COMPARATIVE EVALUATION OF SELECTED EVAPOTRANSPIRATION MODELS

(Case Study of Bida, Niger state, Nigeria)

BY

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MATRIC No. 2005/21585EA

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FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

DECEMBER, 2010

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BEING A FINAL YEAR PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF ENGINEERING (B. ENG) DEGREE IN AGRICULTURAL AND BIORESOURCES ENGINEERING, FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA, NIGER STATE.

DECEMBER, 2010

DECLARATION

hereby declare that this project work is a record of a research work that was undertaken and written by me. It has not been presented before for any degree or diploma or certificate at any university or institution. Information derived from personal communication, published and unpublished work were duly referenced in the text.

Baba, Ibrahim Mohammed

Date

CERTIFICATION

his is to certify that the project entitled "Comparative Evaluation of Selected vapotranspiration Models (Case Study of Bida, Niger state, Nigeria)" by Baba, Ibrahim lohammed meets the regulations governing the award of the degree of Bachelor of Engineering 3.ENG.) of the Federal University of Technology, Minna, and it is approved for its contribution › scientific knowledge and literary presentation.

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DEDICATION

I wish to dedicate this work to my parent Mallam Ibrahim Mohammed Salihu and Mallama Fati Mohammed who were never tired of my endless request.

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ABSTRACT

A comparative evaluation of selected evapotranspiration (ET) models (Penman Monteith (1998), Hargreaves – Samani (1985), Blaney – Morin Nigeria (1984)) with open pan evaporation method was carried out for Bida area of Niger state, Nigeria. The data used for this study were collected at National Cereals Research Institute Badeggi (NCRI) Agrometeorological station and Bida meteorological station for a period of 25years (1985–2009). The average daily evapotranspiration for each month of the year were estimated using the models and open pan evaporation measurements. Statistical analyses were carried out to test for the variation in the means of the daily estimated values from the models and those from open pan measurement. The performance of the models compared to open pan method was also considered for three seasons of Bida, Niger state. The crop water requirements of the selected crops (maize, sorghum, groundnut, and sugarcane) were also determined. For the entire seasons Blaney – Morin Nigeria was ranked first among the three models, with a relative difference of 10.38% of the open pan method with absolute mean difference of 0.49mm/day while penman monteith was ranked last with relative difference of 14.22% absolute mean difference of 0.67mm/day. The climate was found to have no significant difference at 5% level of significance at 5years interval on the crop evapotranspiration. The crop water requirements are 412.2mm, 595.4mm, 595.5mm, and 1671.7mm for maize, sorghum, groundnut and sugarcane respectively. The evapotranspiration models showed no significant difference between the individual model and the open pan method but the Blaney-Morin Nigeria model was found to be most preferred to other models for determining crop evapotranspiration for Bida area of Niger state because it shows most close rating to open pan method.

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Abbreviations or Symbols or Notation

e	Evaporation
t	Transpiration
ET	Evapotranspiration
ETo	Reference Evapotranspiration
ETp	Potential Evapotranspiration
ETc	Crop Evapotranspiration
ETc_{Adj}	Crop Evapotranspiration
ET_{rate}	Evapotranspiration Rate
E_{pan}	Pan Evaporation
R	Relative humidity
T	temperature
Ks	water stress coefficient
Kpan	pan coefficient
Rn	net Radiation
H	sensible heat
λET	latent heat flux

I	Irrigation
P	Rainfall
RO	Surface runoff
Dp	Deep percolation
CR	Capillary rise
T_{mean}	Mean Temperature
T_{min}	Minimum Temperature
T_{max}	Maximum Temperature
Ra	Daily Extraterrestrial Radiation
λ	Latent Heat of Vaporization
D	Slope of the saturation vapour pressure temp curve
r_t	Radiation Ratio

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CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the Study.

For a long time now much emphasis has been placed on the estimating evapotranspiration from climatic based observations. This has led to the development of a large number of empirical formulae relating evapotranspiration to standard climatological data. Some of the formulae commonly found in literatures include: modified Penman (1975), Thornthwaite (1948), Blaney-criddle (1950), Blaney-morin Nigeria (Duru 1984), Hargreaves (1974), Priestly-taylor (1972), Jensen-haise (1970), open pan method, just to mention a few.

Crop water requirement is generally equated to the rate of evapotranspiration necessary to sustain optimum crop growth. Specifically, the water requirement of crop is defined as the rate of evapotranspiration of disease free crop growing in a field of not less than one hectare under optimal soil condition (Doorenbos and Pruitt, 1977). This optimal soil conditions assume adequate fertility and water to achieve the full protection potential under the prevailing environment.

Evapotranspiration refer to all waters transpired by the plant and that evaporated from crop and from the soil surfaces. The two terms evaporation and transpiration though fused into evapotranspiration have different working mechanisms. Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapour removal to the atmosphere. Crops predominately lose their water through stomata, evaporation (e) is the process whereby liquid water is converted to water vapour (vaporization) and

removed from the evaporating surface (vapour removal). Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation. (Edoga and Suzzy, 2008)

1.2 Statement of the Problem.

The major constraint in crop production in arid and semi arid region under irrigation system is the availability of sufficient water to meet up crop water requirement. Due to this constraint crop are sometimes subjected to moisture stress which consequently gives rise to temperature stress during that growing such adverse condition reduces growth potential and subsequent yield of the crops in addition to the loss of water through excessive soil evaporation. To address this problem a good plan for irrigation scheduling programme is required such that water is supply to the crop only when necessary and in required quantity.

1.3 Objectives of the Study.

The objectives of this study are:-

i). To determine the potential evapotranspiration for the selected models and open pan method.

ii). To determine the crop water coefficient (Kc) for each of the selected crops.

iii). To compare the crop evapotranspiration values (ETc) for the selected models.

iv). To determine the crop water requirement of each of the selected crop.

v). To determine the effect of climate on the crop water requirement.

1.4 Justification of the Study

Davey et al. (1976) observed that water is the most important nutrient of a crop, which does not just need water to grow, but requires it as a vehicle in which other nutrients are transported. Knowledge of the amount available and its distribution in relation to other nutrients in the soil is therefore of fundamental importance in the study of crop growth and production As numerous as the empirical expressions for estimating evapotranspiration are very few of them are being used by researchers, irrigation scientist and farmers. The reasons been that some of these models or expressions requires numerous and cumbersome computation. More so some of the data required in their computation are not readily available for intended users. One other set back to the use of the empirical model is that many of them are valid only in region where they are developed. They can only be used in areas that have similar climatic variation. Verifications and modifications in therefore required before they can be used in regions other than where they are derived. This study will help determine which one best suite the study area and the crop water requirement of the selected crops.

1.5 Scope of the Study

The study is based on three evapotranspiration models: Penman-Monteith (1998), Blaney-Morin Nigeria (Duru 1984) and Hargreaves-Samani (1985) were compared to open pan method. The data used for the study area (Bida, Niger state) were collected from the National Cereals Research Institute (NCRI) Badeggi agrometeorological station and Bida meteorological station for a period of 25years (1985-2009). The monthly average evapotranspiration for each of the year were estimated using the models and

from open pan evaporation measurement. In addition the crop water requirement for maize, sorghum, groundnut and sugar cane were also estimated from the models under study.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Evapotranspiration (ET)

Evapotranspiration is the transfer of water to the atmosphere by direct evaporation of solid and liquid water from soil and plant surfaces as well as transpiration. Evapotranspiration can also be defined as sum of evaporation and plant transpiration. It is difficult, and of little value, to separate evaporation and transpiration for vegetated surfaces; thus they are often lumped together and termed evapotranspiration (*ET*). Other terms are sometimes used, such as consumptive use, or crop water requirement. The rate of evapotranspiration is expressed as volume of water evaporated per unit area per unit time and hence, units of rate of ET (ET_{rate}) are in mm per day :

$ET_{rate} = mm^3\ mm^{-2}\ d^{-1} = mm\ d^{-1}$

Where, d is expressed in day(s)

2.1.1 Evaporation

Evaporation is the process whereby liquid water is converted to water vapour (vaporization) and removed from the evaporating surface (vapour removal). Water evaporates from a variety of surfaces, such as lakes, rivers, pavements, soils and wet vegetation. Energy is required to change the state of the molecules of water from liquid to vapour. Direct solar radiation and, to a lesser extent, the ambient temperature of the air provide this energy. The driving force to remove water vapour from the evaporating

surface is the difference between the water vapour pressure at the evaporating surface and that of the surrounding atmosphere. As evaporation proceeds, the surrounding air becomes gradually saturated and the process will slow down and might stop if the wet air is not transferred to the atmosphere. The replacement of the saturated air with drier air depends greatly on wind speed. Hence, solar radiation, air temperature, air humidity and wind speed are climatological parameters to consider when assessing the evaporation process.

2.1.2 Transpiration

Transpiration consists of the vaporization of liquid water contained in plant tissues and the vapour removal to the atmosphere. Crops predominately lose their water through stomata. These are small openings on the plant leaf through which gases and water vapour pass. The water, together with some nutrients, is taken up by the roots and transported through the plant. The vaporization occurs within the leaf, namely in the intercellular spaces, and the vapour exchange with the atmosphere is controlled by the stomatal aperture. Nearly all water taken up is lost by transpiration and only a tiny fraction is used within the plant. Transpiration, like direct evaporation, depends on the energy supply, vapour pressure gradient and wind.

Hence, radiation, air temperature, air humidity and wind terms should be considered when assessing transpiration. The soil water content and the ability of the soil to conduct water to the roots also determine the transpiration rate, as do water logging and soil water salinity. The transpiration rate is also influenced by crop characteristics, environmental aspects and cultivation practices. Different kinds of plants may have different

transpiration rates. It should be noted that it's not only the type of crop, but also the crop development stage, environment and management should be considered when assessing transpiration.

2.2 Factors Affecting Evapotranspiration

Weather parameters, crop characteristics, management and environmental aspects are factors affecting evaporation and transpiration.

2.2.1 Weather Parameters

The principal weather parameters affecting evapotranspiration are radiation, air temperature, humidity and wind speed. The evaporation power of the atmosphere is expressed by the reference crop evapotranspiration (ETo). The reference crop evapotranspiration represents the evapotranspiration from a standardized vegetated surface.

2.2.2 Crop Factors

The crop type, variety and development stage should be considered when assessing the evapotranspiration from crops grown in large, well-managed fields. Differences in resistance to transpiration, crop height, crop roughness, reflection, ground cover and crop rooting characteristics result in different ET levels in different types of crops under identical environmental conditions

2.2.3 Management and Environmental Conditions

Factors such as soil salinity, poor land fertility, limited application of fertilizers, the presence of hard or impenetrable soil horizons, the absence of control of diseases and pests and poor soil management may limit the crop development and reduce the evapotranspiration. Other factors to be considered when assessing ET are ground cover, plant density and the soil water content. The effect of soil water content on ET is conditioned primarily by the magnitude of the water deficit and the type of soil. On the other hand, too much water will result in water logging which might damage the root and limit root water uptake by inhibiting respiration.

2.3 Reference Evapotranspiration (ETo)

The rate of evapotranspiration at a given place and time depends upon Interaction of the weather and the plant. The influence of the weather alone, can be described by defining a reference condition.

The international FAO definition of 'reference crop' evapotranspiration is the evapotranspiration rate from (Doorenbos & Pruitt, 1977) an extended surface of green grass (or alfalfa) cover 8 – 15 cm tall of uniform height actively growing completely shading the ground and not short of water. This has been defined more precisely by Allen et al. (1994). ETo reflects the evaporative demand of the atmosphere as a function of the weather only. The concept of the reference evapotranspiration was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development and management practices. As water is abundantly available at the reference evapotranspiring surface, soil factors do not affect ET. Relating ET to a specific surface

provides a reference to which ET from other surfaces can be related. It obviates the need to define a separate ET level for each crop and stage of growth. ET_o values measured or calculated at different locations or in different seasons are comparable as they refer to the ET from the same reference surface.

2.4 Crop Evapotranspiration Under Standard Conditions (ET_c)

The crop evapotranspiration under standard conditions, denoted as ET_c, is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for crop evapotranspiration and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. The irrigation water requirement basically represents the difference between the crop water requirement and effective precipitation. The irrigation water requirement also includes additional water for leaching of salts and to compensate for non uniformity of water application. (Allen et.al ,1998)

2.5 Crop Evapotranspiration Under Non-Standard Conditions ($ET_{c\ Adj}$)

The crop evapotranspiration under non-standard conditions ($ET_{c\ adj}$) is the evapotranspiration from crops grown under management and environmental conditions that differ from the standard conditions. When cultivating crops in fields, the real crop evapotranspiration may deviate from ET_c due to non-optimal conditions such as the

presence of pests and diseases, soil salinity, low soil fertility, water shortage or waterlogging. This may result in scanty plant growth, low plant density and may reduce the evapotranspiration rate below ET_c.

