CROP COEFFICIENT VALUES OF OKRA FOR THE HUMID TROPICAL REGION USING LYSIMETER

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DECLARATION

We hereby declare that this project report entitled **“CROP COEFFICIENT VALUES OF OKRA FOR THE HUMID TROPICAL REGION USING LYSIMETER”** is a bonafide record of project work done by us under the supervision of Asha Joseph, Professor, Department of Irrigation and Drainage Engineering during the course of academic programme in the Kerala Agricultural University and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

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CERTIFICATE

Certified that this project report entitled **“CROP COEFFICIENT VALUES OF OKRA FOR THE HUMID TROPICAL REGION USING LYSIMETER”** is a bonafide record of project work jointly done by **Ms. Dilshana Jasmin (2014-02-019), Mrs. Khamarunneesa. M (2014-02-026), and Ms. Shahna Thasneem K (2014-02-039)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associate ship, or other similar title of any other university or society to them.

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Dedicated
to
Our beloved parents

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SYMBOLS AND ABBREVIATIONS

% : Percentage

& : And

= : Equal to

° : Degree

°C : Degree Celsius

AET : Actual Evapotranspiration

atm : Atmosphere

CHM : Christiansen (1968) pan evaporation model

cm : Centimeter

cm^3 : Centimeter cube

Dept. : Department

ET : Evapotranspiration

et al. : And others

ETc : Crop evapotranspiration

ETo : Reference evapotranspiration

exp : Exponential

FAO : Food and Agricultural Oganisation

Fig. : Figure

g : Gram

g/cc : Gram per cubic centimeter

h : Hour

ha : Hectare

Hort. : Horticulture

J. : Journal

K : Potassium

KAU : Kerala Agricultural University

Kc : Crop Coefficient

KCAET : Kelappaji College of Agricultural Engineering and Technology

kg/m^2 : Kilogram per square meter

km/h : Kilometer per hour

K Pa : Kilo Pascal

l/day/plant : Liter per day per plant

LDPE : Low density polyethylene

lph : Litre per hour

m : Metre

m^2 : Square metre

m^3 : Cubic metre

MJ/m^2/day : Mega joules per square meter per day

mm : Millimeter

mm/day : Millimeter per day

m/s : meter per second

OPM : FAO-24 Open pan (1977) model

PMM : FAO-56 Penman-Monteith (1991) model

PVC : Poly vinyl chloride

RARS : Regional Agricultural Research Station

RH : Relative humidity

s : Second

Sci. : Science

viz. : Namely

WUE : Water use efficiency

Introduction

CHAPTER 1

INTRODUCTION

Globally, water is considered as a precious element for agricultural sector. Water being a scarce resource, it is necessary to scientifically manage and judiciously use this natural resource to sustain life on earth. Irrigation is the major consumer of water in the country and therefore water used for irrigation must be prudently managed in order to ensure high efficiency.

One of the most important factors for water resources planning and irrigation scheduling is crop evapotranspiration or crop water use. The water requirement of a crop varies from crop to crop, location to location and season to season according to climate change. Optimum water management will play a significant role in minimizing water loss by optimizing the water use. Therefore, it is necessary to know the actual crop water requirement. Crop co-efficient values are required for estimating the actual crop water requirement. It is always cumbersome and expensive to determine the water requirements of a particular variety of crop in different places by setting experiment every time. Rather, it is much easier to estimate crop evapotranspiration to a large degree of accuracy.

Evapotranspiration is the major component of the hydrologic cycle, by which, most precipitation that falls on land surface returns back to the atmosphere in the form of evaporation from the soil surface and from the plant tissue as a result of transpiration (Allen *et al.*, 1998). Globally, about 60% of yearly precipitation falling over the land surface is used by ET (Irmak, 2009). Evapotranspiration is expressed in two forms: actual evapotranspiration and potential evapotranspiration. Potential evapotranspiration (PET) is defined as “the maximum water lost from a short green crop under climatic conditions, when unlimited water is available” (Jensen *et al.*, 1990). The term reference evapotranspiration (ET_o), which is the rate of evapotranspiration from a well-defined reference environment, is commonly used as the standard. Reference evapotranspiration (ET_o) is defined as “the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec/m and albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered and completely shading the ground" (Allen *et al.*, 1998).

For most of the agricultural crops a relationship can be found between evapotranspiration and climate by introducing a crop coefficient (K_c), which is the ratio of crop evapotranspiration (ET_c) to reference crop evapotranspiration (ET_o). Values of K_c are available in literature (Doorenbos and Pruitt., 1977), but none is recommended for a specific location. Also, the values can be estimated from the standard values by adjusting a number of factors like temperature, humidity, irrigation sequences, soil textures, etc. But for more accuracy, it is better to determine the factors locally. Physiological characteristics of crop varieties differ under different soil and climatic conditions, thus, showing varying physiological demands including crop water requirements (Crop ET). For proper irrigation scheduling and efficient water management, the determination of crop coefficient and estimation of ET_o in stage wise are required.

The most reliable method for determining the crop coefficient value is the lysimetric study. Climatological approaches for estimating ET are empirical to varying extent and require local calibrations which are impossible without a lysimeter. So, this experiment is planned to determine the crop coefficient values of Okra which is one of the most important vegetable crop all over India.

