5	1.05	
	21 - 31	21.6	8.4	0.76	0.31
APRIL	1 - 10		5.5	0.55	
	11 - 20		25.9	2.59	
	21 - 30	46.6	16.0	1.60	1.05
MAY	1 - 10		27.9	2.79	
	11 - 20		46.8	4.68	
	21 - 31	126.6	51.9	4.72	1.68
JUNE	1. 10		50.3	5.03	
	11 - 20		51.6	5.16	
	21 - 30	156.9	55.0	5.50	1.70
JULY	1 - 10		57.7	5.77	
	11 - 20		66.1	6.61	
	21 - 31	206.6	82.8	7.53	2.83
AUGUST	1 - 10		84.9	8.49	
	11 - 20		47.3	4.73	
	21 - 31	265.3	106.1	9.65	1.74
SEPTEMBER	1 - 10		61.7	6.17	
	11 - 20		79.6	7.96	
	21 - 30	199.1	57.8	5.78	2.94
OCTOBER	1 - 10		39.6	3.96	
	11 - 20		38.1	3.81	
	21 - 31	82.5	4.80	0.44	1.81
NOVEMBER	1 - 10		2.81	0.28	
	11 - 20		-	-	
	21 - 30	2.81	-	-	5.3
DECEMBER	1 - 10		-	-	

TABLE A. 8: MEAN MONTHLY SUNSHINE DURATION - MINNA - 1979 - 1993

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
SUNSHINE DURATION	7.3	7.7	6.8	7.3	7.1	6.8	4.4	4.6	5.5	6.4	8.9	7.1
STANDARD DEVIATION	1.2	1.0	1.4	1.0	0.7	0.9	1.0	1.3	0.6	0.8	0.4	2.0

TABLE A.9: MEAN MONTHLY CLOUD COVER - MINNA - 1979 - 1993

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
CLOUD COVER (TENTHS)	6	6	7	7	7	7	8	8	8	6	5	5
STANDARD DEVIATION	0.4	0.2	0.1	0.3	0.6	1.2	0.2	0.2	0.1	0.4	0.2	0.2

APPENDIX 'B'

TABLES AND FIGURES USED IN COMPUTATIONS AND ANALYSIS

Sources: Dooreabos and Pruitt(1977) : Guidelines for Predicting Crop water requirements.

1. Table 3.3.4 Vapour pressure from dry and wet bulb temperature data (Aspirated Psychrometer)
2. Table 3.5.1 Extra terrestrial Radiation (Ra) expressed in equivalent evaporation in mm/day
3. Table 3.5.1 Mean Daily duration of possible sunshine Hours (N) for different months and latitudes
4. Figure 4.4.1 Prediction of ETo from f in temperature method.
5. Figure 4.1.2 Prediction of ETo W.Rs for different conditions of mean relative humidity
6. Table 4.1.2 Values of weighing factor W for the effect of Radiation on ETo at different temperature and attitude.
7. Table 4.4.4.2 Conversion factors fro Ra and Rns
8. Table 4.1.4.3 Effect of temperature f(T) on Rnl
9. Table 4.1.4.4 Effect of vapour pressure f(ed) on Rnl
10. Table 4.1.4.5 Effect of f(n/N) on Rnl
11. Table 4.1.4.6 Adjustment factor C in presented Penman equation
12. Table 4.1.1 Table of P-values in presented temperature method
13. Table 4.1.3.1 Class A and Sunken Pan evaporation tables.

Table 3.3.4 Vapour Pressure (ed) in mbar from Dry and Wet Bulb Temperature Data in °C (Aspirated Psychrometer)

dry bulb T°C	Depression wet bulb T°C altitude 0-1 000 m: 0	2	4	6	8	10	12	14	16	18	20	22
40	73.8	64.9	56.8	49.2	42.2	35.8	29.8	24.3	19.2	14.4	10.1	6.0
38	66.3	58.1	50.5	43.6	37.1	31.1	25.6	20.5	15.8	11.4	7.3	
36	59.4	51.9	44.9	38.4	32.5	26.9	21.8	17.1	12.7	8.6	4.9	
34	53.2	46.2	39.8	33.8	28.3	23.2	18.4	14.0	10.0	6.2		
32	47.5	41.1	35.1	29.6	24.5	19.8	15.4	11.3	7.5	4.0		
30	42.4	36.5	30.9	25.8	21.1	16.7	12.6	8.8	5.3			
28	37.8	32.3	27.2	22.4	18.0	14.0	10.2	6.7	3.4			
26	33.6	28.5	23.8	19.4	15.3	11.5	8.0	4.7	1.6			
24	29.8	25.4	20.7*	16.6	12.8	9.3	6.0	2.9				
22	26.4	22.0	18.0	14.2	10.6	7.4	4.3	1.4				
20	23.4	19.3	15.5	12.0	8.7	5.6	2.7					
18	20.6	16.8	13.3	10.0	6.9	4.1	1.4					
16	18.2	14.6	11.4	8.3	5.4	2.7						
14	16.0	12.7	9.6	6.7	4.0	1.5						
12	14.0	10.9	8.1	5.3	2.8							
10	12.3	9.4	6.7	4.1	1.7							
8	10.7	8.0	5.5	3.1	0.8							
6	9.3	6.8	4.4	2.1								
4	8.1	5.7	3.4	1.6								
2	7.1	4.8	2.8	0.8								
0	6.1	4.0	2.0									