2.6 Relationship Between Actual and Reference Evapotranspiration

The crop evapotranspiration differs distinctly from the reference evapotranspiration (ET_o) as the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The effects of characteristics that distinguish field crops from grass are integrated into the crop coefficient (K_c). In the crop coefficient approach, crop evapotranspiration is calculated by multiplying ET_o by K_c. Differences in evaporation and transpiration between field crops and the reference grass surface can be integrated in a single crop coefficient (K_c) or separated into two coefficients: a basal crop (K_{cb}) and a soil evaporation coefficient (K_e), i.e., $K_c = K_{cb} + K_e$. The approach to follow should be selected as a function of the purpose of the calculation, the accuracy required and the data available. (Allen et al, 1998)

2.7 Determination of Crop Water Use

There are various methods used to determine the crop water use or consumptive use which could be through the use direct measurement of the crop parameters or through the use evapotranspiration models.

2.8 Direct Method

The evapotranspiration rate from a cropped surface can be directly measured by the mass transfer or the energy balance method. It can also be derived from studies of the soil water balance determined from cropped fields or from lysimeters.

2.8.1 Energy Balance and Microclimatological Methods

Evaporation of water requires relatively large amounts of energy, either in the form of sensible heat or radiant energy. Therefore the evapotranspiration process is governed by energy exchange at the vegetation surface and is limited by the amount of energy available. Because of this limitation, it is possible to predict the evapotranspiration rate by applying the principle of energy conservation. The energy arriving at the surface must equal the energy leaving the surface for the same time period.

All fluxes of energy should be considered when deriving an energy balance equation. The equation for an evaporating surface can be written as (Allen et.al, 1998):

$$R_n - G - \lambda ET - H = 0 \qquad 2.1$$

Where, R_n is the net radiation, H is the sensible heat, G is the soil heat flux and λET is the latent heat flux. The various terms can be either positive or negative. Positive R_n supplies energy to the surface and positive G, λET and H remove energy from the surface

In Equation 2.1 only vertical fluxes are considered and the net rate at which energy is being transferred horizontally, by advection, is ignored. Therefore the equation is to be applied to large, extensive surfaces of homogeneous vegetation only. The equation is

restricted to the four components: R_n, λET, H and G. Other energy terms, such as heat stored or released in the plant, or the energy used in metabolic activities, are not considered these terms account for only a small fraction of the daily net radiation and can be considered negligible when compared with the other four components. The latent heat flux (λET) representing the evapotranspiration fraction can be derived from the energy balance equation if all other components are known. Net radiation (R_n) and soil heat fluxes (G) can be measured or estimated from climatic parameters. Measurements of the sensible heat (H) are however complex and cannot be easily obtained. H requires accurate measurement of temperature gradients above the surface.

2.8.2 Mass Transfer Method

Another method of estimating evapotranspiration is the mass transfer method. This approach considers the vertical movement of small parcels of air (eddies) above a large homogeneous surface.The eddies transport material (water vapour) and energy (heat, momentum) from and towards the evaporating surface. By assuming steady state conditions and that the eddy transfer coefficients for water vapour are proportional to those for heat and momentum; the evapotranspiration rate can be computed from the vertical gradients of air temperature and water vapour via the Bowen ratio. Other direct measurement methods use gradients of wind speed and water vapour. These methods and other methods such as eddy covariance require accurate measurement of vapour pressure, and air temperature or wind speed at different levels above the surface. Therefore, their application is restricted to primarily research situations.

2.8.3 Soil Water Balance

Evapotranspiration can also be determined by measuring the various components of the soil water balance. The method consists of assessing the incoming and outgoing water flux into the crop root zone over some time period (Fig 2.1). Irrigation (I) and rainfall (P) add water to the root zone. Part of I and P might be lost by surface runoff (RO) and by deep percolation (DP) that will eventually recharge the water table. Water might also be transported upward by capillary rise (CR) from a shallow water table towards the root zone or even transferred horizontally by subsurface flow in (SF_{in}) or out of (SF_{out}) the root zone. In many situations, however, except under conditions with large slopes, SF_{in} and SF_{out} are minor and can be ignored. Soil evaporation and crop transpiration deplete water from the root zone. If all fluxes other than evapotranspiration (ET) can be assessed, the evapotranspiration can be deduced from the change in soil water content (D SW) over the time period(Allen et.al, 1998):

$$ET = I + P - RO - DP + CR \pm D\,SF \pm D\,SW \qquad 2.2$$

Where, ET is evapotranspiration, I is irrigation, P is rainfall, RO is surface runoff, DP is deep percolation, CR is the capillary rise, D SF is the change in subsurface flow in or out of the root zone and D SW is change in soil water content over the time period.

Some fluxes such as subsurface flow, deep percolation and capillary rise from a water table are difficult to assess and short time periods cannot be considered. The soil water balance method can usually only give ET estimates over long time periods of the order of week-long or ten-day periods.

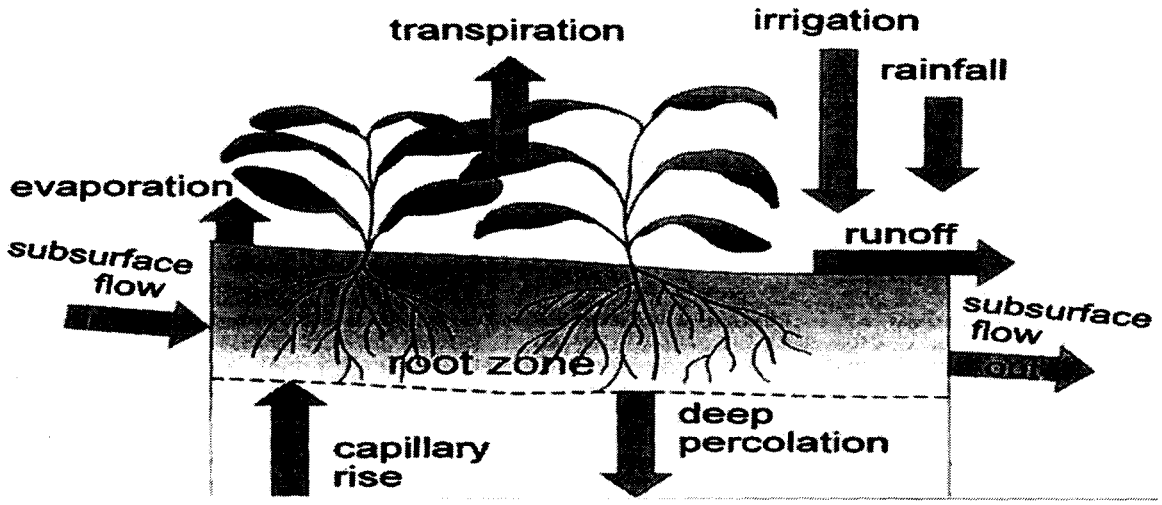


Fig 2.1: soil water balance of the root zone. Source: Allen et.al, (1998)

2.8.4 Lysimeters

By isolating the crop root zone from its environment and controlling the processes that are difficult to measure, the different terms in the soil water balance equation can be determined with greater accuracy. This is done in lysimeters where the crop grows in isolated tanks filled with either disturbed or undisturbed soil. In precision weighing lysimeters, where the water loss is directly measured by the change of mass, evapotranspiration can be obtained with an accuracy of a few hundredths of a millimeter, and small time periods such as an hour can be considered. In non-weighing lysimeters the evapotranspiration for a given time period is determined by deducting the drainage water, collected at the bottom of the lysimeters, from the total water input.

A requirement of lysimeters is that the vegetation both inside and immediately outside of the lysimeter be perfectly matched (same height and leaf area index).

2.9 Computation of ET From Meteorological Data

Owing to the difficulty of obtaining accurate field measurements, ET is commonly computed from weather data. A large number of empirical or semi-empirical equations have been developed for assessing crop or reference crop evapotranspiration from meteorological data. Some of the methods are only valid under specific climatic and agronomic conditions and cannot be applied under conditions different from those under which they were originally developed.

Numerous researchers have analyzed the performance of the various calculation methods for different locations. As a result of an Expert Consultation held in May 1990, the FAO Penman-Monteith method is now recommended as the standard method for the definition and computation of the reference evapotranspiration, ET_o (Allen et.al, 1998). The ET from crop surfaces under standard conditions is determined by crop coefficients (K_c) that relate ET_c to ET_o. The ET from crop surfaces under non-standard conditions is adjusted by a water stress coefficient (K_s) and/or by modifying the crop coefficient.

2.9.1 Crop Coefficient (Kc).

The crop coefficient integrates the effect of characteristics that distinguish a typical field crop from the grass reference, which has a constant appearance and a complete ground cover. Consequently, a given crop will have different K_c values at different stage of development The changing characteristics of the crop over the growing season also affect the K_c coefficient. Finally, as evaporation is an integrated part of crop evapotranspiration, conditions affecting soil evaporation will also have an effect on K_c.

2.9.2 Factors Determining Crop Coefficient

The factors that determine crop coefficient include (Allen et.al, 1998):

a) Crop type.

b) Climate

c) Soil evaporation.

d) Crop growth stage

2.10 Crops Selection

The crops selected are widely grown in the study area Bida, Niger State and also they have high economic value to the country at large.

Table 2.1 Some properties of the selected crops

properties	maize	guinea corn	Sugarcane	groundnut
Botanical name	*Zea mays*	*Sorghum spp*	*Saccharum officinarum*	*Arachis hypogea*
Varieties	Flour corn, sweet corn	Red grains, white grain,	Thick cane, thin cane	Upright, spreading
Seed rate(kg/ha or setts/ha)	12	10	20000	50 -80
Geography	Tropics to temperate regions.	Asia, Africa	Hot wet tropics	west Africa high latitudes Mediterranean
Required temp (^{o}C)	≥ 15	≥20	22 to 30	22 to 28
Maturation(days)	125	145	280	130
Yield	15000cobs/ha	1000kg/ha	20tonnes cane	5000kg/ha

Source: Derek and John (1979)

CHAPTER THREE

3.0 MATERIAL AND METHOD

3.1 Climate of the Study Area

Bida is one of the largest city in Niger state with an estimated population of 188181(2006 census) and 51km^2. It is located at a longitude of 09 ^{0} 06 N, latitude of 06 ^{0} 01 E and altitude of 137m. Vegetation in Bida belong to the guinea savanna and experiences distinct dry and wet seasons with annual rainfall varying from 1100mm to 1600mm and last for about 120 – 150 days from June - October. The maximum annual temperature (usually not more than 34^{0}C) is recorded between March and June while minimum is usually recorded between December and January. It contain vegetations like *Adropogen spp, Imperical cylindrical, Daniella spp, parkia biglobossa, Buterosperum spp, Ammarindus indica.* (Umaru 1999)

Generally, the climates of the area can classify into three seasons:

a) Wet humid season of June to September. This season is characterized with rainfall, high relative humidity which ranges from 76.4% to 86.6% with peak value recorded in the month of august. The mean daily temperature during the season ranges from 26.8°C to 27.7°C with the highest value in June.
b) The dry, cold harmattan season of October to mid-February. This season is characterized with little or no-rainfall, low temperatures ranging from 16°C to 23°C, low relative humidity ranging from 26% to 43% and high wind speed. The season is cold due to poor incident radiation because of harmattan dust.

c) The dry-hot season of February ending to may. This season is characterized by no rainfall, low humidity and high mean temperatures ranging from 25°C to 29°C. Evaporation is usually very high and the weather generally harsh.

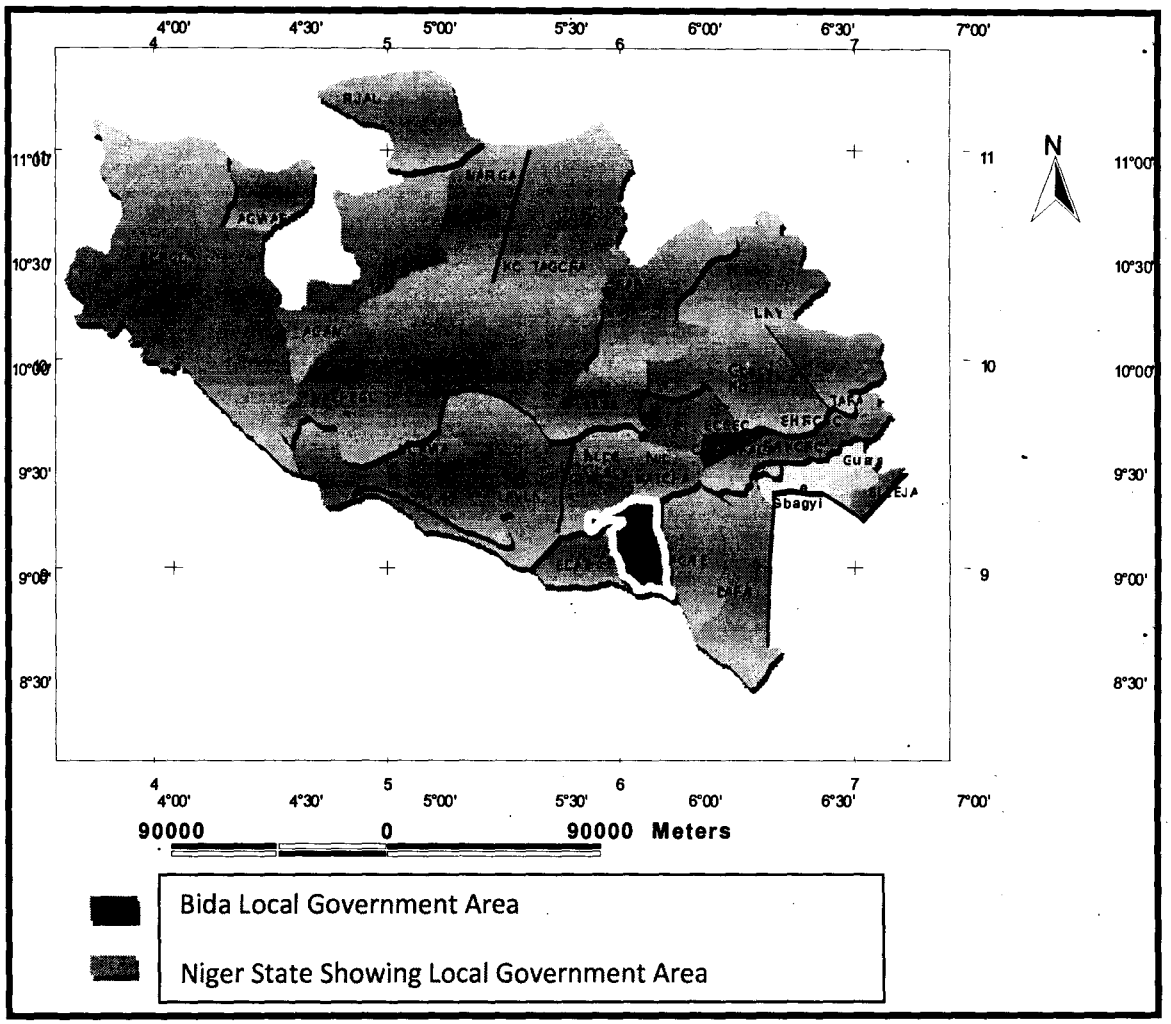


Fig 3.1: Map of the study area (Bida)