Only a few studies have been conducted in India to measure and estimate evapotranspiration. In all these studies many of the existing ET models were tested and calibrated for arid and semi-arid environments. However, no major models have been specifically developed for use in humid tropical environments. In view of all the above facts the present investigation is planned with the following specific objectives:

1. To determine the reference crop evapotranspiration (ET_o) using different empirical models
2. To measure the actual crop evapotranspiration (ET_c) of Okra using lysimeter.
3. To develop regional scale crop coefficient values of Okra in the humid tropical region.
4. To calculate water productivity and water use efficiency of Okra.

Review of Literature

CHAPTER 2

REVIEW OFLITERATURE

The most significant factor in agriculture is the water availability. Water resources for agricultural use are decreasing day by day in the context of climate change and environmental pollution. Therefore crop water use is to be accurately determined to improve water management strategies and then to increase the water use efficiency. Determination of evapotranspiration (ET) is a major component of agricultural water management, in local and regional water balance studies and hydrological modeling. Experimentally determined crop coefficient values and crop water requirement are important for proper irrigation scheduling, efficient water management, optimum yield and profit. This chapter provides a brief introduction about evapotranspiration mechanism and processes behind evapotranspiration. It also includes the description of different theoretical models and water balance study for estimating the evapotranspiration. According to the objectives of this study the previous studies relevant to the topic are briefly reviewed in the forgoing section under the following subtitles.

2.1 SIGNIFICANCE OF EVAPOTRANSPIRATION (ET)

Evapotranspiration (ET) is the sum of the amount of water returned to the atmosphere through the processes of evaporation and transpiration (Hansen *et al*., 1980). In irrigation planning, hydrological cycle and water management processes, the most important component is the evapotranspiration process (Allen *et al*., 1998).). ET and precipitation components are essential for proper planning and operating water resource projects.

Water, the critical component in agriculture is provided to the crops through precipitation and subsurface moisture, but when this proves to be inadequate for crop use, farmers should provide irrigation to crops. For effective water use, the amount of water irrigated should not exceed the maximum water content that can be used by evapotranspiration. Accurate irrigation scheduling is dependent on an accurate determination of ET (Hansen *et al*., 1980; Allen *et al*., 1998).

Loss of water from soil surface to the atmosphere is known as evaporation whereas loss of water from vegetation through its stomata and leaves is known as transpiration (Jensen *et al.*, 1990). Transpiration process supports to absorb and transport mineral nutrients in plants.

Mila *et al.* (2016) reported that one of the most important concepts regarding water balance in arid and semi-arid areas is crop evapotranspiration which is a key factor for determining proper irrigation scheduling and for improving water use efficiency in irrigated agriculture. Water requirement vary from crop to crop according to season. Therefore, it is necessary to know the actual crop water requirement, and water management will thus play a significant role in minimizing water loss by optimizing water use. Also, information on crop water requirement is necessary for policy planning on water management.

Marek *et al.* (2005) showed that there is a need to optimize all irrigation water use in arid and semi-arid regions where water resources are limited, and competition between urban users, industry, and agriculture is intense. Currently, actual crop water requirements for many crops, detailed by crop phonological stage, are not available, and many producers often apply significantly more or less irrigation water than the crop requires.

Weather parameters such as temperature, humidity, wind speed and solar radiation; crop factors such as crop variety, type, management and plant density and environmental factors such as poor land fertility and soil salinity are influenced on ET process (Allen *et al.*, 1998; Jensen *et al.*, 1990). Considering both components of evapotranspiration separately, weather parameters influenced on evaporation whereas crop characteristics and soil moisture are influenced on transpiration process. ET is often expressed as energy per unit area over a specified time (MJ m^{-2} day $^{-1}$) or units of depth per time (mm/day) (Allen *et al.*, 1998). The evapotranspiration can be expressed as either potential evapotranspiration (PET) or actual evapotranspiration (AET).

2.2 CONCEPT OF EVAPOTRANSPIRATION

When soil water is limited, the AET can be occurred in the case of arid environment. Therefore, the soil water content is very much influenced on evapotranspiration. Islam and Hossain (2010) shows that physiological characteristics of crop varieties differ under different soil and climatic conditions, thus, showing varying physiological demands including crop water requirements (Crop ET).

Reference evapotranspiration is a representation of the evaporative demand of the atmosphere, independent of crop growth and management factors. It can be estimated from the weather data. Penman (1956) defined PET as “if unlimited water is available, the amount of water transpired from a short green crop in unit time, and the grass is completely shading the ground of uniform height”. The available water is very limited and then the potential evapotranspiration is extremely high in arid regions.

Reference evapotranspiration (ET_o) provides a standard crop (a short, clipped grass) with an unrestrained water supply for calculating maximum evaporative demand from that surface for a given period. This value adjusted for a specific crop is the consumptive use and deficit represents that component of the consumptive use that goes unfilled, either by precipitation or by irrigation, during the given time period. This deficit value is the amount of water that must be supplied through irrigation to meet the water demand of the crop. Allen *et al*. (1994) defined ET_o as the rate of ET from a hypothetical reference crop with an assumed crop height of 0.12 m, a fixed surface resistance of 70 sec/m and an albedo of 0.23, closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well-watered, and completely shading the ground. ET_o estimates the loss of water from an identical vegetated surface, which helps in setting up the base value of ET for specific site.

Reference evapotranspiration (ET_0) can be estimated by using local atmospheric boundary conditions such as sunshine, temperature, humidity and wind speed. Previously, many researchers estimated ET_0 for various climatic conditions (Mila *et al*., 2016).