dry bulb T°C	Depression wet bulb T°C altitude 1 000-2 000 m: 0	2	4	6	8	10	12	14	16	18	20	2.
40	73.8	65.2	57.1	49.8	43.0	41.8	31.0	25.6	20.7	16.2	12.0	8.
38	66.3	58.2	50.9	44.1	37.9	36.7	26.8	21.8	17.3	13.2	9.2	5.
36	59.4	52.1	45.2	39.0	33.3	32.1	23.0	18.4	14.3	10.4	6.8	3.
34	53.2	46.4	40.1	34.4	29.1	24.1	19.6	15.4	11.5	8.0	4.6	1.
32	47.5	41.3	35.5	30.2	25.3	20.7	16.6	12.6	9.1	5.8	2.6	
30	42.4	36.7	31.3	26.4	21.9	17.7	13.8	10.2	6.9	3.8	0.9	
28	37.8	32.5	27.5	23.0	18.9	14.9	11.4	8.0	4.9	2.1		
26	33.6	28.7	24.1	20.0	16.1	12.5	9.2	6.0	3.2	0.5		
24	29.8	25.3	21.1	17.2	13.9	10.3	7.2	4.3	1.6			
22	26.4	22.3	18.3	14.3	11.5	8.3	5.5	2.7	0.2			
20	23.4	19.5	15.9	12.6	9.5	6.6	3.9	1.3				
18	20.6	17.1	13.7	10.6	7.8	5.0	2.5	0.1				
16	18.2	14.9	11.7	8.9	6.2	3.6	1.3					
14	16.0	12.9	10.0	7.3	4.8	2.4	0.3					
12	14.0	11.2	8.4	5.9	3.6	1.4						
10	12.3	9.6	7.0	4.7	2.6	0.4						
8	10.7	8.2	5.8	3.7	1.6							
6	9.3	7.0	4.8	2.7	0.7							
4	8.1	5.0	3.8	1.8								
2	7.1	3.0	2.9	1.0								
0	6.1	4.1	2.1									

Table 3.5.1 Extra Terrestrial Radiation (Ra) expressed in equivalent evaporation in mm/day

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

Table 3.5.2 Mean Daily Duration of Maximum Possible Sunshin : Hours (N) for Different Months and Latitudes

Northern Lats	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Southern Lats	July	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June
50°	8.5	10.1	11.8	13.8	15.4	16.3	15.9	14.5	12.7	10.8	9.1	8.
48	8.8	10.2	11.8	13.6	15.2	16.0	15.6	14.3	12.6	10.9	9.3	8.
46	9.1	10.4	11.9	13.5	14.9	15.7	15.4	14.2	12.6	10.9	9.5	8.
44	9.3	10.5	11.9	13.4	14.7	15.4	15.2	14.0	12.6	11.0	9.7	8.
42	9.4	10.6	11.9	13.4	14.6	15.2	14.9	13.9	12.6	11.1	9.8	9.
40	9.6	10.7	11.9	13.3	14.4	15.0	14.7	13.7	12.5	11.2	10.0	9.
35	10.1	11.0	11.9	13.1	14.0	14.5	14.3	13.5	12.4	11.3	10.3	9.
30	10.4	11.1	12.0	12.9	13.6	14.0	13.9	13.2	12.4	11.5	10.6	10.
25	10.7	11.3	12.0	12.7	13.3	13.7	13.5	13.0	12.3	11.6	10.9	10.
20	11.0	11.5	12.0	12.6	13.1	13.3	13.2	12.8	12.3	11.7	11.2	10.
15	11.3	11.6	12.0	12.5	12.8	13.0	12.9	12.6	12.2	11.8	11.4	11.
10	11.6	11.8	12.0	12.3	12.6	12.7	12.6	12.4	12.1	11.8	11.6	11.
5	11.8	11.9	12.0	12.2	12.3	12.4	12.3	12.3	12.1	12.0	11.9	11.
0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.