3.2 Data Collection and Computation

The data used to evaluate the models were collected from the National cereals research institute (NCRI) and the Nigeria meteorological agency Bida Aerodrome. The data collected include open pan evaporation measured with the use of class A pan; maximum and minimum temperatures; air movement (wind speed or wind run) at 2m

height; relative humidity of the air at 10.00am and 4.00pm ; solar radiation and sunshine hours for each month of the year. Data collected covered a period of 25years (1985-2009).

3.3 weather stations

The methods for calculating evapotranspiration from meteorological data require various climatological and physical parameters. Some of the data are measured directly in weather stations. Other parameters are related to commonly measured data and can be derived with the help of a direct or empirical relationship. Meteorological data are recorded at various types of weather stations. Agrometeorological stations are sited in cropped areas where instruments are exposed to atmospheric conditions similar to those for the surrounding crops. In these stations, air temperature and humidity, wind speed and sunshine duration are typically measured at 2 m above an extensive surface of grass or short crop.

Data collected at stations other than agrometeorological stations require a careful analysis of their validity before their use. For example, in aeronautic stations, data relevant for aviation are measured. As airports are often situated near urban conditions, temperatures may be higher than those found in rural agricultural areas. Wind speed is commonly measured at 10 m height above the ground surface. For this project work the meteorological data used are from the National cereals research institute (NCRI) badeggi agrometeorological station which is located at latitude $9^0$045N, longitude $6^0$07E and has an altitude of 70.57m above sea level.

3.3.1 Temperature

Agrometeorology is concerned with the air temperature near the level of the crop canopy. In traditional and modem automatic weather stations the air temperature is measured inside shelters (Stevenson screens or ventilated radiation shields) placed in line with World Meteorological Organization (WMO) standards at 2 m above the ground. The shelters are designed to protect the instruments from direct exposure to solar heating. The louvered construction allows free air movement around the instruments. Daily minimum temperature (T_{min}) and maximum temperature (T_{max}) are available at the station. From there an estimate of daily mean is going to computed.

$$T_{mean} = \frac{T_{max} + T_{min}}{2} \qquad 3.1$$

The unit of temperature at the station was in degree centigrade (°C).

3.3.2 Temperature Measurement

Air temperature is measured with thermometers. The type available at the station are the Minimum and maximum thermometers which record the minimum and maximum air temperature over a 24-hour period. The maximum thermometer is a mercury-in-glass thermometer containing a small glass index which the mercury pushes along when the temperature falls. The maximum is shown by the end of the index near the mercury. After observation the index is brought back to the mercury by tilting the thermometer. The minimum thermometer is an alcohol-in-glass thermometer in which when the temperature rises the alcohol expands and flows past the index and when the temperature falls the alcohol contracts and drags the index back because of its surface tension. The end of the

index nearer the meniscus shows the minimum temperature and the instrument is reset by tilting. The minimum and maximum temperature for the 25years considered was collected and analyzed to give the mean using equation 3.1.

3.3.3 Humidity

Humidity is the term used to describe the water vapour content in the atmosphere which varies with temperature. It does not cover the other form in which moisture may be present in the atmosphere e.g. liquid form (water droplets) and solid form (ice).

There are various ways of measuring the moisture content of the atmosphere. The following are the indices of humidity usually used.

i). *Absolute humidity* which is expressed in grams per cubic meter of air is the total mass of water in a given volume of air.

ii). *Specific humidity* is the mass of water vapour per kilogram of air including its moisture.

iii). *Mass mixing ratio or humidity mixing ratio* is the mass of water vapour per kilogram of dry air.

iv). *Relative humidity* is the ratio of actual moisture content of a sample of air to that the same volume air can hold at the same temperature and pressure when saturated. It is usually expressed in percentage form. It is usually calculated by

$$\frac{actual\ amount\ of\ water\ vapour\ in\ the\ air}{maximum\ amount\ of\ water\ vapour\ the\ air\ can\ hold} \times 100\% \qquad 3.2$$

v). *Dew point temperature* is the temperature at which saturation will occur if the air is cooled at constant pressure without addition or removal of vapour.

vi). *Vapour pressure* is the pressure exerted by the vapour content of the atmosphere in millibars.

3.3.4 Relative Humidity and Its Measurement

A hygrometer is used to measure relative humidity. The type at the station is the common type which consist of two thermometers the wet and dry bulb thermometer. The dry bulb thermometer is used to measure temperature of the air. The wet bulb thermometer has wick which is dipped in a bottle of water attached to it bottom.

There are two steps involved in getting the relative humidity. The first is to get the readings from the two thermometers to find out the wet bulb depression (difference in the reading from the two thermometers). Then the relative humidity is obtained by referring to the relative humidity table.

3.3.5 Wind

Wind can be described in terms of it speed and it's direction, so two different instrument are used to measure these two aspect of wind.

3.3.6 Measuring of Wind Speed

In the station the instrument used in measuring wind speed is an anemometer, it consist of three caps joined to the ends of horizontal metal rod that are fixed to a vertical spindle. When there is wind the cup rotate and the movement are transmitted to an electrically operated dial. The dial records the wind speed in knots where one knots equal to 1.85km per hour.

3.3.7 Solar Radiation and Sunshine Hour

Solar radiation is usually estimated from the duration of bright sunshine. The actual duration of sunshine, n, is measured with a Campbell-Stokes sunshine recorder. This instrument records periods of bright sunshine by using a glass globe that acts as a lens. The sun rays are concentrated at a focal point that burns a hole in a specially treated card mounted concentrically with the sphere. The movement of the sun changes the focal point throughout the day and a trace is drawn on the card. If the sun is obscured, the trace is interrupted. The hours of bright sunshine are indicated by the lengths of the line segments.

3.3.8 Description of Class A Pan

The Class A Evaporation pan is circular, 120.7 cm in diameter and 25 cm deep. It is made of galvanized iron (22 gauge) or Monel metal (0.8 mm). The pan is mounted on a wooden open frame platform which is 15 cm above ground level. The soil is built up to within 5 cm of the bottom of the pan. The pan must be level. It is filled with water to 5 cm below the rim, and the water level should not be allowed to drop to more than 7.5 cm below the rim. The water should be regularly renewed, at least weekly, to eliminate extreme turbidity. The pan, if galvanized, is painted annually with aluminium paint. Screens over the pan are not a standard requirement and should preferably not be used. Pans should be protected by fences to keep animals from drinking.

The site should preferably be under grass, 20 by 20 m, open on all sides to permit free circulation of the air. It is preferable that stations be located in the centre or on the leeward side of large cropped fields.

Pan readings are taken daily in the early morning at the same time that precipitation is measured. Measurements are made in a stilling well that is situated in the pan near one edge. The stilling well is a metal cylinder of about 10 cm in diameter and some 20 cm deep with a small hole at the bottom.

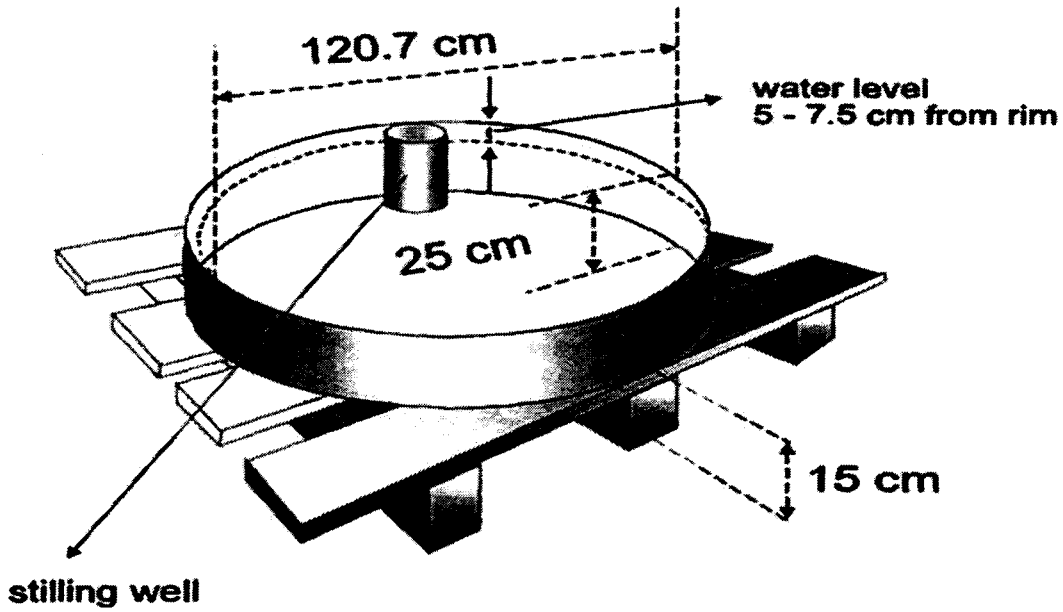


Fig 3.2: Description and dimension of a class A pan (Brouwer and Heibloem, 1986).

The principle of the evaporation pan is the following:

i). The pan is installed in the field

ii). The pan is filled with a known quantity of water (the surface area of the pan is known and the water depth is measured)

iii). The water is allowed to evaporate during a certain period of time (usually 24 hours For example, each morning at 7 o'clock a measurement is taken). The rainfall, if any, is measured simultaneously

iv). After 24 hours, the remaining quantity of water (i.e. water depth) is measured

v). The amount of evaporation per time unit (the difference between the two measured water depths) is calculated; this is the pan evaporation: Epan (in mm/24 hours).

vi). When using the evaporation pan to estimate the ETo, a comparison is made between the evaporation from the water surface in the pan and the evapotranspiration of the standard grass. The water in the pan and the grass do not react in exactly the same way to the climate. Therefore a special coefficient is used known as pan evaporation factor (kpan). For the Class A evaporation pan, the Kpan varies between 0.35 and 0.85. Average Kpan = 0.70.

If the water depth in the pan drops too much (due to lack of rain), water is added and the water depth is measured before and after the water is added. If the water level rises too much (due to rain) water is taken out of the pan and the water depths before and after is measured.

3.4 Determination of the Reference Evapotranspiration (ETo)

The ET models studied are Hargreaves-Samani (1985), penman Monteith (1998), Blaney- Morin (Duru 1984) as well as the open pan evaporation method. The reference ET was obtained from the potential ET values from these ET models under study.

3.4.1 Hargreaves-Samani Equation

The Hargreaves-Samani (H/S) 1985 ET model is one of the more recent versions of one of the older evapotranspiration models (Hargreaves and Allen 2003). The H/S model used in this study has conceptually similar versions (Hargreaves 1974, Hargreaves

and Samani 1982), which intended to be computationally simple and applicable to a variety of climates using only commonly available meteorological data. The creation of the H/S model used in this study was intended to simplify the previous versions further by reducing the amount of measured meteorological data to air temperature and by using extraterrestrial radiation (Ra) as a substitute for measured sunshine or radiation data (Hargreaves and Allen 2003). The H/S model was later adopted for used by the FAO for areas where air temperature alone is the only available variable (Allen et al. 1998, Hargreaves and Allen 2003). The form of the H/S equation presented in FAO 56 by Allen et al. (1998) is:

$$ETo = 0.0023(T_{mean} + 17.8)(T_{max} - T_{min})^{0.5} R_a \qquad 3.3$$

Where ETo is the reference evapotranspiration (mm day-1), T_{mean} is the mean air temperature (°C), T_{max} is the daily maximum temperature (°C), T_{min} is the daily minimum temperature (°C), and R_a is the daily extraterrestrial radiation (mm day^{1}). Equation 3.3 does not account for any local factors such relative humidity as the previous Hargreaves models do, which may be a limitation. This equation, however, is computationally simple and can be used over a variety of climates with a minimal amount of climate data required (Hargreaves and Allen 2003) Ra was derived from appendix A, table A2.