ETo can be estimated from meteorological data using empirical and semi-empirical equations. Numerous empirical methods have been developed to estimate evapotranspiration from different climatic variables. Examples of such methods include Penman-Monteith (Monteith, 1965) and Blaney-Criddle (Blaney and Criddle, 1950). One of the most important factors governing the selection of a method is the data availability. For instance, Blaney-Criddle requires only the temperature data while the Penman-Monteith requires additional parameters such as wind speed, humidity, solar radiation in addition. Since the Blaney-Criddle method is used to calculate monthly Kc values as compared to daily, less data is needed for this method.

Several studies have been conducted over the years to evaluate the accuracy of different ETo methods. Most of these studies have concluded that Penman-Monteith equation in its different forms provides the best ETo estimates under most conditions. Therefore, the Food and Agricultural Organization (FAO) recommended FAO-Penman Monteith (FAO-PM) method as the sole standard method for computation of ETo (Allen *et al*., 1998). FAO-PM can provide accurate ETo estimates for weekly or even hourly periods. In some instances, a specific method has been modified to better suit a region or a specific type of use such as a water allocation tool by water management districts.

The actual crop water use depends on climatic factors, crop type and crop growth stage. While ETo provides the climatic influence on crop water use, the effect of crop type and management is addressed by ETc. Factors affecting ETc such as ground cover, canopy properties and aerodynamic resistance for a crop are different from the factors affecting reference crop (grass or alfalfa) evapotranspiration (ETo), therefore, ETc differs from ETo (Allen *et al*., 1998; Snyder *et al*., 1987a, 1987b; Wright, 1982).

The characteristics that distinguish field crops from the reference crop are integrated into a crop factor or crop coefficient (Kc) (Allen et al., 1998). Kc is used to determine the actual water use (ETc) for any crop in conjunction with ETo as the following form;

$$ET_C = K_C * ET_O$$

2.3 CROP COEFFICIENT

The crop coefficient (Kc) is computed as the ratio of reference and crop ET as expressed above. Factors affecting Kc include crop type, crop growth stage, climate, soil moisture. Kc is commonly expressed as a function of time. However, Kc as a function of time does not take into account environmental and management factors that influence the rate of canopy development (Grattan et al., 1998). Therefore, most researchers have reported that Kc as a function of days after transplanting which helps to reference the Kc on crop development stage (Allen *et al*., 1998; Tyagi *et al*., 2000; Kashyap and Panda, 2001; Sepashkah and Andam, 2001)

Accurate prediction of crop water use is the key to develop efficient irrigation management practices making it imperative to develop Kc for a specific crop. Numerous studies have been conducted over the years to develop the Kc for different agricultural crops. Since most of the studies have been specific to one or two crops, Doorenbos and Pruitt (1977) prepared a comprehensive list of Kc for various crops under different climatic conditions by compiling results from different studies. Similar list of Kc was also given by Allen et al. (1998) and Doorenbos and Kassam (1979). However, Kc for a crop may vary from one place to another, depending on factors such as climate, soil, crop type, crop variety, irrigation methods (Kang *et al.*, 2003). Thus, for an accurate estimation of the crop water use, it is imperative to use a regional Kc value. Researchers have emphasized the need for regional calibration of Kc under a given climatic conditions (Doorenbos and Pruitt, 1977; and Kang et al., 2003). Therefore, the reported values of Kc should be used only in situations when regional data are not available. In summary, there is a need to develop regional Kc for a realistic estimation of water use to better schedule irrigation.

2.4 ROLE OF LYSIMETERS IN MEASUREMENT OF ET_C

A lysimeter is a device that separates soil and water hydrologically from its surroundings, but still represents the adjoining soil as closely as possible. Lysimeters are capable to be used as a research tool to study plant-water relations if they are designed sufficiently to approximate the physical system (Marek *et al.*, 2005).

Lysimeters provide a controlled soil-water or nutrient environment system for precise measurement of water and nutrient use and their movement. Drainage lysimeters or Non-weighing lysimeters are used to approximately calculate ET by calculating the water balance. The water balance involves quantification of all the water inputs and outputs to and from the lysimeter and the change in storage (soil moisture) over a predetermined period of time. These lysimeters provide viable estimates of ET_c for longer periods such as weekly or monthly. The term lysimeter means differential measuring instrument and may be taken, in general, to apply to all instruments which measure weight changes, especially weight reduction due to evapotranspiration in a particular volume of soil with or without accompanying vegetation (Torbjorn Johnson and Hans Odin, 1978).

According to Mila and Akanda (2016) lysimeter is a primary method for direct ET measurements. In this system, crop is grown in a totally controlled environment and gives accurate and precise ETc value. Besides, this system is not affected by other parameters such as surface runoff, interflow, deep percolation, and ground water contribution. Therefore, it is recommended and published that no further replication is necessary. Measured quantity of water was applied to the lysimeter tank as well as adjacent plot outside of the tank. Drainage water from lysimeters were collected and measured by graduated cylinder and ETc was calculated by using water balance equation.

Field studies using lysimetric data acts as an accurate tool in the determination of water balance variables, representing the existing field conditions. Lysimeters are usually more accurate for evaluating the water balance when compared to the use of soil water sensors. Lysimeters are used for determining actual evapotranspiration and groundwater recharge and therefore for setting up a water balance. The original sense of lysimeters gained more and more importance in the last decades and lysimeters are used not only for quantitative but qualitative aspects also (Loos *et al*., 2007).