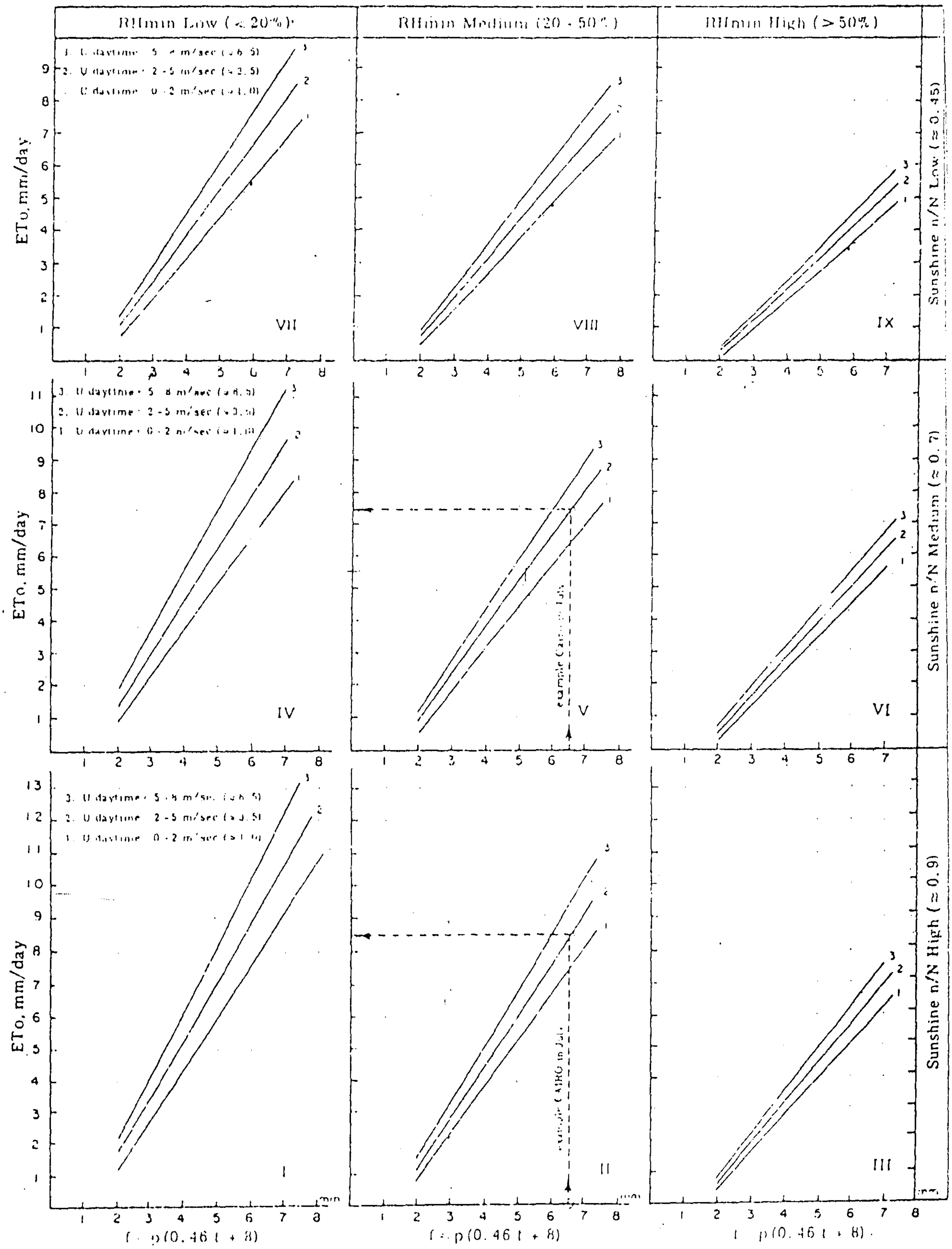
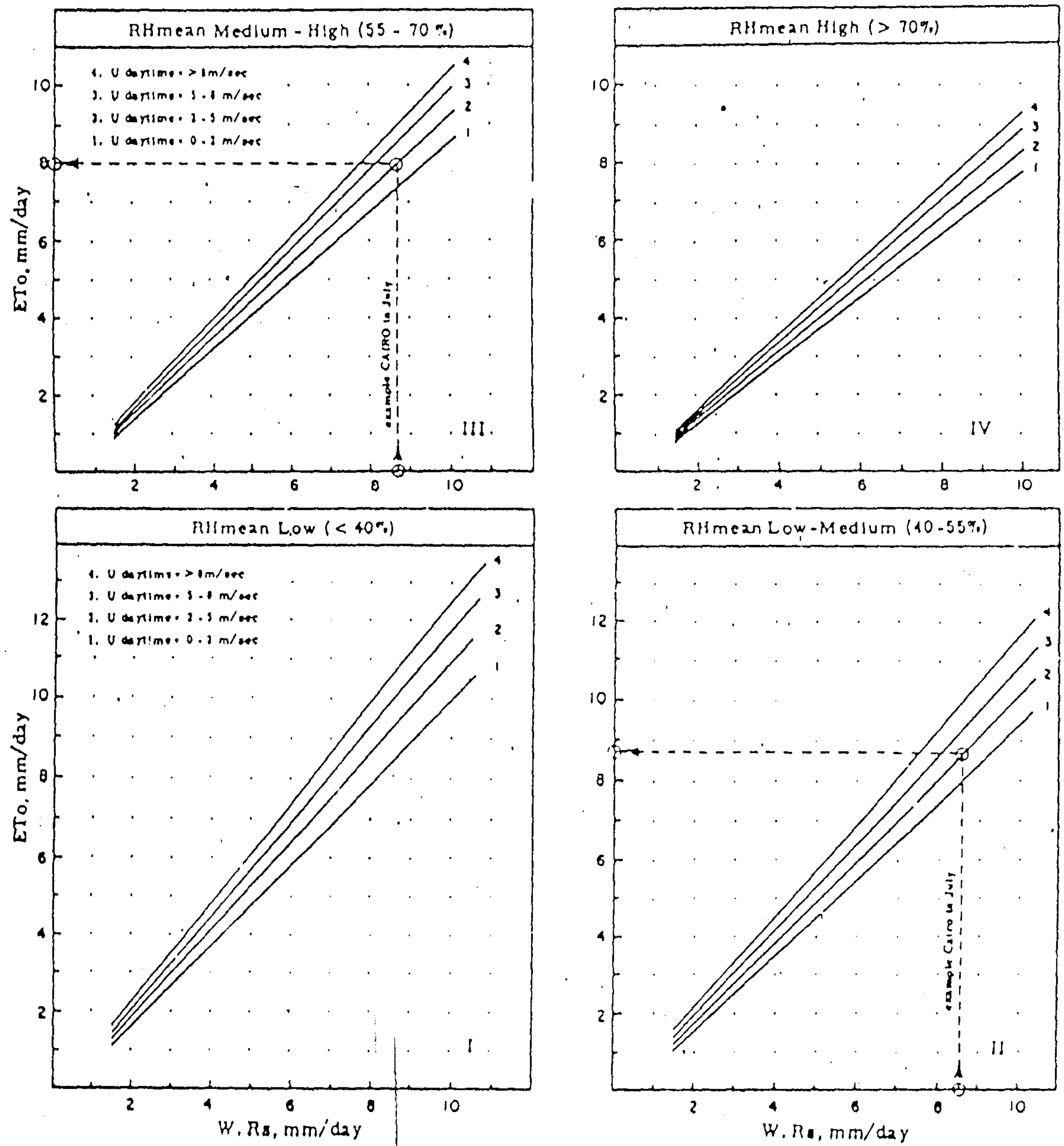


Fig.4.4.13 Prediction of ETo from Blaney-Criddle f factor for different conditions of minimum relative humidity, sunshine duration and day time wind.



Prediction of ETo from W. RS for different conditions of mean relative humidity and day time wind.

Fig.4.1.2

Table 4.1.4 Values of Weighting Factor (W) for the Effect of Radiation on ETo at Different Temperatures and Altitudes

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

Table 4.1.4.2 Conversion Factor for Extra-Terrestrial Radiation (Ra) to Net Solar Radiation (Rns) for a Given Reflection α of 0.25 and Different Ratios of Actual to Maximum Sunshine Hours $(1-\alpha)(0.25 + 0.50\ n/N)$

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

Table 4.1.4.3 Effect of Temperature f(T) on Longwave Radiation (Rnl)

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

Table 4.1.4.4 Effect of Vapour Pressure f(ed) on Longwave Radiation (Rnl)

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

Table 4.1.4.5 Effect of the Ratio Actual and Maximum Bright Sunshine Hours f(n/N) on Longwave Radiation (Rnl)

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

Table 4.1.4.6 Adjustment Factor (c) in Presented Penman Equation

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

Table 4.4.4.1 Values of Wind Function $f(u) = 0.27\left(1 + \frac{U_2}{100}\right)$ for Wind Run at 2 m height in km/day