3.4.2 FAO Penman-Monteith

The Penman family of models is generally considered among the most accurate ET models in virtually any climate (Anyadike 1987, Barnett et al. 1998, Qiu et al. 2002). The FAO version of the Penman-Monteith model (hereafter referred to as PM) is so accurate that it is recommended as the sole method of calculating ETo, if data are

available (Allen et al. 1998). The major limitation to the Penman family of models is that they require many meteorological inputs, thereby limiting their utility in data-sparse areas (Hansen et al. 1980, Dingman 1994). Several major versions of the Penman model exist, each with its own variations for specific climates, crops, etc. The PM model is a variant of the original 1948 Penman model, but the PM model accounts for aerodynamic (ra) and bulk surface resistance (rs) (Allen et al.1998). These terms modify the original equation to take into account the increasing resistances involved in transporting moisture from the evaporating surface upward and to the atmosphere under increasingly dry surface conditions. Specifically, ra describes the physical resistance in transporting moisture from the evaporating surface (plant leaf) into the atmosphere (Allen et al. 1998) by modeling stomatal resistance of the vegetation and rs models resistance from the soil surface (Allen et al. 1998). The addition of these two terms allows the original Penman model to better approximate the actual processes of evapotranspiration from a vegetated surface. It also allows the adaptation of the equation to a specific type of vegetation, such as a particular crop. The basic form of the PM equation is given as (Allen et al. 1998):

$$\lambda ET = \frac{\Delta(R_n - G) + \rho_a C_P \frac{(e_s - e_s)}{r_a}}{\Delta + \gamma\left(1 + \frac{r_s}{r_a}\right)} \qquad 3.4$$

Where λ is the latent heat of vaporization (J kg^{-1}), ET is evapotranspiration (Jm^{-2} s^{-1}) , Δ is the slope of the saturation vapor pressure-temperature curve (Pa K^{-1}), γ is the psychrometric constant (Pa K^{-1}), R_n is the net radiation(J m^{-2} s^{-1}), G is the soil heat flux (J m^{-2} s^{-1}), (e_s – e_a) is the difference between the saturation vapor pressure e_s (Pa) and the actual vapor pressure e_a (Pa), ρ_a is the mean air density (kg m^{-3}), c_p is the specific heat of

air (J kg^{-1} k^{-1}), and r_a and r_s are the aerodynamic and surface resistances (s^{-1} m) (Allen et al. 1998).

i) Aerodynamic resistance (r_a)

The transfer of heat and water vapour from the evaporating surface into the air above the canopy is determined by the aerodynamic resistance:

$$r_a = \ln\left[\frac{z_m - d}{z_{om}}\right] \ln\left[\frac{z_h - d}{z_{oh}}\right] / k^2 u_z \qquad 3.5$$

Where r_a aerodynamic resistance (s m^{-1}), z_m height of wind measurements (m), z_h height of humidity measurements (m), d zero plane displacement height (m), z_{om} roughness length governing momentum transfer (m), z_{oh} roughness length governing transfer of heat and vapour (m),k von Karman's constant, 0.41 (-), u_z wind speed at height z (m s-1).

ii) (Bulk) surface resistance (r_s)

The 'bulk' surface resistance describes the resistance of vapour flow through the transpiring crop and evaporating soil surface. Where the vegetation does not completely cover the soil, the resistance factor should indeed include the effects of the evaporation from the soil surface. If the crop is not transpiring at a potential rate, the resistance depends also on the water status of the vegetation.

$$r_s = \frac{r_i}{LAI_{active}} \qquad 3.6$$

Where, r_s (bulk) surface resistance [s m^{-1}], r_i bulk stomatal resistance of the well-illuminated leaf [s m^{-1}], LAI_{active}(sunlit) leaf area index. The LAI values for various crops differ widely but values of 3-5 are common for many mature crops.

For a given crop, green LAI changes throughout the season and normally reaches its maximum before or at flowering. LAI further depends on the plant density and the crop variety.

A general equation for LAI_{active} is:

$$LAI_{active} = 0.5\, LAI \qquad 3.7$$

Which takes into consideration the fact that generally only the upper half of dense clipped grass is actively contributing to the surface heat and vapour transfer? For clipped grass a general equation for LAI is:

$$LAI = 24\, h \qquad 3.8$$

Where h is the crop height (m).

As the reference grass surface concept was introduced and its parameters were defined, Allen et al. (1998) modified the basic form of PM to incorporate these variables and to produce a simplified PM equation (56PM). The final form of the 56PM equation is described by Equation 3.9 (Allen et al, 1998):

$$ET_O = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad 3.9$$

where ET_o is grass reference evapotranspiration (mm day^{-1}), R_n is net radiation (MJ m^{-2} day^{-1}), G is soil heat flux (MJ m^{-2} day^{-1})' γ is the psychometric constant (kPa $°C^{-1}$), e_s is the saturation vapor pressure (kPa), e_a is the actual vapor pressure (kPa), and is the slope of the saturation vapor pressure-temperature curve (kPa $°C^{-1}$), T is the average daily air temperature (°C), and u_2 is the mean daily wind speed at 2 m (m s^{-1}) (Allen et al. 1998). On a daily scale, the nature of the climate system allows for the soil heat flux term, G, to be ignored as soil heat flux on a daily scale is essentially zero (Allen et al. 1998). The

term cannot be ignored for longer time scales, such as monthly data. In this study, daily soil heat flux is assumed to be zero and is ignored.

3.4. Pan Evaporation

Doorenbos and Pruitt (1977) described a method to convert pan evaporation to ET_o. This method, known as FAO 24 Pan Evaporation, adjusts the measured pan evaporation by a coefficient to estimate ET_o. The basic form of the model, as described by Allen et al. (1998) is:

$$ET_O = K_P E_{Pan} \qquad 3.10$$

Where ET_o is in mm day^{-1}, K_P is the pan coefficient, and E_{pan} is the pan evaporation (mm day^{-1}). The coefficient, K_P, is dependent on several factors, including pan type (Class "A" pan or a "Colorado" pan), the upwind fetch, humidity, and wind speed (Allen et al. 1998, Doorenbos and Pruitt 1977, Jensen et al. 1990). The coefficient K_P was derived from the table presented in Appendix A table A2.

3.4.4 Blaney – Morin Nigeria Equation

Blaney and Morin (1942) proposed a simple evapotranspiration model which in a generalized form may be expressed as (Duru 1984)

$$ETc = KPT(H - R^m)/100 \qquad 3.11$$

In which, ETo is the crop evapotranspiration (in.), For a given period, K ia the crop factor, P is the ratio of maximum, T is temperature (°F), R is relative humidity(%), H and m are constants. In the S I unit measurement Equation 3.12 takes the form

$$ETo = P(0.45T + 8)(H - R^m)/100 \quad 3.12$$

The modification of the Blaney-Morin (1942) model to Blaney–Morin Nigeria ET model by Duru (1984) used solar radiation, temperature and relative humidity as climatic variables. The constant in equation were evaluated with measured value of T, R and open evaporation measured with class A pans ($E_{class\ A}$). ETo was not measured directly and was defined as $0.7E_{class\ A}$ which was to determine a fixed value of H and m such that it minimize the error in ETo for all values of temperature and relative humidity. It was also decided to replace the ratio of sunshine hour with radiation ratio. Thus,

$$ETo = r_t(0.45T + 8)(520 - R^{1.31})/100 \quad 3.13$$

Where, ETo is reference evapotranspiration (mm/day^{-1}), r_t is ratio of maximum possible incident radiation outside the atmosphere to the annual maximum, T is the mean daily temperature (^oC), R is relative humidity (%) which is computed using Equation 3.2.

3.5 Method of Analysis of Result

a) Analysis of variance (ANOVA) was carried out to test for significant difference in the means of the estimated reference evapotranspiration from the open pan and the other three models. A't' test was also conducted between each of the models and open pan evapotranspiration to determine the significant difference between the means of each of the model and the open pan. The absolute mean differences between the open pan ETp and each of the model was also calculated

b) The year was divided into divided into three according to the three season as described in section 3.1. Statistical analysis using ANOVA,'t' test and mean difference computation was carried out for each season. The essence of this is to determine the performance of each model for each season of a given year.

c) The models were ranked in accordance to the close their estimated evapotranspiration values were to those of the open pan.

d) The 25years data was divided into five years intervals and the ETp for each of the five year was computed using each of the models and open pan evaporation to determine the effect of climate on the crop water requirement

3.6 Determination of ETo Per Decade (10 days value)

The mean ETo that was obtained was from mean monthly climatic data. However a shorter period of ten days is required for the calculation of the crop water requirement. This will be achieved through the use of graphical interpolation procedure.

a) The monthly mean daily ETo was plotted against the length of each monthly period

b) The length of each monthly period was them divided into 10 day intervals.

3.7 Determination of the Crop Coefficient (Kc)

As crops develops, the ground cover, crop height and the leaf area change. Due to differences in evapotranspiration during the various growth stages, the K_c for a given crop will vary over the growing period. The growing period can be divided into four distinct growth stages: initial, crop development, mid-season and late season. The length of the each stage determines the rate of change of Kc.

3.8 Determination of Crop Growth Stage

For all the crops consider the growing period was divided into.

i). Initial stage: The initial stage runs from planting date to approximately 10% ground cover. The length of the initial period is highly dependent on the crop, the crop variety, the planting date and the climate. The end of the initial period is determined as the time when approximately 10% of the ground surface is covered by green vegetation. For perennial crops, the planting date is replaced by the 'Greenup' date, i.e., the time when the initiation of new leaves occurs.

ii). Crop development stage: The crop development stage runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering.

iii). Mid- Season stage: The mid-season stage runs from effective full cover to the start of maturity. The start of maturity is often indicated by the beginning of the ageing, yellowing or senescence of leaves, leaf drop, or the browning of fruit to the degree that the crop evapotranspiration is reduced relative to the reference ET_o. The mid-season stage is the longest stage for perennials and for many annuals, but it may be relatively short for vegetable crops that are harvested fresh for their green vegetation.

iv). Late season stage: The late season stage runs from the start of maturity to harvest or full senescence.

Average planting date was collected from National Cereals Research Institute (NCRI) Badeggi for the crops, while length of the growth stage was from FAO paper 56 (Allen et al. 1998).

3.9 Determination of Kc Value.

Kc values at each growth stage for the selected crops were obtained from suggested values by Allen et al. (1998) as reported in FAO paper 56.

3.10 Drawing of the Kc Curve.

From the Kc value obtained, a graph known as the Kc curves was drawn for each of the selected crops which was also use to obtain a mean kc value for 10 days period.

3.11 Calculation of ETc.

The Etc was determined for each 10 days period by multiplying ET_o by K_c. The values were computed for the growing season for each of the crop selected. Hence the water requirement of each of the crops was determined per hectare.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Result of Potential Evapotranspiration

The result of the computed average daily potential evapotranspiration (mm/day) for each month of the year, for the three models and the open pan evaporation are presented in appendix B. A graphical comparison of the methods is presented in Fig 4.5.

4.1.1 Hargreaves –Samani Model

The result of this model seems consistent throughout the year with a minimum ETp of 4.32mm/day in the month of august, the maximum is 6.50mm/day in the month of March and the mean for the month is 5.28mm/day as shown in appendix B (Table B.1).

4.1.2 Penman-Monteith Model

The result of this model also seems consistent throughout the year with a minimum ETo of 3.43mm/day also in the month of August, the maximum is 5.13mm/day in the month of April and the mean for the month is 4.06mm/day as shown in appendix B (Table B.2).

4.1.3 Open Pan Evaporation Method

The result of this model also seems to be consistent throughout the year with a minimum ETp of 3.07mm/day also in the month of December, the maximum is 7.33mm/day in the month of June and the mean for the month is 4.73mm/day as shown in appendix B (Table B.3).

4.1.4 Blaney –Morin Nigeria method

The result of this model also seems consistent throughout the year with a minimum ETp of 2.54mm/day also in the month of July, the maximum is 6.53mm/day in the month of February and the mean for the months is 4.24mm/day as shown in appendix B (Table B.4).

4.2 Effect Of Climate

From the data obtained from the 5years interval which is presented in appendix B Table B.6 it was observed that there was no significant difference at 5% level of significance in the ETp values obtained from each of the five years data as shown in Appendix C(Table C.11).

4.3 Statistical Analysis

The results are presented in Appendix C (Table C1-C6). The standard mean was found to be 4.58mm/day while the absolute mean deviation are 0.15, 0.31, 0.70 and 0.52 for open pan evaporation, Blaney-Morin, Hargreaves and penman monteith respectively. The absolute mean ETp difference between open pan evaporation and Blaney-Morin, Hargreaves and penman monteith were 0.49, 0.55 and 0.67mm/day respectively. From ANOVA table F_{etp}= 4.406,$F_{.50,3,33}$ = 2.891. From the t-test open pan and Blaney-Morin, Hargreaves and penman monteith t stat value are 1.008, -1.557 and 2.790 respectively. Appendix C (Table C.1) shows the overall rating of the models as they predicted ETp close to open pan. The Blaney- Morin was ranked first while penman monteith was ranked last among other models.