2.5 REFERENCE CROP EVAPOTRANSPIRATION MODELS

Based on meteorological data many empirical models have been developed to estimate reference crop evapotranspiration (ETo) for different regions of world. To evaluate their performance many studies have been conducted. Some of these models are physically-based and others are semi-empirical and empirical based (Jensen *et al*., 1990). Based on climatic parameters these models can be categorized into three groups. They are combination models, radiation based models and temperature based models (Igbadun, 2012). The availability of climatic parameters plays a dominant role in the selection of these models.

2.5.1 Combination models

Penman model (1948) is a combination model. Penman proposed the first estimation model in 1948. It works to combine water vapour with the surface energy balance equation and the aerodynamic formulae for the vertical transfer of sensible heat (Jensen *et al*., 1990). Air saturation at the surface and horizontal uniformity of the surface were the assumptions of

Penman's model (1948). The complexity occurs when the surface was partly wetted or dry because the model was only applicable for open water and completely wet land surfaces. Negligence of the advection effects led to serious errors when considering open water such as rivers or lakes (Hooghart, 1987). During the 1940s there is no direct measurements of net radiation existed. In the evaporation process the net radiation as a significant factor, this was first considered by Penman's model. By using percentage of sunshine, extra-terrestrial radiation (Ra) and humidity Penman model estimated the net radiation (Jensen *et al.*, 1990). Hence it became necessary to revise this Penman's model over time as depended on semi-empirical expressions

Using the same physical principles as the Penman model, Monteith revised a formula that describe the transpiration from a dry, extensive-horizontal uniform surface in 1965and it was used to a dry crop which is completely shading the ground (Hooghart, 1987). He discussed the relationship of aerodynamic and canopy resistance. His model was later referred to as the Penman-Monteith equation (Katul *et al.*, 1992).

2.5.2 Radiation models

When wind speed and humidity are not measured, the radiation methods were adopted by Makkink (1957), Turc (1961), Priestley and Taylor (1972) (Doorenbos and Pruitt, 1977). The performances of these models vary from under or over prediction depending on the region where they were applied.Therefore these models did not perform well always. In a semi-arid environment radiation models are not recommended (Berengena and Gavilan, 2005; Trajkovic and Gocic, 2010). However, Priestley-Taylor performed well in a semiarid environment (Stannard, 1993). In arid regions, Jensen and Haise (1963) are recommended only radiation models (Mustafa *et al.*, 1989; Ismail, 1993; Alazba *et al.*, 2003). In estimating reference evapotranspiration (ETo) FAO-56 Penman-Monteith (FAO-56 PM) model performance is superior. Hence evaluation of radiation models based on FAO-56 PM has been focused in recent researches (Alexandris *et a*l., 2006; Trajkovic and Kolakovic, 2009; Tabari, 2010). Before radiation models inferred to another environment calibration is needed for these models.

2.5.3 Temperature models

Hargreaves-Samani (1985), and Thornhwaite (1948) are the temperature based models.

Due to the simplicity of temperature models, these have been tested worldwide. The temperature-based methods performance variation depends on the version of the model. Before extrapolating temperature models to another environment calibrationis needed for these models too.

For estimating reference evapotranspiration, Food and Agriculture Organization has been selected the FAO-56 Penman-Monteith as a standard equation all over the world (Tabari, 2010). The meteorological data such asrelative humidity, temperature, solar radiation and wind speed were required for the FAO-56 Penman-Monteith equation, but in developing countries like India these data are not always available. Models that use readily available weather data are therefore preferable (Tabari, 2010).

2.6 PERFORMANCE OF EVAPOTRANSPIRATION MODELS

To test the applicability of different models in different climates the ETo estimated by different empirical models are compared with measured ETo data from lysimeters (Jensen *et al*., 1990; Alazba *et al*., 2003; Denmirtas *et al*., 2007; Saghravani *et al*., 2009; Trajkovic and Gocic, 2010).

Masteorilli *et al*. (1994) conducted experiment on operational estimate of reference ET at regional scale in arid region. Reference ET was calculated using eight different models. The results showed that ETo estimates varied between methods and their accuracy was dependent on the selection of empirical coefficients. Direct measurements of ETo from a weighing type evaporimeter were utilized to provide local coefficients for converting estimates of ETo to measurements. The Blaney-Criddle formula was found to be highly correlated with measured ETo. However after calibration the penman method appeared to represent best evapotranspiration demand of the site.

Meshram *et al*. (2010) conducted a study on reference crop evapotranspiration of western part of Maharashtra, India. In this study, six reference crop evapotranspiration methods were studied. Comparison was made between the Modified Penman, Hargreaves-Samani, Pan Evaporation, Blaney-Criddle, FAO Radiation methods and the Penman-Monteith equation (which was standardized by Food and Agricultural Organization as FAO56-Penman-Monteith).

To evaluate the performance of these models the least root mean square error and regression analysis were used. The results of this study showed that modified Penman gave best performance when compared to the other methods like Blaney-Criddle, Pan Evaporation, Hargreaves-Samani and the radiation method.

George and Raghuwanshi (2012) conducted a study on inter-comparison of reference evapotranspiration estimation using six methods namely, Hargreaves (Temperature based), FAO-24 Radiation, Priestley-Taylor and Turc (Radiation Based) and FAO-24 Penman and Kimberly-Penman (Combination model). They evaluated the models using meteorological data from four climatological stations to determine the best and worst method for each location. The reference crop evapotranspiration (ETo) values estimated by all methods were compared with the FAO-56 Penman-Monteith ETo estimates. Based on the Standard Error Estimates, the FAO-24 radiation method ranked first for the Jagdalpur and Bombay stations. The 1982 Kimberly-Penman ranked first for Kharagpur and Bellary.