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

Table

Mean Daily Percentage (p) of Annual Daytime Hours for Different Latitudes

Latitude North / South[1]	Jan / July	Feb / Aug	Mar / Sept	Apr / Oct	May / Nov	June / Dec	July / Jan	Aug / Feb	Sept / Mar	Oct / Apr	Nov / May	Dec / June
60°	.15	.20	.26	.32	.38	.41	.40	.34	.28	.22	.17	.13
58	.16	.21	.26	.32	.37	.40	.39	.34	.28	.23	.18	.15
56	.17	.21	.26	.32	.36	.39	.38	.33	.28	.23	.18	.16
54	.18	.22	.26	.31	.36	.38	.37	.33	.28	.23	.19	.17
52	.19	.22	.27	.31	.35	.37	.36	.33	.28	.24	.20	.17
50	.19	.23	.27	.31	.34	.36	.35	.32	.28	.24	.20	.18
48	.20	.23	.27	.31	.34	.36	.35	.32	.28	.24	.21	.19
46	.20	.23	.27	.30	.34	.35	.34	.32	.28	.24	.21	.20
44	.21	.24	.27	.30	.33	.35	.34	.31	.28	.25	.22	.20
42	.21	.24	.27	.30	.33	.34	.33	.31	.28	.25	.22	.21
40	.22	.24	.27	.30	.32	.34	.33	.31	.28	.25	.22	.21
35	.23	.25	.27	.29	.31	.32	.32	.30	.28	.25	.23	.22
30	.24	.25	.27	.29	.31	.32	.31*	.30	.28	.26	.24	.23
25	.24	.26	.27	.29	.30	.31	.31	.29	.28	.26	.25	.24
20	.25	.26	.27	.28	.29	.30	.30	.29	.28	.26	.25	.25
15	.26	.26	.27	.28	.29	.29	.29	.28	.28	.27	.26	.25
10	.26	.27	.27	.28	.28	.29	.29	.28	.28	.27	.26	.26
5	.27	.27	.27	.28	.28	.28	.28	.28	.28	.27	.27	.27
0	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27	.27

1/ Southern latitudes: apply 6 month difference as shown.

APENDIX C

RESULTS OF WORK AND ANALYSIS

1.	Worksheet 1	:	Temparature method of computing ET_o
2.	Worksheet 2	:	Radiation method of computing ET_o
3.	Worksheet 3	:	Penman method of computing ET_o
4.	Worksheet 4	:	Evaporation Pan method of computing ET_o
5.	Table 4.2	:	Results of Statistical analysis
6.	Table 4.4.1	:	Mean water budgets in 10 day periods Niger State
7.	Table 4.5	:	Gross diversion requirement
8.	Table 4.6.1	:	Computation of crop water requirement (Sorghum)
9.	Table 4.6.2	:	Computation of crop water requirement (Wheat)
10.	Table 4.6.3	:	Computation of crop water requirement (Maize)
11.	Table 4. 6. 4	:	Computation of crop water requirement (Millet)

WORKSHEET1: TEMPARATURE METHOD FOR COMPUTING ETO

STATE: NIGER STATE LAYITUDE: 09° 37'N

PLACE: MINNA

MONTH	TMEAN oC	P	F mm/Day	n/N	RHMEAN	UDAY	BLK/Ln	ET mm/Day
JAN	27.4	0.26	5.36	Low	Low	Light/ Moderate	VII,1	4.5
FAB	29.8	0.27	5.86	Low	Low	Light/ Moderate	VII,1	5.3
MAR	30.7	0.27	5.97	Low	Medium/ Low	Light/ Moderate	VIII,1	4.9
APR	30.8	0.28	6.2	Low	Medium/ Low	Light/ Moderate	VIII,1	4.7
MAY	28.9	0.28	5.96	Low	Medium Low	Light/ Moderate	IX,1	4.5
JUN	26.7	0.29	5.88	Low	High	Light	IX,1	3.9
JUL	25.7	0.29	5.75	Low	High	Light	IX,1	3.6
AUG	25.3	0.28	5.50	Low	High	Light	IX,1	3.1
SEP	25.6	0.28	5.54	Low	High	Light	IX,1	3.0
OCT	26.8	0.27	5.49	Low/ Med.	High	Light	IX,1	3.3
NOV	27.1	0.26	5.32	Low/ Med.	Medium Low	Light	VIII,1	4.2
DEC	27.3	0.26	5.35	Low/ Med.	Low	Light	VII,1	4.1

SHEET2: RADIATION METHOD FOR COMPUTING ETO

STATE:	NIGER STATE	LATITUDE:	09^{o} 37^{1} N
PLACE:	MINNA	ALTITUDE:	848M

ONTH	Tmean (oC)	Ra mm/day	N (hrs)	n (hrs)	Rs mm/day	W	W.Rs mm/day	RH mean	Uday	Blk/ LM	ET mm/day
AN	27.4	13.2	11.6	7.3	5.54	0.78	4.3	Low	Light	I,1	4.2
EB	29.8	14.2	11.8	7.7	6.11	0.80	4.9	Low	Light	I,1	4.8
AR	30.7	15.3	12.0	6.8	5.93	0.80	4.7	M/L	Light	II,1	4.6
PR	30.8	15.7	12.3	7.3	6.30	0.81	5.0	M/L	Light	III,1	5.2
AY	28.9	15.5	12.6	7.1	6.04	0.80	4.8	High	Light	IV,1	4.6
UN	26.7	15.3	12.7	6.8	5.97	0.79	4.6	High	Light	IV,1	4.4
UL	25.7	15.3	12.6	4.4	4.89	0.76	3.6	High	Light	IV,1	3.5
UG	25.3	15.5	12.4	4.4	4.90	0.76	3.4	High	Light	IV,1	3.1
EP	25.6	15.3	12.1	5.5	5.49	0.77	4.1	M/L	Light	III,1	3.8
CT	26.8	14.7	11.8	6.4	5.73	0.76	4.33	M/L	Light	III,1	4.1
OV	27.1	13.6	11.6	8.9	6.60	0.78	5.1	M/L	Light	II, 1	4.5
EC	27.3	12.9	11.5	7.1	6.10	0.79	4.8	Low	Light	I,1	4.3