Table C.2 in appendix C presents the ETp according to the three seasons described in section 3.1, the absolute mean difference between the open pan and each of the models and the rating as they predict ETp close to open pan. In the dry-cold harmattan of October to January the absolute mean difference mean ETp difference between open pan and Blaney-Morin, Hargreaves and penman monteith are 0.90, 1.68 and 0.17 respectively. The penman monteith was ranked first with estimate of 95.5% of open pan ETp while Hargreaves was ranked last among other models with 68.2% of open pan ETp. . In the dry-hot season of February to May the absolute mean difference mean ETp difference between open pan and Blaney-Morin, Hargreaves and penman monteith are 0.66, 0.13 and 1.46 respectively. The Hargreaves was ranked first with 97.9% of open pan ETp while penman monteith was ranked last among other models with 76.3% of open pan ETp. In the wet-humid season of June to September the absolute mean difference mean ETp difference between open pan and Blaney-Morin, Hargreaves and penman monteith are 1.70, 0.10 and 0.72 respectively. The Hargreaves was again ranked first with 97.9% of open pan etp while Blaney-Morin was ranked last among other models with 61.2% of the open pan etp.

In the statistical analysis of variance conducted for the dry-cold harmattan, the dry-hot season and the wet-humid season have F_{etp} value as 8.463, 2.610 and 26.759 respectively. In the t- test analysis conducted between open pan and each of the model ETp in the dry-cold harmattan the t-stat value between open pan and Blaney-Morin, Hargreaves and penman monteith are -1.536, -4.155 and -1.489 respectively, for dry-hot season are 0.630, 0.174 and 3.589 respectively and for wet-humid season 14.278, -0.638 and 6.713 respectively.

4.4 Crop Coefficients.

The crop coefficient values for each of the selected crops are presented in appendix D The crop coefficient (kc) curve for each of the selected crops is presented in Fig 4.1 to 4.4 (the x-axis is expressed in days of maturity of 125, 130, 130, and 365days for maize, groundnut, sorghum and sugarcane respectively.)

4.5 Crop Evapotranspiration Values.

The result of the crop evapotranspiration for the selected crops are presented in appendix D

4.5.1 Maize

The result for maize shows a maximum evapotranspiration of 3.80mm/day in the second decade of July and minimum of 1.35mm/day in the third decade of May while the total water requirement per hectare of maize was found to be $3603m^3$/ha.

4.5.2 Groundnut

The result for groundnut shows a maximum evapotranspiration of 3.44mm/day in the second decade of July and minimum of 1.73mm/day in the first decade of June while the total water requirement per hectare of maize was found to be $3801m^3$/ha.

4.5.3 Sorghum

The result for sorghum shows a maximum evapotranspiration of 3.46mm/day in the second decade of September and minimum of 1.93mm/day in the third decade of

October while the total water requirement per hectare of maize was found to be 4030m^3/ha.

4.5.4 Sugarcane

The result for sugarcane a maximum evapotranspiration of 5.39mm/day in the first decade of June and minimum of 1.76mm/day in the second decade of February while the total water requirement per hectare of maize is found to be 14325m^3/ha

4.6 Discussion of Results

4.6.1 ETo Result Obtained

From the values of the ETo obtained and the graphical evaluation of the Eto model and open pan method, it was found out that there was no significant difference between the values obtained from them

4.6.2 Statistical Analysis

Statiscal analysis of variance (anova) showed that the variation in the mean of the ETp for three models and open pan were highly significant at 5% level of significance which means that the models are highly related to that of the open pan evaporation. The comparison between each of the models and open pan showed no significant different at 5% level of significance from the open pan. From the t-test conducted showed that the models were significant at 5% level of significant. From the rating of the models as they predicted ETp close to open pan, the Blaney- Morin was ranked first. Incidentally, the Penman Monteith model which was considered to provide the most satisfactory results because it incorporates all the climate which open pan is exposed to was ranked last

last among the other three models. This may be due to the fact that some of the data required for computation were not directly measured but were extracted from relevant tables.

Statistical analysis showed that the variation in the mean of the evapotranspiration for the models and open pan for the dry-cold harmattan season and the wet-humid season were highly significant. The dry-hot season was not significant at 5% level of significance.

The comparison between the open pan etp and each of the models for the dry cold harmattan season of October to January showed that they are not significant at 5% level of significance. The comparison between the open pan ETp and each of the models for the dry hot season of February to May showed that they are not significant at 5% level of significance. However it was the Hargreaves model that was highly significantly to the open pan during the wet-humid season of June to September. During the dry- cold harmattan season, the penman Monteith was rank first although any of the three models could be used as they show no significantly different from open pan.

4.6.3 Kc Curves

Major deviation of the estimated kc point from the curves is due to the short wet and dry spells (Abdulmunin 1988).

4.6.4 Crop Evapotranspiration (ETc)

The crop water requirement of the selected crops obtained compared well with that given values given by FAO (2002) which are

i). Maize value obtained 412.2 mm FAO value range from 400 to 750 while relative difference to FAO is 28.32%

ii). Sorghum value obtained 595.4 mm FAO value range from 450 to 650 while relative difference to FAO is 7.63%

iii). Groundnut value obtained 595.4 mm FAO value range from 500 to 700 while relative difference to FAO is 7.63%

iv). Sugar cane value obtained 1671.7 mm FAO value range from 1500 to 2500 while relative difference to FAO is 16.41%