Nikam *et al*. (2014) made a comparative evaluation of different potential evapotranspiration estimation models. This study used two most popular temperature based approaches (Hargreaves and Thornthwaite) and two radiation based approaches (Priestley-Taylor and Turc) to estimate monthly potential evapotranspiration (ETo) at Pantnagar (Uttarakhand), India. The performance of all these methods were evaluated based on the regression and error analysis between standard ETo derived using FAO-56 Penman-Monteith method. The Turc method performed well on the monthly basis with lowest RMSE and high coefficient of determination. Based on the season values, the Priestley-Taylor method was found to be the best for Rabi season with lowest error values. In Rabi season Turc method holds second rank. However Turc method performed better than any other method in Kharif season with lowest error terms. In summer season all the methods performed poorly compared to other two seasons, but Hargreaves method performed better than any other methods.

Naorem and Devi (2014) conducted a study on estimation of potential evapotranspiration for Imphal. In this study, ten empirical methods were used to estimate the potential evapotranspiration (PET) viz. Blaney-Criddle, Thornthwaite, Hargreaves, Penman, Penman-Monteith, Jensen-Haise, Turc, Priestley-Taylor, Makkink and Open pan method. The empirically estimated PET values from all these models were validated with the actual measured mesh covered pan evaporation values, by using calibration coefficients. The results of this study showed that, Hargreaves method with least biasness and minimum errors was found to be the most suitable method for the region

Edebeatu and Callistus (2015) compared four empirical evapotranspiration models against the Penman–Montieth in a mangrove zone. In this study, comparison was made between the four empirical evapotranspiration equation models such as Jensen–Haise, Lincare, Romanenko's and Hargreaves with the FAO-56 Penman–Monteith as a standard method. He reported that Jensen–Hasie model proved a better value of evapotranspiration among the ET models. This was strictly followed by the Lincare method.

Yanga *et al*. (2016) evaluated the Penman-Monteith model for short-term forecasting of daily reference evapotranspiration using weather forecasts. They forecasted daily 7-day-ahead ETo. The results indicated that the forecasting performance for the minimum temperature was the best, followed by maximum temperature, sunshine duration and wind speed. Also, it was found that use of public weather forecasts and the Penman-Monteith model improved the forecasting performance of daily ETo compared to those attained when using the Hargreaves−Samani model, Hence it is clear that weather type and wind scale forecasts also have positive influence on ETo forecasting. Further, the highest impact on ETo forecasting error was found to be caused by the errors in sunshine duration and wind speed, followed by maximum and minimum temperature forecasts.

2.7 WATER BALANCE STUDIES USING LYSIMETER

Allen and fisher (1990) studied about low cost electronic weighing lysimeters for measuring evapotranspiration. By using commercially available cantilever load cells the research lysimeters with 1 m^2 area 1.2 m depth were designed and constructed. From the fescue/forage grass mix the daily measurements of evapotranspiration was made. Lysimeter measurements agreed well with evapotranspiration estimated using the Penman-Monteith model

One of the most important factors controlling the accuracy of a lysimeter is its size (Gangopadhyaya *et al.,* 1966). Clark and Reddell (1990) noted that the lysimeter surface area and its depth should be large enough to minimize root restrictions. Gangopadhyaya *et al*. (1966) reported that miniature lysimeters (10 cm diameter and 10 cm deep) were “sensitive” but not reliable due to distortions in thermal properties. They concluded that the accuracy of lysimeters increases with an increase in their surface area. Boast and Robertson (1982) reported that shallow lysimeters tend to retain more water per unit depth than the actual field and thus introduce a bias by overestimating ET. Yang *et al*. (2000) reported that groundwater evaporation contributes up to 56% of total ET. Therefore, they suggested that lysimeters measuring ET should be deep enough to account for soil-water and groundwater exchanges and water table fluctuations.

Lysimeters have been successfully used by researchers to measure the ETc and develop Kc for various fruits and vegetables (Haman *et a*l., 1997; Clark *et al*., 1996) and field crops (Steele *et al*., 1997; Simon *et. al*, 1998; Tyagi *et al*., 2000). ET_o is the evapotranspiration from a reference crop such as grass or alfalfa with specific characteristics and standard conditions (Allen *et al*., 1994). So many methods are available to compute evapotranspiration directly. For instance, a lysimeter is used to measure ET by regularly measuring the change in soil moisture of a known volume of soil planted with the crop under study and monitoring the other inflow-outflow parameters (Watson and Burnett, 1995).

Steele *et al*. (1997) developed mean crop curves for corn based on Jensen and Haise (1963) and modified Penman equation (Allen 1986) ETo methods. Using 11 years of data from four drainage lysimeters, they developed fifth order crop curves for corn using both ETo methods. They noted that the lack of soil moisture monitoring at the bottom 0.3 m region of lysimeter added to the uncertainty in the results. Another complicating part of their study was negative Kc for periods when lysimeters were drained after rainfall. They did not discuss the reasons for negative Kc, but, they noted that it can be avoided by increasing the time step for estimating ETo to two or more periods. They noted that referencing Kc to the beginning or end of the growing period could change the shape, amplitude and position of the crop curve significantly, thereby, reducing its accuracy.