WORKSHEET 3: MODIFIED PENMAN/COMBINATION METHOD FOR COMPUTING ETO

STATE: NIGER STATE LATITUDE: 09^{o} 37^{1} N

PLACE: MINNA ALTITUDE: 848M

MONTH	Tmean (oC)	RH mean	U (km/day)	ed (mb)	N (hrs)	n (hrs)	Rs (mm/day)	Rns (mm/day)	F(T)	F(ed)	F(n/N)	Rnc (mm/day)	Rn (mm/d	W	C	ET mm/
JAN	27.4	27	121	11.4	11.6	7.3	5.54	4.16	16.12	0.19	0.67	2.09	2.07	0.78	0.90	4.4
FEB	29.8	33	130	11.0	11.8	7.7	6.11	4.58	16.70	0.19	0.69	2.25	2.33	0.80	0.90	5.0
MAR	30.7	53	125	16.9	12.0	6.80	5.93	4.45	16.90	0.16	0.60	1.57	2.88	0.80	0.90	5.0
APR	30.8	61	119	14.7	12.3	7.3	6.30	4.72	16.90	0.17	0.64	1.8	2.88	081	0.95	5.2
MAY	28.9	73	113	24.2	12.6	7.1	6.04	4.50	16.7	0.12	0.60	1.2	3.3	0.80	0.98	4.4
JUN	26.7	82	87	25.0	12.7	6.87	5.97	4.47	15.9	0.12	0.60	1.14	3.27	0.79	1.06	3.8
JUL	25.7	84	73	29.1	12.6	4.4	4.89	3.61	15.9	0.11	0.46	0.80	2.79	0.76	1.06	2.8
AUG	25.3	87	73	26.5	12.4	4.4	4.90	3.72	15.6	0.12	0.42	0.86	2.85	0.76	1.06	2.7
SEP	25.6	86	65	25.1	12.1	5.5	5.49	4.12	15.65	0.12	0.51	0.96	3.16	0.77	1.03	3.3

OCT	26.8	76	69	24.5	11.8	6.4	5.73	4.30	16.1	0.12	0.69	1.03	3.9	0.76	1.06	3.73
NOV	27.1	44	103	17.2	11.6	8.9	6.60	4.99	16.3	0.17	0.82	2.2	2.8	0.78	0.98	4.05
DEC	27.3	39	109	15.8	11.5	7.1	6.10	4.56	16.3	0.16	0.68	2.1	2.21	0.79	0.90	4.14

worksheet 4: EVAPORATION PAN METHOD FOR COMPUTING ET.

STATE: NIGER STATE LATITUDE: 09° 37' N

PLACE: MINNA

DESCRIPTION OF PAN LOCATION :WITHIN SEVERAL HECTARES OF CROPPED AREA

WINDWARD DISTANCE TO CROP OR FALLOW: >100m

PAN LOCATION CASE : A

MONTH	WIND (LEVEL)	RH mean (LEVEL)	KP	EPAN (MM/DAY)	ET (MM/DAY)
JAN	Light/moderate	Low	0.70	6.7	4.69
FEB	Light/Moderate	Low	0.70	6.3	4.41
MAR	Light/Moderate	Medium/Low	0.80	5.6	4.48
APR	Light/Moderate	Medium/Low	0.80	5.4	4.32
MAY	Light/Moderate	High	0.85	3.4	2.89
JUN	Light	High	0.85	1.5	1.28
JUL	Light	High	0.85	1.3	1.11
AUG	Light	High	0.85	1.0	0.85
SEP	Light	High	0.85	1.2	1.02
OCT	Light	High	0.85	1.4	1.19
NOV	Light	Medium/Low	0.80	2.9	2.32
DEC	Light/Moderate	Low	0.70	5.0	3.5

TABLE 4.2: RESULTS OF STATISTICAL ANALYSIS

MONTH	TEMP. METHOD	RAD.METHOD	PENMAN METHOD	PAN. A METHOD	MEANS
JANUARY	4.5	4.2	4.44	4.69	4.46
FEBRUARY	5.3	4.8	5.18	4.41	4.92
MARCH	4.9	4.6	5.04	4.48	4.76
APRIL	4.7	5.2	5.25	4.32	4.87
MAY	4.5	4.6	4.41	2.89	4.10
JUNE	3.9	4.4	3.88	1.28	3.38
JULY	3.6	3.5	2.82	1.11	2.76
AUGUST	3.1	3.1	2.74	0.84	2.45
SEPTEMBER	3.0	3.8	3.34	1.02	2.80
OCTOBER	3.3	4.1	3.73	1.19	3.16
NOVEMBER	4.2	4.5	4.05	2.32	3.77
DECEMBER	4.1	4.3	4.14	3.5	4.01
MEANS	4.1	4.3	4.14	3.5	3.88
DEVIATIONS	0.212	0.378	0.207	1.208	

H. There is no significant variation in choosing an ETo method

H_1: There is no significant variation in Eto obtained from one month and another.