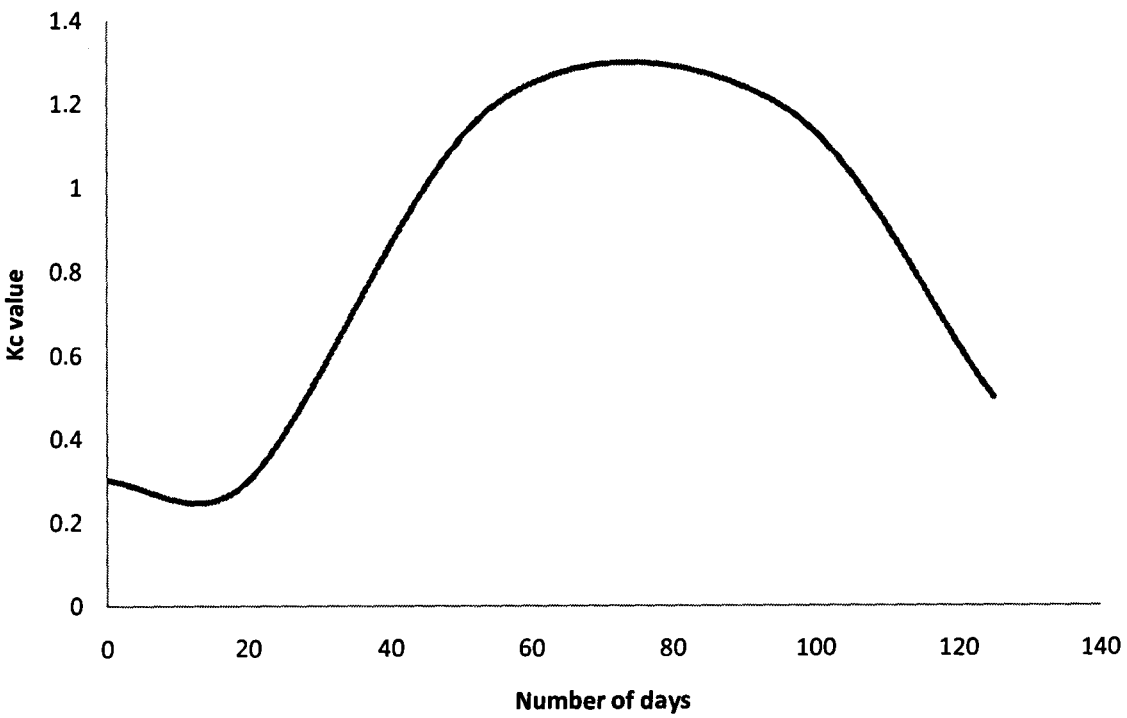


Fig 4.1: Kc curve for maize

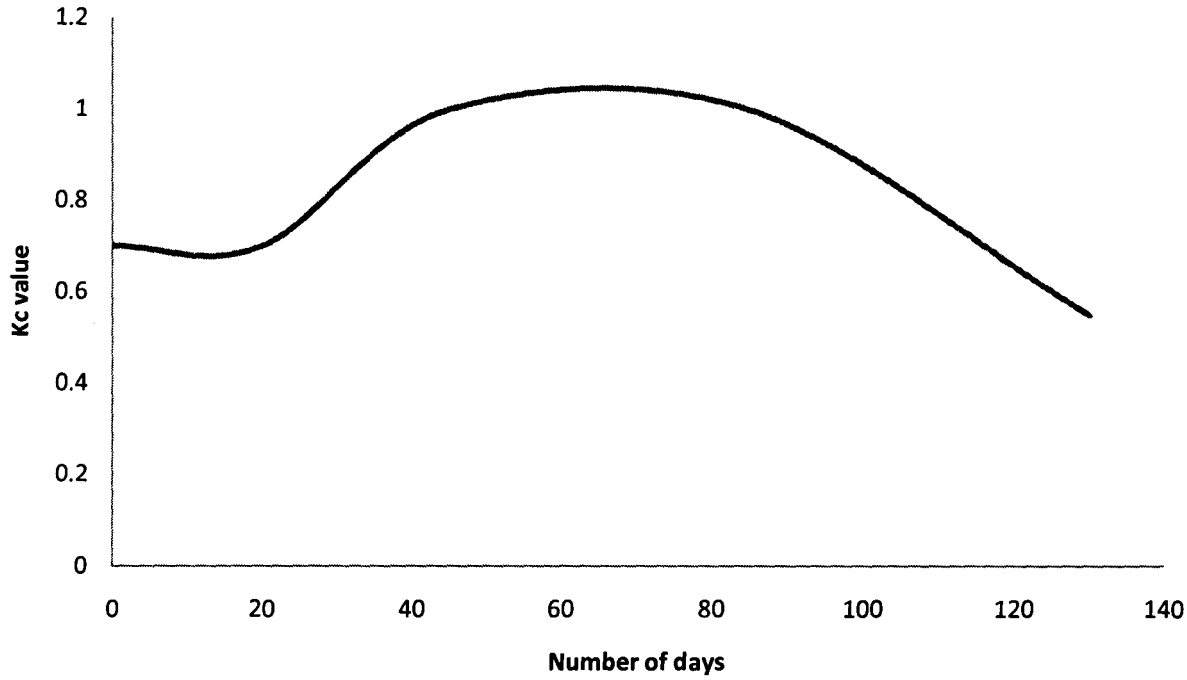


Fig 4 2: Kc curve for sorghum

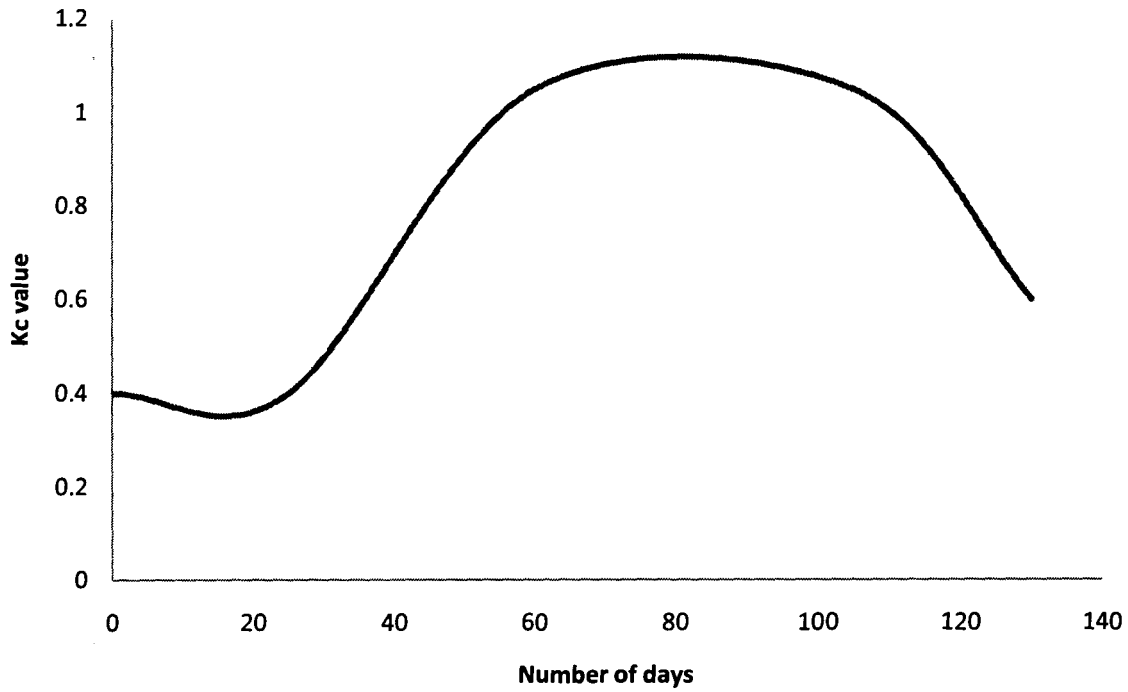


Fig 4.3: Kc curve for Groundnut

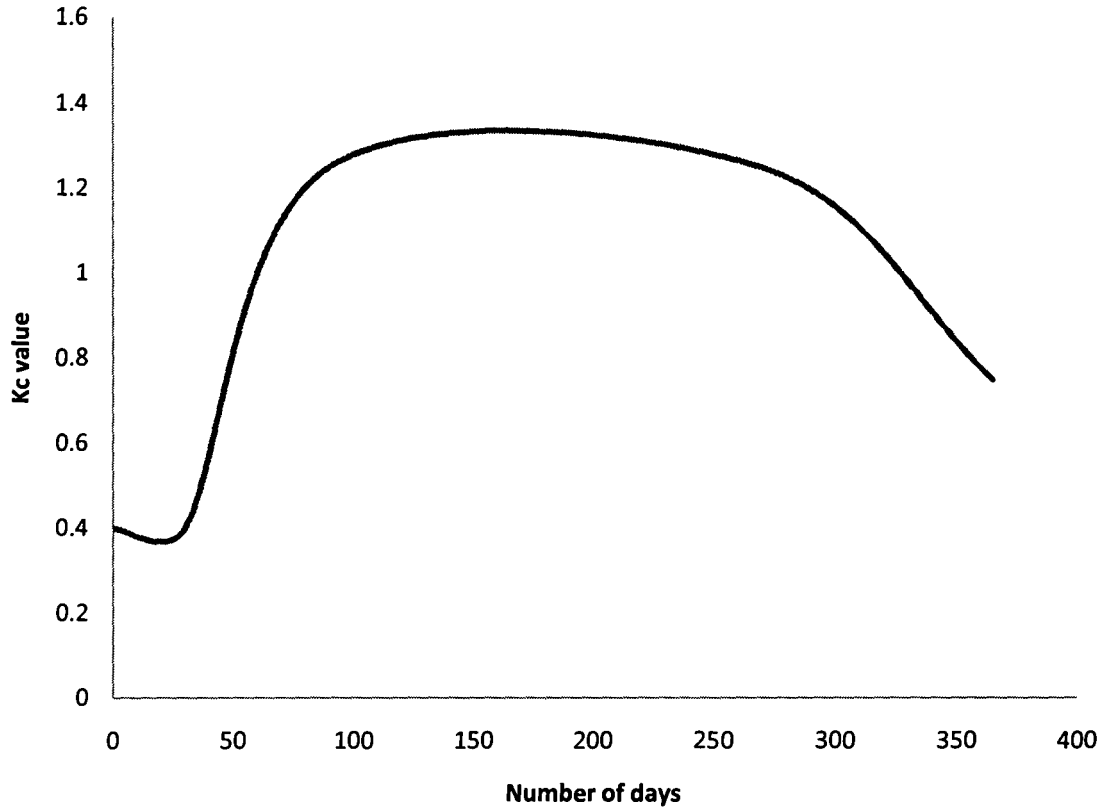


Fig 4.4: Kc curve for sugarcane

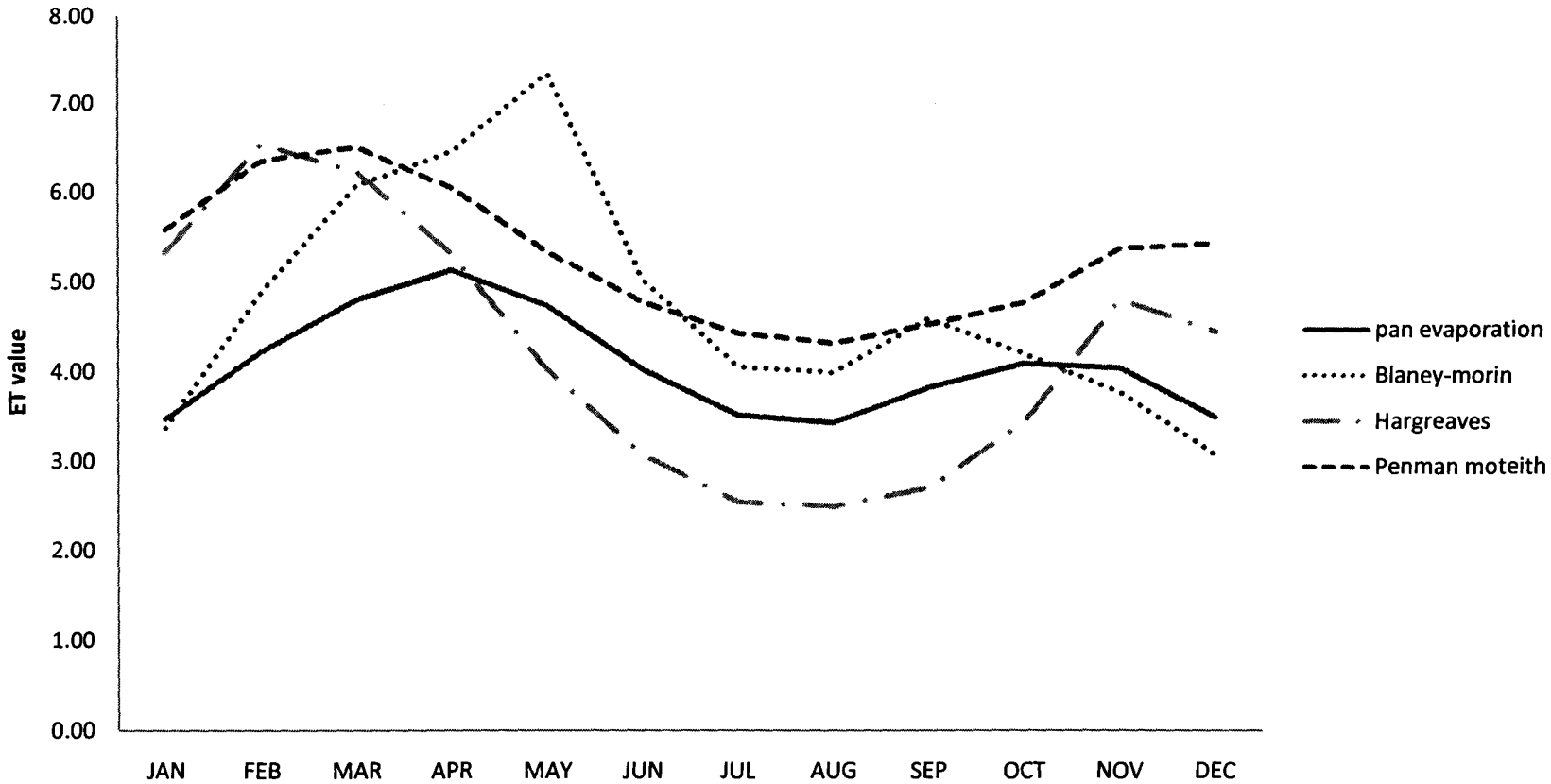


Fig 4.5: Comparison of ET method

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The conclusion deduced from this study include

i). The evapotranspiration models show no significant difference between them and open pan method.

ii). The penman-Monteith model was rated most suitable for use in the dry-cold harmattan while Hargreaves method was rated most suitable for the dry-hot season and the wet humid season.

iii). The crop evapotranspiration for the selected crops were found to tally with that given by FAO(2002)

5.2 Recommendation

The following recommendation were made with the experience gained from this work

i). The comparative evaluation of the ET models should be extended to other models like Thornwaite, Jensen haise, Blaney-criddle and others.

ii). That sugar cane should be planted in a swampy area (fadama) to reduce the need for irrigation and hence save water and energy cost.

iii). The result of this project should be verify and publish so that farmers, research institutes and other organization can make use of it to reduce the problem of either over irrigating or under irrigating.

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APPENDIX A

Table A.1: The average climatic data.

	Rainfall (mm^3)	Class a pan (mm/day)	Max temp (°c)	Min temp (°c)	Mean temp (°c)	Relative humidity (%)	Wind speed (km/day)	Radiation ($MJ/m^2/day$)	Radiation ratio	Sunshine hours
January	0.00	4.22	34.62	16.65	25.63	57.42	50.20	15.76	0.08565	6.03
February	1.48	6.10	37.08	19.23	28.15	49.31	63.24	17.03	0.08906	6.81
March	20.23	7.59	38.23	23.38	30.81	60.00	92.42	17.78	0.09289	6.15
April	64.11	8.06	37.00	24.81	30.90	69.62	121.43	16.95	0.09299	6.78
May	145.27	8.63	34.42	23.92	29.17	76.38	116.57	16.06	0.08381	7.12
June	190.67	5.90	32.31	23.00	27.65	83.31	81.63	14.99	0.07834	6.31
July	211.29	4.77	31.08	22.88	26.98	86.12	74.00	13.45	0.07120	4.82
August	256.93	4.70	30.58	22.96	26.77	86.62	72.50	12.94	0.07119	4.41
September	210.67	5.40	31.08	22.62	26.85	85.65	72.68	15.11	0.07481	5.88
October	85.84	4.94	32.73	22.77	27.75	82.50	55.03	17.13	0.08559	7.20
November	3.07	4.43	34.77	19.81	27.29	72.35	37.87	17.43	0.09573	8.09
December	0.00	3.84	34.38	16.27	25.33	63.27	36.69	15.07	0.07874	6.96
Average	99.13	5.71	34.02	21.53	27.77	72.71	72.86	15.81	0.08333	6.38