Haman *et al*. (1997) used drainage lysimeters to study ET and develop Kc for two varieties of young blueberries for Florida. They used cylindrical tanks as lysimeters (1.6 m diameter and

1.8 m deep) equipped with porous plates to extract drainage water. They noted that their computed Kc was different from the standard Kc, but it provided information for actual crop water use. Although Kc for both the varieties followed the same general trend, Kc values for the two varieties were different from each other.

Clark *et al*. (1996) used drainage lysimeters to compute ETc and develop Kc for drip irrigated strawberry in Florida. They used 16 drainage lysimeters 2.4 m × 0.6 m × 0.6 m equipped with rain shelters for their study. Since drip irrigation applies water directly to the root zone, actual crop water use can be different from the seepage irrigation system which has high water table and wet row middles. To study differences due to high water table and wet row middles, they used two types of plant arrangements: first arrangement estimated ETc only from the plants while second estimated ETc from the plants and the exposed row middles. They reported monthly Kc based on modified Penman (PENET) (Burman et al., 1980), modified Blaney-Criddle (BCRAD) (Shih et al., 1977) and pan evaporation (PANET) (Doorenboss and Pruitt, 1977). Their results indicated that for lysimeters with plants and exposed row middles, ETc and Kc were higher than those with plants only. They estimated that 25 - 35% of ETc was Ea from exposed row middles. Using linear regression, they observed high R^2 for their Kc curves (PENET =0.97, PANET = 0.94, BCRAD = 0.94.). They recommended that Kc developed from their study was useful for irrigation scheduling and developing water budgeting procedures for drip irrigated strawberry production in a humid region.

Simon *et al*. (1998) conducted a study to develop regional Kc for maize in Trinidad. They used 2 m × 2 m × 1.2 m drainage lysimeter for three seasons to develop Kc. The effects of dry and wet season (temporal variability of climate) on Kc were also discussed. They found that Kc during a wet season (Kc = 1.13 to 1.41) was greater than during a dry season. (Kc= 0.73 to 0.94). They attributed the differences between the wet and dry season Kc to lower ETo during the wet season. Mean Kc for maize was found to be greater than the reported values by Doorenboss and Pruitt (1977). Therefore, the authors stressed on the importance of developing regional Kc for accurate irrigation scheduling.

Sepaskhah and Andam (2001) used drainage lysimeters to estimate Kc for sesame for semi-arid regions of Iran. They developed Kc based on Modified Penman-Monteith (Jensen et al., 1990) and FAO- PM, as a function of DAT. Authors reported that their observed Kc was different from those given by Doorenboss and Pruitt (1977) and Allen et al. (1998) for similar crops. In a similar study, Lie et al. (2003) used cylindrical drainage lysimeter (diameter = 1 m; depth = 0.8 m) to develop Kc for watermelon and honey dew melons in China using ETo from pan evaporation. Their reported Kc for watermelon varied from 0.35 - 2.43. These values were considerably higher than the Kc (0.4 - 1.0) as reported by Allen et al. (1998). A study by Kang et al. (2003) reported Kc for wheat and maize for semi-humid conditions of northwestern China. They used three 3 m × 2 m × 2 m drainage lysimeters equipped with rain shelters. Average Kc was developed from 10 years of measured data. Although, their Kc matched well with the Kc given by Doorenboss and Pruitt (1977) during the initial growth period for both the crops, it was higher during the mid and late season.

Mila *et al.* (2016) conducted a lysimeter study on sunflower to develop crop co-efficient values for different growth stages. The results revealed that irrigation at 15 days interval produced the highest yield and was considered suitable for estimating ETc and Kc. The seasonal total ETc was found as 270.89 mm, whereas the Kc values of sunflower under different ETo methods for initial, development, mid-season and late season ranged from 0.34 to 0.48, 0.80 to 1.10, 1.06 to 1.55 and 0.27 to 0.36 respectively. Radiation, temperature, Penman-Monteith and Hargreaves models were used to compare the lysimeter values. Among these methods, Penman-Monteith model gave relatively higher value than the other models.

Islam and Hossain (2010) conducted a lysimetric study on determination of crop coefficient value of hybrid maize at different growth stages. They used micro-lysimeter situated at BARI farm, Gazipur. It has four tanks spaced at equal distances (4 m) in a line. The lysimeter tank has 1 meter square area with effective soil depth of 100 cm followed by 2cm thick sand pack. Below the sand layer, 3 meshes of no. 4, 20, and 40 are placed. Below the mesh, a 13 cm thick gravel pack collects the excess water from the upper parts and discharges it to the drainage collector placed in the working chamber through a drainage pipe.Maize was sown in four lysimeter tanks, each having 1 m^2 area on 29 November 2002. Also, to maintain a similar environment, the same crop was grown in the lands surrounding the tanks. Results obtained showed that the crop co-efficient values at initial, development, mid-season and late season stages of hybrid maize (variety: BARI Hybrid Maize-I) were determined as 0.38, 0.87, 1.36 and

0.75 respectively.

Hakkim *et al*. (1989) conducted an experiment to estimate the evapotranspiration of a short duration variety paddy red triveni in the wetland of Tavanur region during the mundakan season. The evapotranspiration obtained by lysimeter measurement was compared with that estimated using various formulae viz. Blaney–Criddle, Modified Penman and radiation methods. The average evapotranspiration and crop coefficient of red triveni paddy was obtained as 555.37 mm and 1.45 respectively for the season. ET estimated using Modified Penman method was more close to the ET obtained by direct measurement.