TWO - WAY ANOVA TABLE

VARIATION	SS	df	MS	Fcal
Method of Eto	19.8	11	217.8	Fet=4.41
Monthly Nalnes	34.1	3	102.3	
Error	1.3	33	49.2	Fmr=2.77

Fet. Cal. > F3,11,19.8 - (1)

Fmr.Cal > F3,11,34.4 - (2)

TABLE 4.41: MEAN WATER IN 1o-DAY PERIODS NIGER STATE (1979-1993)

MONTH	10-DAY PERIODS	EVAPO TRANSPIRATION (MM)	RAINFALL (MM)	WATER DEFICIT	WATER SURPLUS (MM)
JANUARU	1-10 11 -20 21 -31	4.23 4.44 4.58	0.00 0.00 0.00	4.23 4.44 4.58	
FEBRUARY	1 -10 11 -20 21 -28	5.08 5.18 5.17	0.00 0.00 0.00	5.08 5.18 5.17	
MARCH	1 -10 11 -20 21 -31	5.10 5.04 5.09	0.27 1.05 0.76	4.83 3.99 4.33	
APRIL	1 -10 11 -20 21 -30	5.21 5.25 5.16	0.55 2.59 1.60	4.66 2.66 3.56	
MAY	1 -10 11 -20 21 -31	4.51 4.41 4.28	2.79 4.68 4.72	1.72	 0.27 0.44
JUNE	1 -10 11 -20 21 -30	3.71 3.88 3.61	5.03 5.16 5.50		1.32 1.28 1.89
JULY	1 -10 11 -20 21 -31	2.93 2.82 2.78	5.77 6.61 7.53		2.84 3.79 4.75
AUGUST	1 -10 11 -20 21 -31	2.76 2.74 2.81	8.49 4.73 6.17		5.73 1.99 3.36
SEPTEMBER	1 -10 11 -20 21 -30	3.19 3.34 3.42	7.96 6.17 5.78		4.77 2.83 2.36
OCTOBER	1 -10 11 -20 21 -31	3.64 3.73 3.81	3.96 3.81 0.44	 3.37	0.32 0.08
NOVEMBER	1 -10 11 -20 21 -30	3.96 4.05 4.09	0.28 0.00 0.00	3.68 4.05 4.09	
DECEMBER	1 -10 11 -20 21 -31	4.11 4.14 4.23	0.00 0.00 0.00	4.11 4.14 4.23	
TOTAL (MM)		146.48	102.40	82.10	38.02

TABLE 4.5: GROSS DIVERSION REQUIREMENTS @IGNORING DISTRIBUTION AND SYSTEM LOSSES
b. INCLUDING 45% LOSSES NIGER STATE.

MONTH	DECADES	(A) DIVERSION REQUIREMENT IGNORING DISTRIB. LOSSES (M3/ha)	(B) DIVERSION REQUIREMENT INCLUDING DISTRIB. LOSSES (M3/ha)
	1	359	521
	2	377	546
JANUARY	3	389	564
	1	432	624
	2	440	638
FEBRUARY	3	439	637
	1	433	628
	2	428	621
MARCH	3	433	627
	1	443	642
	2	446	647
APRIL	3	438	635
	1	383	555
	2	374	542
MAY	3	364	527
	1	309	448
	2	317	459
OCTOBER	3	324	469
	1	337	489
	2	344	498
NOVEMBER	3	349	506
	1	349	506
	2	352	510
DECEMBER	3	359	520
	TOTAL	$9218m^3/ha$	$13359m^3/ha$

TABLE 4.6.1 : COMPUTATION OF CROP WATER REQUIREMENTS

COUNTRY :	NIGERIA	LATITUDE :	9^{o} N
STATE :	NIGER	ALTITUDE :	848m

CROP : SORGHUM	Et. METHOD
MAX CROP DURATION: 130 DAYS	MODIFIED PENMAN

MONTH	10 DAY PERIOD NO	ET. (MM)	K C	ET CROP (MM)	TOTAL WATER REQUIRED (M^3 ha)
JUNE	1				
	1,2	3.88	0.40	1.56	156
	3	3.61	0.53	1.91	191
JULY	1	2.93	0.66	1.93	193
	2	2.82	0.76	2.14	214
	3	2.78	0.85	2.36	236
AUGUST	1	2.76	0.96	2,65	265
	2	2.74	1.0	2.74	274
	3	2.81	0.98	2.75	275
SEPTEMBER	1	3.19	0.95	3.03	303
	2	3.34	0.86	2.87	287
	3	3.42	0.75	2.57	257
OCTOBER	1	3.64	0.62	2.26	226
	2	3.73	0.60	2.24	224
	3	3.81	0.50	1.91	191
				TOTAL	$3292M^3$/ha

TABLE 4.6.2 : COMPUTATIONS OF CROP WATER REQUIREMENTS

COUNTRY : NIGERIA	LATITUDE: 9° N
STATE : NIGER	ALTITUDE: 848M

CROP : WHEAT	Et. METHOD
MAX. CROP DURATION : 120 DAYS	

MONTH	10-DAY PERIOD NO	ET. (MM)	K C	ET CROP (MM)	TOTAL WATER REQUIRED (M^3/ha)
NOV.	1				
	2				
	3	4.09	0.35	1.43	143
DEC.	1	4.11	0.46	1.89	189
	2	4.14	0.60	2.48	248
	3	4.23	0.79	3.34	334
JAN.	1	4.23	0.91	3.85	385
	2	4.44	1.00	4.44	444
	3	4.58	1.05	4.81	481
FEB.	1	5.08	1.03	5.23	523
	2	5.18	0.98	5.07	507
	3	5.17	0.80	4.14	414
MAR	1	5.10	0.45	2.30	230
	2	5.04	0.33	1.66	166
	3	5.09	0.25	1.27	127
				TOTAL	4002M^2/ha

TABLE 4.6.3 : COMPUTATIONS OF CROP WATER REQUIREMENTS

COUNTRY: NIGERIA	LATITUDE: 9° N
STATE : NIGER	ALTITUDE: 848M

CROP : MAIZE	ET. METHOD
MAX. CROP DURATION : 125 DAYS	MODIFIED PENMAN

MONTH	10-DAY PERIOD NO	ET.(MM)	K. C	ET CROP (MM)	TOTAL WATER REQUIRED (M^3/ha
MAY	1				
	2	4.41	0.40	1.76	176
	3	4.28	0.47	2.01	201
JUNE	1	3.71	0.65	2.41	241
	2	3.88	0.76	2.95	295
	3	3.61	0.86	3.11	311
JULY	1	2.93	0.95	2.78	278
	2	2.82	1.02	2.88	288
	3	2.78	1.05	2.92	292
AUGUST	1	1.76	1.02	2.83	283
	2	2.74	0.94	2.58	258
	3	2.81	0.77	2.16	216
SEPT.	1	3.19	0.60	1.91	191
	2	3.34	0.55	1.84	184
	3				
				TOTAL	3214M^3/ha