Table A.2: extraterrestrial radiation

Northern Hemisphere												Lat.	Southern Hemisphere											
Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	deg.	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
0.0	2.6	10.4	23.0	35.2	42.5	39.4	28.0	14.9	4.9	0.1	0.0	70	41.4	28.6	15.8	4.9	0.2	0.0	0.0	2.2	10.7	23.5	37.3	45.3
0.1	3.7	11.7	23.9	35.3	42.0	38.9	28.6	16.1	6.0	0.7	0.0	68	41.0	29.3	16.9	6.0	0.8	0.0	0.0	3.2	11.9	24.4	37.4	44.7
0.6	4.8	12.9	24.8	35.6	41.4	38.8	29.3	17.3	7.2	1.5	0.1	66	40.9	30.0	18.1	7.2	1.5	0.1	0.5	4.2	13.1	25.4	37.6	44.1
1.4	5.9	14.1	25.8	35.9	41.2	38.8	30.0	18.4	8.5	2.4	0.6	64	41.0	30.8	19.3	8.4	2.4	0.6	1.2	5.3	14.4	26.3	38.0	43.9
2.3	7.1	15.4	26.6	36.3	41.2	39.0	30.6	19.5	9.7	3.4	1.3	62	41.2	31.5	20.4	9.6	3.4	1.2	2.0	6.4	15.5	27.2	38.3	43.9
3.3	8.3	16.6	27.5	36.6	41.2	39.2	31.3	20.6	10.9	4.4	2.2	60	41.5	32.3	21.5	10.8	4.4	2.0	2.9	7.6	16.7	28.1	38.7	43.9
4.3	9.6	17.7	28.4	37.0	41.3	39.4	32.0	21.7	12.1	5.5	3.1	58	41.7	33.0	22.6	12.0	5.5	2.9	3.9	8.7	17.9	28.9	39.1	44.0
5.4	10.8	18.9	29.2	37.4	41.4	39.6	32.6	22.7	13.3	6.7	4.2	56	42.0	33.7	23.6	13.2	6.6	3.9	4.9	9.9	19.0	29.8	39.5	44.1
6.5	12.0	20.0	30.0	37.8	41.5	39.8	33.2	23.7	14.5	7.8	5.2	54	42.2	34.3	24.6	14.4	7.7	4.9	6.0	11.1	20.1	30.6	39.9	44.3
7.7	13.2	21.1	30.8	38.2	41.6	40.1	33.8	24.7	15.7	9.0	6.4	52	42.5	35.0	25.6	15.6	8.8	6.0	7.1	12.2	21.2	31.4	40.2	44.4
8.9	14.4	22.2	31.5	38.5	41.7	40.2	34.4	25.7	16.9	10.2	7.5	50	42.7	35.6	26.6	16.7	10.0	7.1	8.2	13.4	22.2	32.1	40.6	44.5
10.1	15.7	23.3	32.2	38.8	41.8	40.4	34.9	26.6	18.1	11.4	8.7	48	42.9	36.2	27.5	17.9	11.1	8.2	9.3	14.6	23.3	32.8	40.9	44.5
11.3	16.9	24.3	32.9	39.1	41.9	40.6	35.4	27.5	19.2	12.6	9.9	46	43.0	36.7	28.4	19.0	12.3	9.3	10.4	15.7	24.3	33.5	41.1	44.6
12.5	18.0	25.3	33.5	39.3	41.9	40.7	35.9	28.4	20.3	13.9	11.1	44	43.2	37.2	29.3	20.1	13.5	10.5	11.6	16.8	25.2	34.1	41.4	44.6
13.8	19.2	26.3	34.1	39.5	41.9	40.8	36.3	29.2	21.4	15.1	12.4	42	43.3	37.7	30.1	21.2	14.6	11.6	12.8	18.0	26.2	34.7	41.6	44.6
15.0	20.4	27.2	34.7	39.7	41.9	40.8	36.7	30.0	22.5	16.3	13.6	40	43.4	38.1	30.9	22.3	15.6	12.8	13.9	19.1	27.1	35.3	41.8	44.6
16.2	21.5	28.1	35.2	39.9	41.8	40.8	37.0	30.7	23.6	17.5	14.8	38	43.4	38.5	31.7	23.3	16.9	13.9	15.1	20.2	28.0	35.8	41.9	44.5
17.5	22.6	29.0	35.7	40.0	41.7	40.8	37.4	31.5	24.6	18.7	16.1	36	43.4	38.9	32.4	24.3	18.1	15.1	16.2	21.2	28.8	36.3	42.0	44.4
18.7	23.7	29.9	36.1	40.0	41.6	40.8	37.6	32.1	25.6	19.9	17.3	34	43.4	39.2	33.0	25.3	19.2	16.2	17.4	22.3	29.6	36.7	42.0	44.3
19.9	24.8	30.7	36.5	40.0	41.4	40.7	37.9	32.8	26.6	21.1	18.5	32	43.3	39.4	33.7	26.3	20.3	17.4	18.5	23.3	30.4	37.1	42.0	44.1
21.1	25.8	31.4	36.8	40.0	41.2	40.6	38.0	33.4	27.6	22.2	19.8	30	43.1	39.6	34.3	27.2	21.4	18.5	19.6	24.3	31.1	37.5	42.0	43.9
22.3	26.8	32.2	37.1	40.0	40.9	40.4	38.2	33.9	28.5	23.3	21.0	28	43.0	39.8	34.8	28.1	22.5	19.7	20.7	25.3	31.8	37.8	41.9	43.6
23.4	27.8	32.8	37.4	39.9	40.6	40.2	38.3	34.5	29.3	24.5	22.2	26	42.8	39.9	35.3	29.0	23.5	20.8	21.8	26.3	32.5	38.0	41.8	43.3
24.6	28.8	33.5	37.6	39.7	40.3	39.9	38.3	34.9	30.2	25.5	23.3	24	42.5	40.0	35.8	29.8	24.6	21.9	22.9	27.2	33.1	38.3	41.7	43.0
25.7	29.7	34.1	37.8	39.5	40.0	39.6	38.4	35.4	31.0	26.6	24.5	22	42.2	40.1	36.2	30.6	25.6	23.0	24.0	28.1	33.7	38.4	41.4	42.6
26.8	30.6	34.7	37.9	39.3	39.5	39.3	38.3	35.8	31.8	27.7	25.6	20	41.9	40.0	36.6	31.3	26.6	24.1	25.0	28.9	34.2	38.6	41.2	42.1
27.9	31.5	35.2	38.0	39.0	39.1	38.9	38.2	36.1	32.5	28.7	26.8	18	41.5	40.0	37.0	32.1	27.5	25.1	26.0	29.8	34.7	38.7	40.9	41.7
28.9	32.3	35.7	38.1	38.7	38.6	38.5	38.1	36.4	33.2	29.6	27.9	16	41.1	39.9	37.2	32.8	28.5	26.2	27.0	30.6	35.2	38.7	40.6	41.2
29.9	33.1	36.1	38.1	38.4	38.1	38.1	38.0	36.7	33.9	30.6	28.9	14	40.6	39.7	37.5	33.4	29.4	27.2	27.9	31.3	35.6	38.7	40.2	40.6
30.9	33.8	36.5	38.0	38.0	37.6	37.6	37.8	36.9	34.5	31.5	30.0	12	40.1	39.6	37.7	34.0	30.2	28.1	28.9	32.1	36.0	38.6	39.8	40.0
31.9	34.5	36.9	37.9	37.6	37.0	37.1	37.5	37.1	35.1	32.4	31.0	10	39.5	39.3	37.8	34.6	31.1	29.1	29.8	32.8	36.3	38.5	39.3	39.4
32.8	35.2	37.2	37.8	37.1	36.3	36.5	37.2	37.2	35.6	33.3	32.0	8	38.9	39.0	37.9	35.1	31.9	30.0	30.7	33.4	36.6	38.4	38.8	38.7
33.7	35.8	37.4	37.6	36.6	35.7	35.9	36.9	37.3	36.1	34.1	32.9	6	38.3	38.7	38.0	35.6	32.7	30.9	31.5	34.0	36.8	38.2	38.2	38.0
34.6	36.4	37.8	37.4	36.0	35.0	35.3	36.5	37.3	36.6	34.9	33.9	4	37.6	38.3	38.0	36.0	33.4	31.8	32.3	34.6	37.0	38.0	37.6	37.2
35.4	37.0	37.8	37.1	35.4	34.2	34.6	36.1	37.3	37.0	35.6	34.8	2	36.9	37.9	38.0	36.4	34.1	32.6	33.1	35.2	37.1	37.7	37.0	36.4
36.2	37.5	37.9	36.8	34.8	33.4	33.9	35.7	37.2	37.4	36.3	35.6	0	36.2	37.5	37.9	36.8	34.8	33.4	33.9	35.7	37.2	37.4	36.3	35.6

Source: Allen et al, (1998)

Table A.3: Pan Coefficient (k pan) for class a pan for different ground cover and levels of mean relative humidity and 24 hour wind

Class A pan	Case A: Pan placed in short green cropped area				Case B[1]: Pan placed in fallow area			
RH mean %		low <40	medium 40-70	High > 70		low <40	medium 40-70	high > 70
Wind km/day	Windward side distance of green crop m				Windward side distance of dry fallow m			
Light	1	.55	.65	.75	1	.70	.80	.85
< 175	10	.65	.75	.85	10	.60	.70	.80
	100	.70	.80	.85	100	.55	.65	.75
	1000	.75	.85	.85	1000	.50	.60	.70
Moderate	1	.50	.60	.65	1	.65	.75	.80
175-425	10	.60	.70	.75	10	.55	.65	.70
	100	.65	.75	.80	100	.50	.60	.65
	1000	.70	.80	.80	1000	.45	.55	.60
Strong	1	.45	.50	.60	1	.60	.65	.70
425-700	10	.55	.60	.65	10	.50	.55	.65
	100	.60	.65	.70	100	.45	.50	.60
	1000	.65	.70	.75	1000	.40	.45	.55
Very strong	1	.40	.45	.50	1	.50	.60	.65
> 700	10	.45	.55	.60	10	.45	.50	.55
	100	.50	.60	.65	100	.40	.45	.50
	1000	.55	.60	.65	1000	.35	.40	.45

Source: Brouwer and Heibloem (1986)

Table A.4: Kc value for the selected crops and the Numbers of days

plant	Kc initial	Kc dev	Kc mid	Kc late
maize	0.3(20days)	-- (35day)	1.2 (40days)	0.5(30days)
sorghum	0.7(20days)	--(35days)	1.2(45days)	1.05(30days)
groundnut	0.4(25days)	--(35days)	1.05(45days)	0.6(25days)
Sugarcane	0.43(30days)	--(55days)	1.25(180days)	0.75(100days)

Source: Allen .et al (1998)

APPENDIX B

Table B.1 ET values using Hargreaves-Samani model Period: 25 years

months	Max temp (°c)	Min temp (°c)	Mean temp (°c)	Extra-radiation (mm/day)	ETp (mm/day)
January	34.62	16.65	25.63	32.31	5.58
February	37.08	19.23	28.15	34.84	6.35
March	38.23	23.38	30.81	37.00	6.50
April	37.00	24.81	30.90	37.87	6.04
May	34.42	23.92	29.17	37.33	5.33
June	32.31	23.00	27.65	36.65	4.77
July	31.08	22.88	26.98	36.80	4.43
August	30.58	22.96	26.77	37.39	4.32
September	31.08	22.62	26.85	37.11	4.52
October	32.73	22.77	27.75	35.33	4.77
November	34.77	19.81	27.29	32.80	5.37
December	34.38	16.27	25.33	31.46	5.42
Average					5.28

Table B.2: ET computed values using penman monteith model. Period: 25years

Month	Min temp (°c)	Max temp (°c)	Humidity (%)	Wind (Km/day)	Sun (Hours)	Rad (Mj/m²/day)	Eto (Mm/day)
January	16.6	34.6	57	50	6	16.5	3.47
February	19.2	37.1	49	63	6.8	18.8	4.22
March	23.4	38.2	60	92	6.2	18.8	4.80
April	24.8	37	70	121	6.8	20	5.13
May	23.9	34.4	76	117	7.1	20	4.73
June	23	32.3	83	82	6.3	18.4	4.02
July	22.9	31.1	86	74	4.8	16.3	3.51
August	23	30.6	87	73	4.4	16	3.43
September	22.6	31.1	86	73	5.9	18.3	3.82
October	22.8	32.7	83	55	7.2	19.6	4.09
November	19.8	34.8	72	38	8.1	19.7	4.04
December	16.3	34.4	63	37	7	17.5	3.49
Average	21.5	34	73	73	6.4	18.3	4.06

Table B.3 ET values computed using open pan evaporation method

Windward distance from the pan = 100m Pan Location case: A

Period: 25years

Months	Wind speed (km/day)	Wind	R/humidity (%)	R/humidity	Kc	Epan (mm/day)	ETp (mm/day)
January	50.20	light	57.42	Medium	0.80	4.22	3.38
February	63.24	light	49.31	Medium	0.80	6.10	4.88
March	92.42	light	60.00	Medium	0.80	7.59	6.07
April	121.43	light	69.62	Medium	0.80	8.06	6.45
May	116.57	light	76.38	High	0.85	8.63	7.33
June	81.63	light	83.31	High	0.85	5.90	5.02
July	74.00	light	86.12	High	0.85	4.77	4.05
August	72.50	light	86.62	High	0.85	4.70	3.99
September	72.68	light	85.65	High	0.85	5.40	4.59
October	55.03	light	82.50	High	0.85	4.94	4.20
November	37.87	light	72.35	High	0.85	4.43	3.77
December	36.69	light	63.27	Medium	0.80	3.84	3.07
Average	72.86		72.71				4.73

Table B.4 ET values using Blaney-Morin Nigeria model Period: 25 years

Month	Mean temp (°c)	R/humidity (%)	Radiation ratio	ETp (mm/day)
January	25.63	57.42	0.08565	5.33
February	28.15	49.31	0.08906	6.53
March	30.81	60.00	0.09289	6.23
April	30.90	69.62	0.09299	5.31
May	29.17	76.38	0.08381	4.02
June	27.65	83.31	0.07834	3.07
July	26.98	86.12	0.07120	2.54
August	26.77	86.62	0.07119	2.49
September	26.85	85.65	0.07481	2.70
October	27.75	82.50	0.08559	3.44
November	27.29	72.35	0.09573	4.80
December	25.33	63.27	0.07874	4.45
Average				4.24

Table B.5: Average daily potential evapotranspiration (ETp) values computed from the various models

	Pan evaporation	Blaney-morin	Hargreaves	Penman moteith	Average
January	3.38	5.33	5.58	3.47	4.44
February	4.88	6.53	6.35	4.22	5.50
March	6.07	6.23	6.50	4.8	5.90
April	6.45	5.31	6.04	5.13	5.73
May	7.33	4.02	5.33	4.73	5.35
June	5.02	3.07	4.77	4.02	4.22
July	4.05	2.54	4.43	3.51	3.63
August	3.99	2.49	4.32	3.43	3.56
September	4.59	2.70	4.52	3.82	3.91
October	4.20	3.44	4.77	4.09	4.12
November	3.77	4.80	5.37	4.04	4.49
December	3.07	4.45	5.42	3.49	4.11
Average	4.73	4.24	5.28	4.06	4.58

Table B.6: ET values computed using 5years intervals

	Hargreaves	Blaney - Morin	Penman-Monteith	Pan evaporation	Average
1st five years	5.170	4.100	4.050	4.770	4.523
2nd five years	5.370	3.940	3.850	4.770	4.483
3rd five years	5.350	4.370	4.190	4.710	4.655
4th five years	5.330	4.390	4.180	4.730	4.658
5th five years	5.190	4.390	4.050	4.710	4.585
Average	5.282	4.238	4.064	4.738	4.581

APPENDIX C

Table C.1: Average daily potential evapotranspiration, absolute mean difference and each model rating

months	Open Pan evaporation	Blaney-morin Nigeria	Hargreaves	Penman monteith
Average	4.73	4.24	5.28	4.06
Deviation	0.15	0.34	0.70	0.52
Absolute mean difference		0.49	0.55	0.67
Rating close to open pan (%)		89.62%	89.60%	85.78%

Table C.2: Average daily potential evapotranspiration for the seasons, absolute mean difference and their model rating

		pan evaporation	*Blaney-morin*	*Hargreaves*	*Penman Monteith*
The dry cold Harmattan	October	4.20	3.44	4.77	4.09
	November	3.77	4.80	5.37	4.04
	December	3.07	4.45	5.42	3.49
	January	3.38	5.33	5.58	3.47
	Average	3.60	4.50	5.28	3.77
	mean difference		0.90	1.68	0.17
	Rating close to open pan (%)		80.0%	68.2%	95.5%