Dewidar *et al*. (2015) conducted a study on lysimeter based water requirements and crop coefficient of surface drip-irrigated date palm in Saudi Arabia. Non-weighing lysimeters were used to grow alfalfa (*Mcdicagosativa*) and grass (*Cynodondactylon*) as a reference crops and date palm (*Phoenix dactylifera*) as experimental crop to obtain the daily water requirements and crop coefficient throughout productive cycle of datepalm. The results showed that estimated potential evapotranspiration of alfalfa and grass crops throughout the experimental period were approximately 2185 and 2068 mm, with a daily average of 5.98 and 5.66 mm/day respectively. The date palm evapotranspiration increased from 3.09 mm/day in February at pollination stage to 8.25 mm/day in July at fruit maturity stage, and then dipped to 5.42 mm/day in September at the end of harvest. The average crop coefficient for the date palm productive cycle through the whole year was 0.83.

Mini-lysimeters was fitted in a farm of Milano University to obtain direct measurement of evapotranspiration from reference crop. An indirect estimation of evapotranspiration has been carried out by means of micro meteorological algorithm of Penman–Monteith. Data produced by the Mini-lysimeters has been compared with Penman-Monteith model. The results indicated that the two methods were closer to each other. The results of statistical indexes represented the same results for lysimeters and Penman-Monteith (Parisi *et al*., 2009).

Tyagi *et al*. (2000) carried a study on determination of evapotranspiration and crop coefficients of rice and sunflower with lysimeter at Karnal. Lysimeter experiments were conducted on rice during rainy season (July-October) and sunflower during summer seasons (March-June) in a set of two electronic weighing type lysimeters of size 2 m x 2 m x 2 m. The weekly average ET of rice varied from <3 mm/day at the early growing period to > 6.6 mm/day at milking stage. When LAI was 3.4, the peak ETc was 6.61 mm/day and it proceeded for 11 weeks after transplanting up to the reproductive stage. In case of sunflower, at the initial stage ETc was <1.0 mm/day, acquired a peak value of 14.1 mm/day between 8 and 9 weeks after sowing and during maturity phase it declined to 3 mm/day. The estimated values of Kc values for sunflower were 0.52, 1.1, 1.32 and 0.41 and corresponding crop coefficient for rice at the four crop growth stages (initial, crop development, reproductive and maturity) were 1.15, 1.23, 1.14 and 1.02 respectively. The values suggested by FAO were less than 11.6-74.2 per cent of the estimated Kc values of sunflower.

Materials and Methods

CHAPTER 3

MATERIALS AND METHODS

This chapter explains the various materials used in the study, description of the study area, details of evapotranspiration models, construction of drainage type lysimeter and the meteorological data used for estimation and measurement of evapotranspiration. It also explains the details of water balance study using lysimeter. Each of these parts are discussed in detail under the following subheads.

3.1 EXPERIMENTAL SITE, SOIL AND CLIMATE

The evapotranspiration experiment was conducted in the lysimeter installed at the eastern block of instructional farm, KCAET. It is situated at 10^0 52’ 30” north latitude and 76^0 east longitude. The total geographical area of the instructional farm is about 40.2 ha out of which total area comes under experiment is 35 m^2.Agro-climatically, the area falls within the border line of northern hemisphere and central zone of Kerala. Majority of the rainfall received in this region is from south-west monsoon. The area is humid tropical climate with the maximum and minimum temperature of 22.42°C and 37.73°C respectively. The average relative humidity, sunshine hour and wind speed are 73.66 %, 6.05 and 4.5 km/hr respectively. The soil of experiment field is sandy clay loam with field capacity and bulk density 21.01 % and 1.63 g/cc respectively.

3.2 CROP DETAILS

Okra (Varsha Upahar) was sown in the lysimeter at a spacing of 50x50cm. The crop was also grown in the area surrounding the lysimeter for creating similar micro-climatic condition. The measured quantity of irrigation water will be given in excess till a measurable quantity of drainage comes. Recommended fertilizer, intercultural operation and other necessities are provided according to requirement.

3.3 FIELD INSTRUMENTATION AND MEASUREMENT

The field instrumentations and measurements to collect the data required for estimation and measurement of reference crop evapotranspiration is explained in this section.

3.3.1 Determination of physical properties of soil

Soil is the reservoir in the water balance study. Therefore determination of soil physical properties and soil moisture content measurements are important. Soil samples were taken from the experimental plot at two levels one from 10cm depth and next from 20cm. They were mixed together to determine properties like soil texture, bulk density, particle density, field capacity, wilting point and available soil moisture content. The methods are explained as follows.

3.3.1.1 Bulk density and particle density

Bulk density and dry density of the soil filled in the lysimeter were measured using core cutter method by standard procedure.

Equipments used:

1. Cylindrical core cutter
2. Steel rammer
3. Steel dolly

Procedure:

Height and internal diameter of the core cutter were measured, and the volume of the core cutter was determined. Core cutter was pressed into the soil to its full depth with the help of steel rammer and the soil around the cutter was removed by spade. The cutter was removed and the top and bottom of the sample surface was trimmed carefully. The soil core was removed from the cutter and the weight of the core soil was measured. Representative sample was taken from the cutter in to the moisture container to determine the moisture content. The sample was dried in the oven at 105°C and constant weight was recorded. The detail of core cutter experiment is shown in Plate 3.1.