TABLE 4.6.4 : COMPUTATION OF CROP WATER REQUIREMENT

COUNTRY: NIGERIA	LATITUDE : 9° N
STATE : NIGER	ALTITUDE : 848M

CROP : MILLET	ET. METHOD
MAX. CROP DURATION 105 DAYS	MODIFIED PENMAN

MONTH	10-DAY PERIOD NO	ET. (MM)	K. C	ET CROP (MM)	TOTAL WATER REQUIRED (M^3/ha
MAY	1				
	2				
	3	4.28	0.45	1.93	193
JUNE	1	3.71	0.53	1.97	197
	2	3.88	0.64	2.48	248
	3	3.61	0.71	2.56	256
JULY	1	2.93	0.87	2.55	255
	2	2.82	0.95	2.68	268
	3	2.78	1.00	2.78	278
AUGUST	1	2.76	0.97	2.68	268
	2	2.74	0.73	2.00	200
	3	2.81	0.59	1.66	166
SEPTEMBER	1	3.19	0.30	0.96	96
	2				
	3				
				TOTAL	2425M^3/ha

APPENDIX 'D'

COMPUTER PROGRAMME FOR DETERMINATION OF ET_o

1. Flow Chart

2. Main Programme.

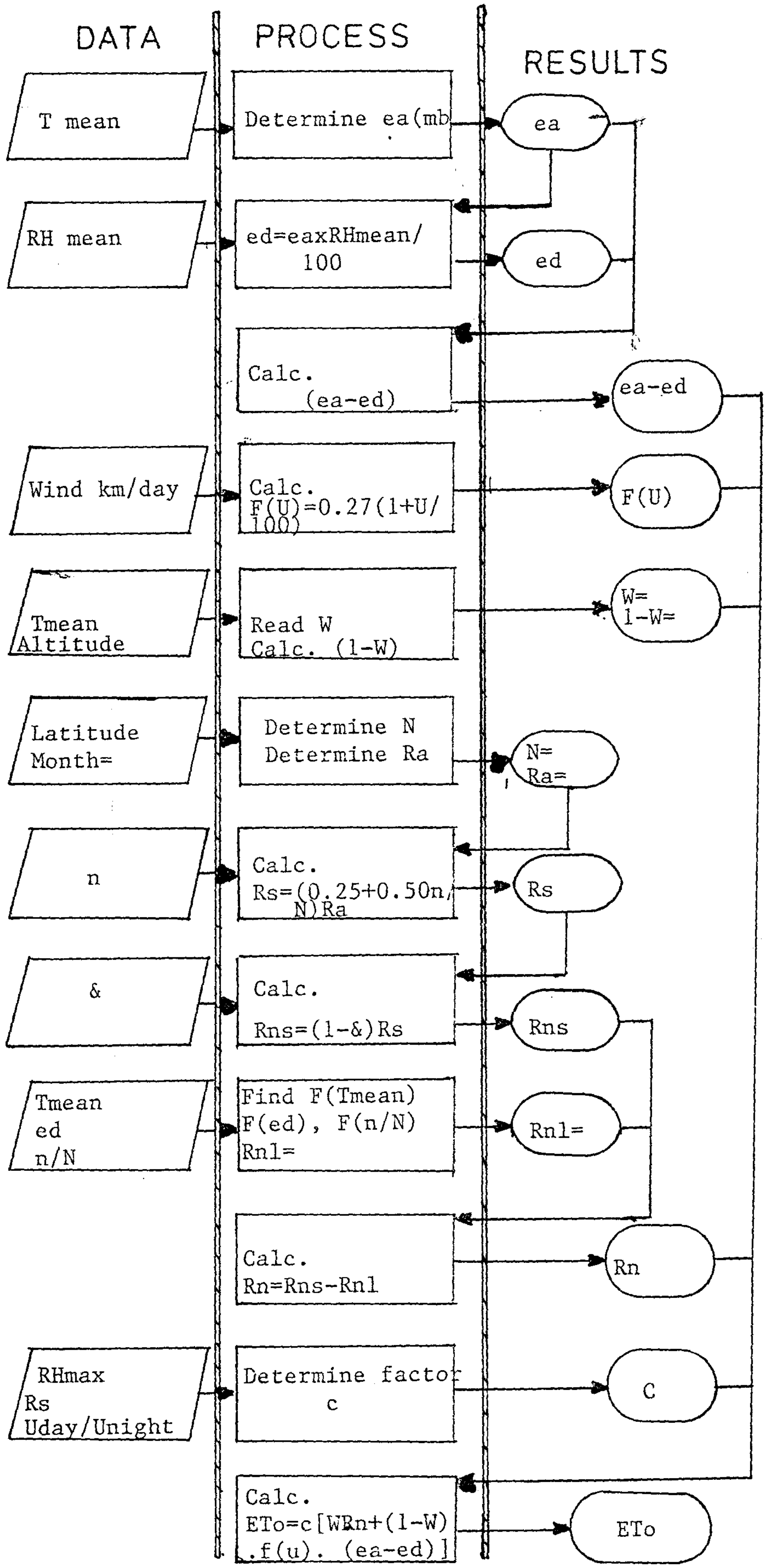


Fig. 4.8: Flow chart for determination of ETo from modified penman method.

```
WRITE(5,*)'*THIS PROGRAM USES THE DOORENBOS ...
WRITE(5,*)'*MODIFIED PENMAN MODEL, FOR COMPUTING ET.
WRITE(5,*)'*WRITTEN BY BASHIR MOHAMMED, MARCH,1994.
WRITE(5,*)'*DEPARTMENT OF AGRICULTURAL ENGINEERING F.U.T.
WRITE(5,*)'*MINNA.
WRITE(5,*)'*DATA REQUIRED
WRITE(5,*)'*TMAX,TMIN,RHMAX,UDAY,MONTH,M,Rs,UDAY/UNIGHT,
            PRECIPITATION.
WRITE(5,*)'*OUTPUT INCLUDES
WRITE(5,*)'*ETO,EFF,RAIN,IRRI,RQT.
WRITE(5,*)'***********************.

IN THIS PROGRAM THE DEVICE NUMBERS FOR EXTERNAL DATA FILES,
THE TERMINAL(SCREEN),AND THE PRINTER ARE 4,5 AND 6 RESPECTI
INTEGER,M(214),D(214),
REAL EP(214),P(214),TM**(214),TMIN(214),RHMAX(214).
RHMIN(214),U(214),X(214,10).
READING CLIMATIC DATAS FROM AN EXTERNAL DATA FILE.


CLIMATIC DATA SHOULD HAVE THE FOLLOWING UNITS:
TEMPARATURE IN DEGREE CENTIGRADE
RELATIVE HUMIDITY IN PERCENT
PRECIPITATION IN MM
SOLAR RADIATION IN MM OF WATER
WIND SPEED IN KM PER DAY

--------------------------------------------------------------
THIS SUB ROUTINE INPUT THE DATA FROM AN EXTERNAL
EXTERNAL DATA FILE
DO 100  I = 1,24
    READ(4,*) (X(I,T), T=1,10
CONTINUE
DO 350 I = 1,214
    M(I) = INT(X(I,1)
    D(I) = INT(X(I,2)
    P(I) = (1,3)
    TMAX = X(I,4)
    TMIN = X(I,6)
    RHMAX = X(I,7)
    RHMIN = X(I,8)
    RS(I) = [illegible]
     U(I) [illegible]


SUB ROUT..E FOR L.TERMI.G SA.URATION DEFI...
REAL TMAX(21. ,TM.N(214),RHMAX(214).RHMIN(214)
TMEAN = (TMAX(I) + .MIN(I)/2
EA = EXP((19.08 TMEAN + 429.4)/(TMEAN + 237.3)
RHMEAN = (RHMEAN(I) + RHMIN(I))/2
ED = (EA * RHMIN)/100
ES = EA - ED
REAL U(214)
F(U) = 0.27(1 + U/100)
```

```
C
C