		Pan evaporation	*Blaney-morin*	*Hargreaves*	*Penman Monteith*
The dry-hot season	February	4.88	6.53	6.35	4.22
	March	6.07	6.23	6.50	4.8
	April	6.45	5.31	6.04	5.13
	May	7.33	4.02	5.33	4.73
	Average	6.18	5.52	6.06	4.72
	Mean difference		0.66	0.13	1.46
	Rating close to open pan (%)		89.3%	97.9%	76.3%

		Pan evaporation	*Blaney-morin*	*Hargreaves*	*Penman Monteith*
	June	5.02	3.07	4.77	4.02
The wet,	July	4.05	2.54	4.43	3.51
humid	August	3.99	2.49	4.32	3.43
season	September	4.59	2.70	4.52	3.82
	Average	4.41	2.70	4.51	3.70
	Mean difference		1.71	0.10	0.72
	Rating close to open pan (%)		61.2%	97.9%	83.8%

Table C.3: Two ways ANOVA for the ET models and month

Source of Variation	SS	df	MS	F	P-value	F crit
Months	29.98023	11	2.7254754	4.406609	0.000441	2.093254
ETo method	10.792443	3	3.5974808	5.816487	0.002634	2.891564
Error	20.410408	33	0.6184972			
Total	61.183081	47				

Table C.4: One way ANOVA for the dry cold Harmattan

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Et models	7.083513	3	2.361171	8.463546	0.002727	3.490295
Within Et models	3.347775	12	0.278981			
Total	10.43129	15				

Table C.5: One way ANOVA for the dry-hot season

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Et models	5.312189	3	1.77073	2.609617	0.099663	3.490295
Within Et models	8.14248	12	0.67854			
Total	13.45467	15				

Table C.6: One way ANOVA for the wet, humid season

Source of Variation	*SS*	*Df*	*MS*	*F*	*P-value*	*F crit*
Between Et models	8.362053918	3	2.787351	26.75904	1.34E-05	3.490295
Within Et models	1.24997826	12	0.104165			
Total	9.612032178	15				

Table C.7: T- tests for open pan and each of the ET models

	pan evaporation	*Penman monteith*
Mean	4.733311538	4.0625
Variance	1.676903076	0.327256818
Observations	12	12
Pearson Correlation	0.884578658	
Hypothesized Mean Difference	0	
Df	11	
t Stat	2.790256186	
P(T<=t) one-tail	0.00878924	
t Critical one-tail	1.795884814	
P(T<=t) two-tail	0.01757848	
t Critical two-tail	2.200985159	

	pan evaporation	*Hargreaves*
Mean	4.733311538	5.282778325
Variance	1.676903076	0.55405852
Observations	12	12
Pearson Correlation	0.382434194	
Hypothesized Mean Difference	0	
Df	11	
t Stat	-1.557398001	
P(T<=t) one-tail	0.073831257	
t Critical one-tail	1.795884814	
P(T<=t) two-tail	0.147662513	
t Critical two-tail	2.200985159	

	pan evaporation	*Blaney-morin*
Mean	4.733311538	4.242120899
Variance	1.676903076	2.022748675
Observations	12	12
Pearson Correlation	0.231190954	
Hypothesized Mean Difference	0	
Df	11	
t Stat	1.008243173	
P(T<=t) one-tail	0.167500918	
t Critical one-tail	1.795884814	
P(T<=t) two-tail	0.335001835	
t Critical two-tail	2.200985159	

Table C.8: T- test between the open pan and each Et models for the dry cold harmattan season

	pan evaporation	*Blaney-morin*
Mean	3.604086538	4.50271301
Variance	0.237721138	0.63643058
Observations	4	4
Pearson Correlation	-0.636591436	
Hypothesized Mean Difference	0	
Df	3	
t Stat	-1.535847726	
P(T<=t) one-tail	0.111076622	
t Critical one-tail	2.353363435	
P(T<=t) two-tail	0.222153244	
t Critical two-tail	3.182446305	

	pan evaporation	*Hargreaves*
Mean	3.604086538	5.28365486
Variance	0.237721138	0.127215029
Observations	4	4
Pearson Correlation	-0.829914678	
Hypothesized Mean Difference	0	
Df	3	
t Stat	-4.15506049	
P(T<=t) one-tail	0.012671473	
t Critical one-tail	2.353363435	
P(T<=t) two-tail	0.025342945	
t Critical two-tail	3.182446305	

	pan evaporation	*Penman moteith*
Mean	3.604086538	3.7725
Variance	0.237721138	0.114558333
Observations	4	4
Pearson Correlation	0.912336906	
Hypothesized Mean Difference	0	
Df	3	
t Stat	-1.489096431	
P(T<=t) one-tail	0.116608732	
t Critical one-tail	2.353363435	
P(T<=t) two-tail	0.233217464	
t Critical two-tail	3.182446305	

Table C.9: T- test between the open pan and each Et models for the dry hot season

	pan evaporation	*Blaney-morin*
Mean	6.184021154	5.522176066
Variance	1.031728355	1.271365095
Observations	4	4
Pearson Correlation	-0.924199891	
Hypothesized Mean Difference	0	
Df	3	
t Stat	0.629611027	
P(T<=t) one-tail	0.286816526	
t Critical one-tail	2.353363435	
P(T<=t) two-tail	0.573633052	
t Critical two-tail	3.182446305	

	pan evaporation	*Hargreaves*
Mean	6.184021	6.056302
Variance	1.031728	0.269533
Observations	4	4
Pearson Correlation	-0.79903	
Hypothesized Mean Difference	0	
Df	3	
t Stat	0.174452	
P(T<=t) one-tail	0.43631	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.872619	
t Critical two-tail	3.182446	

	pan evaporation	*Penman moteith*
Mean	6.18402115	4.72
Variance	1.03172836	0.141533333
Observations	4	4
Pearson Correlation	0.66432313	
Hypothesized Mean Difference	0	
Df	3	
t Stat	3.58912536	
P(T<=t) one-tail	0.01852302	
t Critical one-tail	2.35336343	
P(T<=t) two-tail	0.03704605	
t Critical two-tail	3.1824463	

Table C.10: T- test between the open pan and each Et models for the wet humid season

	pan evaporation	*Blaney-morin*
Mean	4.411827	2.701474
Variance	0.235115	0.068891
Observations	4	4
Pearson Correlation	0.968845	
Hypothesized Mean Difference	0	
Df	3	
t Stat	14.27794	
P(T<=t) one-tail	0.000372	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.000744	
t Critical two-tail	3.182446	

	pan evaporation	*Hargreaves*
Mean	4.411827	4.508378
Variance	0.235115	0.037419
Observations	4	4
Pearson Correlation	0.9647	
Hypothesized Mean Difference	0	
Df	3	
t Stat	-0.63816	
P(T<=t) one-tail	0.284374	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.568747	
t Critical two-tail	3.182446	

	pan evaporation	*Penman monteith*
Mean	4.411827	3.695
Variance	0.235115	0.075233
Observations	4	4
Pearson Correlation	0.995286	
Hypothesized Mean Difference	0	
Df	3	
t Stat	6.713232	
P(T<=t) one-tail	0.003373	
t Critical one-tail	2.353363	
P(T<=t) two-tail	0.006746	
t Critical two-tail	3.182446	

Table C.11: Two ways Anova for the ET models and the 5years interval

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
5 years interval	0.09787	4	0.024468	1.557695	0.248111	3.259167
ET models	4.504935	3	1.501645	95.60051	1.21E-08	3.490295
Error	0.18849	12	0.015708			
Total	4.791295	19				

APPENDIX D

Table D.1: computed crop water requirement for maize

ET method: penman monteith crop duration: 125 days

Month	Decade	Stage	Kc	ETo (mm/day)	Etc (mm/day)	Total H_2O Req (M^3/ha)
May	2	Init	0.30	4.7	1.42	142
May	3	Init	0.30	4.5	1.35	135
Jun	1	Deve	0.36	4.3	1.55	155
Jun	2	Deve	0.58	4.1	2.35	235
Jun	3	Deve	0.81	3.9	3.13	313
Jul	1	Mid	1.03	3.7	3.80	380
Jul	2	Mid	1.10	3.5	3.85	385
Jul	3	Mid	1.10	3.5	3.82	382
Aug	1	Mid	1.10	3.4	3.79	379
Aug	2	Late	1.08	3.4	3.71	371
Aug	3	Late	0.89	3.5	3.15	315
Sep	1	Late	0.64	3.7	2.37	237
Sep	2	Late	0.46	3.8	1.74	174
TOTAL						3603

Table D.2: computed crop water requirement for sorghum

ET method: penman monteith crop duration: 130 days

Month	Decade	Stage	Kc	ETo (mm/day)	Etc (mm/day)	Total H_2O Req (M^3/ha)
Jun	2	Init	0.7	4.03	2.82	282
Jun	3	Init	0.7	3.86	2.70	270
Jul	1	Deve	0.71	3.69	2.62	262
Jul	2	Deve	0.77	3.49	2.69	269
Jul	3	Deve	0.83	3.48	2.89	289
Aug	1	Mid	0.89	3.45	3.07	307
Aug	2	Mid	0.91	3.41	3.10	310
Aug	3	Mid	0.91	3.54	3.22	322
Sep	1	Mid	0.91	3.67	3.34	334
Sep	2	Mid	0.91	3.80	3.46	346
Sep	3	Late	0.85	3.92	3.33	333
Oct	1	Late	0.71	3.99	2.83	283
Oct	2	Late	0.56	4.11	2.30	230
Oct	3	Late	0.47	4.11	1.93	193
TOTAL						4030

Table D.3: Computed crop water requirement for groundnut

ET method: penman monteith crop duration: 130 days

Month	Decade	Stage	Kc	ETo (mm/day)	Etc (mm/day	Total H_2O Req (M^3/ha)
May	2	Init	0.40	4.8	1.90	190
May	3	Init	0.40	4.5	1.80	180
Jun	1	Deve	0.41	4.2	1.73	173
Jun	2	Deve	0.53	4.0	2.11	211
Jun	3	Deve	0.69	3.9	2.67	267
Jul	1	Deve	0.86	3.7	3.17	317
Jul	2	Mid	0.98	3.5	3.44	344
Jul	3	Mid	0.99	3.5	3.43	343
Aug	1	Mid	0.99	3.4	3.40	340
Aug	2	Mid	0.99	3.4	3.37	337
Aug	3	Late	0.97	3.5	3.44	344
Sep	1	Late	0.82	3.7	3.01	301
Sep	2	Late	0.64	3.8	2.43	243
Sep	3	Late	0.54	3.9	2.11	211
TOTAL						3801

Table D.4 computed crop water requirement for Sugarcane

ET method: penman monteith crop duration: 365 days

Month	Decade	Stage	Kc coeff	ETo (mm/day)	ETc (mm/day)	Total H2o Req (M^3/ha)
Feb	2	Init	0.73	4.25	3.10	310.0
Feb	3	Init	0.40	4.40	1.76	176.0
Mar	1	Init	0.40	4.60	1.84	184.0
Mar	2	Deve	0.41	4.83	1.98	198.0
Mar	3	Deve	0.52	4.94	2.57	257.0
Apr	1	Deve	0.66	4.98	3.29	329.0
Apr	2	Deve	0.78	5.13	4.00	400.0
Apr	3	Deve	0.91	4.97	4.52	452.0
May	1	Deve	1.03	4.87	5.02	502.0
May	2	Mid	1.14	4.73	5.39	539.0
May	3	Mid	1.15	4.50	5.18	518.0
Jun	1	Mid	1.15	4.26	4.90	490.0
Jun	2	Mid	1.15	4.02	4.62	462.0
Jun	3	Mid	1.15	3.85	4.43	443.0
Jul	1	Mid	1.15	3.68	4.23	423.0
Jul	2	Mid	1.15	3.51	4.04	404.0
Jul	3	Mid	1.15	3.48	4.00	400.0
Aug	1	Mid	1.15	3.45	3.97	397.0
Aug	2	Mid	1.15	3.43	3.94	394.0

Aug	3	Mid	1.15	3.56	4.09	409.0
Sep	1	Mid	1.15	3.69	4.24	424.0
Sep	2	Mid	1.15	3.82	4.39	439.0
Sep	3	Mid	1.15	3.90	4.49	449.0
Oct	1	Mid	1.15	3.99	4.59	459.0
Oct	2	Mid	1.15	4.09	4.70	470.0
Oct	3	Mid	1.15	4.07	4.68	468.0
Nov	1	Mid	1.15	4.05	4.66	466.0
Nov	2	Late	1.13	4.04	4.56	456.0
Nov	3	Late	1.09	3.83	4.18	418.0
Dec	1	Late	1.04	3.67	3.82	382.0
Dec	2	Late	1	3.48	3.48	348.0
Dec	3	Late	0.95	3.48	3.31	331.0
Jan	1	Late	0.9	3.49	3.14	314.0
Jan	2	Late	0.86	3.47	2.98	298.0
Jan	3	Late	0.81	3.73	3.02	302.0
Feb	1	Late	0.77	3.95	3.04	304.0
Feb	2	Late	0.73	4.25	3.1	310.0
TOTAL						14325.0