C   SUB ROUTINE FOR DETERMINING THE WEIGHING FACTOR W
    REAL TMEAN(214), ALT(214)
00  W = 0.006918 - 0.399912 * COS(RAD(TMEAN)) * 0.07025
    * SIN(RAD(ALT)) - 0.00675 * 8 * COS(RAD(2 * TMEAN))
50  WT = 1 - W
C   SUB ROUTINE TO DETERMINE VALUE OF N, FOR THE MONTH
    AND RA

    MONTH $(1) = 'JANUARY'
    MONTH $(2) = 'FEBUARY'
    MONTH $(3) = 'MARCH'
    MONTH $(4) = 'APRIL'
    MONTH $(5) = 'MAY'
    MONTH $(6) = 'JUNE'
    MONTH $(7) = 'JULY'
    MONTH $(8) = 'AUGUST'
    MONTH $(9) = 'SEPTEMBER'
    MONHT $(10) = 'OCTOBER'
    MONTH $(11) = 'NOVEMBER'
    MONTH $(12) = 'DECEMBER'

    DO 43 I = 1,12
600 KARR (I) = 0.0
    IF (KCCODE,EQ,2) THEN
        J1 = MBEG
      IF (DBEG . LT.15)THEN
        JI = J1-1
      COUNT = DBEG - 15
    ELSE
      COUNT = DBEG - 15
      END IF
      K = MEND
    IF(DENR.GT.15) K = K + 1
    DA(1) = D1(J1) - COUNT + 1
    L = 1
    DO 100 I = J1,K
    L = L + 1
550 N = 0.0521 * COS(0 - 5)
    RA = 0.00907 * SIN(RAD(2 * TMEAN)) - 0.002697 *
    COS (RAD(3 * TMEAN) - 0.00675 * SIN(RAD(3 * TMEAN))

C
C
C   SUB ROUTINE TO DETERMINE SOLAR RADIATION
C
C
    REAL n(214)
600 Rs = (0.25 + 0.50 * (n/N) * RA
700 RNs = (1 - 0.25) * Rs
    F(TMEAN) = (5.6 EXP(-9) * TMEAN EXP(4))
800 RNL = F(TMEAN) * F(ED) * F(n/N)
```

```
C
C
C   SUB ROUTINE TO DETERMINE THE CORRECTION
    FACTOR C
    REAL TMEAN,RHMAX,A COS J,E
900 DEL = 180/3.14159 * DEL
    Hs = A COS (-TAN(RAD(LAT)) * TAN(RAD(DEL))
950 C = 0.98387 - 0.000111403 * J + 0.000052774
   *J**2 - 0.268285E - 8J ** 3 * 3.61634E * J**4

000  ET. = C(N * RN + (1 - W) * F(U) * ES

C
C   DEGREE TO RADIAL CONVERSION FUNCTION
C
    FUNCTION RAD(X)
    REAL LAT
    RAD = X/57.29577952
    END IF
    LAT = 0

C   SUB ROUTINE TO DETERMINE IRRIGATION REQUIREMENT
C
    REAL PRECIPITATION
    EPREP = PREP * 0.75
    IRR RQT = EPREP - ET
100 IF IRR RQT = + THEN 1110,ELSE 1120
110 WRITE (5,*),*'YOU HAVE ENOUGH RAIN'
120 WRITE (5,*),*'YOU NEED TO IRRIGATE'
500 FORMAT(IX,A15,F6.1,A23,F9.2,I)
    WRITE (5,*)'EVAPOTRANPIRATION =,ETO;IRRIGATION
    REQUIREMENT =,IRR RQT ,DT.

C
C   --------CORRECTING INPUT ERROR---------------
    WRITE (5,*)'ANY CHANGES?(Y/N)'
    READ (5,422) B$

422 FORMAT(A1)
    IF (B$.EQ.'Y')THEN
    WRITE (5,*)'WHICH NUMBER WOULD YOU LIKE TO CHANGE?'
     READ(5,*) CHG
    IF (CHG.EQ.1)THEN 100
    IF (CHG.EQ.2)THEN 101
    IF (CHG.EQ.3)THEN 103

    ELSE
      I = 4
      GOTO 500
```