Plate 3.1 Determination of bulk density by core cutter

Physical properties were determined by using the following formulae. The specimen calculations are shown in Appendix I

Bulk density of the soil (g/cm^3) $\gamma = \frac{W}{V}$

Where,

W - Weight of soil (g)

V - Volume of soil (cm^3)

Dry density of the soil (g/cm^3) $\gamma_d = \frac{\gamma}{1+\omega}$ where,

γ - Bulk density of the soil

ω - Moisture content of soil

3.3.1.2 Soil Texture

Soil Texture was determined by sieve analysis.

Procedure:

The complete sieve analysis can be divided into two parts. One is coarse analysis and second is fine analysis. An oven dried sample of soil is separated into two fractions by sieving it through a 4.75 mm IS sieve. The portion retained on it (+ 4.75 mm size) is termed as the gravel fraction and is kept for the coarse analysis, while the portion passing through it (- 4.75 mm size) is subjected to fine sieve analysis. The following sets of sieves are used for coarse sieve analysis: IS: 100, 63, 20, 10 and 4.75 mm, the sieves used for fine sieve analysis are: 2 mm, 1 mm, 600, 425, 300, 212, 150 and 75 micron IS sieves.

Sieving was performed by arranging the various sieves one over the other in the order of their mesh openings. The largest aperture sieve being kept at the top and the smallest aperture sieve at the bottom. A receiver was kept at the bottom and a cover was placed at the top of the whole assembly. The soil sample was put on the top sieve and the whole assembly was fitted on a sieve shaking machine. The amount of shaking depends upon the shape and the number of particles. The portion of the soil sample retained on each sieve was weighed. The percentage of soil retained on each sieve was calculated on the basis of the total mass of soil sample taken and from these results; percentage passing through each sieve was calculated. Calculations are shown in Appendix II. The different sizes of particles retained on different sieves were shown in plate 3.2.

Plate 3.2 Soil retained on different sieves

3.3.1.3 Permanent wilting point and field capacity

A soil moisture characteristic was done with the pressure plate apparatus (Plate 3.3). The apparatus consists of ceramic pressure plate or membranes of high air entry values contained in airtight metallic chambers strong enough to withstand high pressure (15 bars or more). The apparatus enables the development of soil moisture characteristic curves in the higher range of matric potential (>1bar) which is not possible on suction plates.

The procedure for determining soil matric potential and water content relation involved first saturation of the porous plates and the soil sample (undisturbed or disturbed) and was placed on these plates. The plates were transferred to the metallic chambers. The chamber was closed with wrenches to tighten the nuts and bolts with the required torque for ceiling it. Pressure was applied from a compressor through control which helps in maintaining the desired two pressures 1/3atm & 15atm which were applied to get field capacity and permanent wilting point respectively. It was ensured that there was no leakage from the chamber. Water starts to flow out from saturated soil samples through outlet and continues to trickle till equilibrium against the applied pressure was achieved. After that the soil samples were taken out and oven dried for determining moisture content on volume basis (Michael, 2008). The data and calculations are given in Appendix III

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Plate 3.3 Soil samples in pressure plate and membrane apparatus

3.3.1.4 Soil moisture measurement

Gravimetric method was used to determine the soil moisture content. Basic measurements of soil moisture are made on soil samples of known weight or volume. Soil samples are collected with a soil auger. The samples were taken from the desired depth at several locations in the area. They were collected in air tight aluminum containers. The soil samples were weighed and then dried in an oven at 105^0c for about 24 hours, until all the moisture was driven off. After removing from oven they were cooled slowly to room temperature and weighed again. The difference in weight is the amount of moisture in the soil (Michael, 2008). The data and calculations are shown in Appendix IV.

3.4 FIELD EXPERIMENT IN LYSIMETER

The field experiment was conducted in the lysimeter installed at the eastern block of instructional farm, KCAET during 13th October – 31st December 2017. The crop selected was Okra with crop duration of three months. The total geographical area of the instructional farm is about 40.2 ha out of which total area comes under experiment is 35 m^2.

3.4.1 Construction of Drainage Type Lysimeter

A drainage type lysimeter was constructed for the study. A plot of 5x7m Size was selected. For installing the lysimeter, a rectangular pit of 5 m^2 area and 1 m depth was made. A concrete cement tank of size 2.5x2x1 was constructed. Soil was filled to an effective depth of 70cm. Below this a layer of plastic net with mesh opening of 1mm and a 10 cm thick sand layer was provided. And this was followed by another layer of plastic net of same size. Below this plastic net, a layer of 10 cm fine gravel pack followed by another layer of plastic net and a 10 cm of coarse gravel pack were provided. The gravel pack collected the excess water from the upper parts and discharged it into the sump placed outside the tank. A drainage pipe of diameter 2.5 cm with perforations was buried at the bottom of the tank with a slope of 4 per cent to convey the drainage water into the sump. The sump was a plastic container of diameter 40cm and depth 27cm with lid arrangement for collection of drainage water. Lysimeter tank was provided with a PVC pipe of size 1.75 cm which serves as an air vent. This vent was inserted up to the gravel layer and was provided with a cap at the top end. The cross sectional view of lysimeter is shown in Fig. 3.1. Special precautions were taken to refill the top 70 cm soil in the lysimeter to its original status by restoring the correct soil profile and compaction to maintain its original density. Views of the lysimeter during different stages of filling the drainage media is shown in Plates 3.4, 3.5, 3.6 and 3.7.

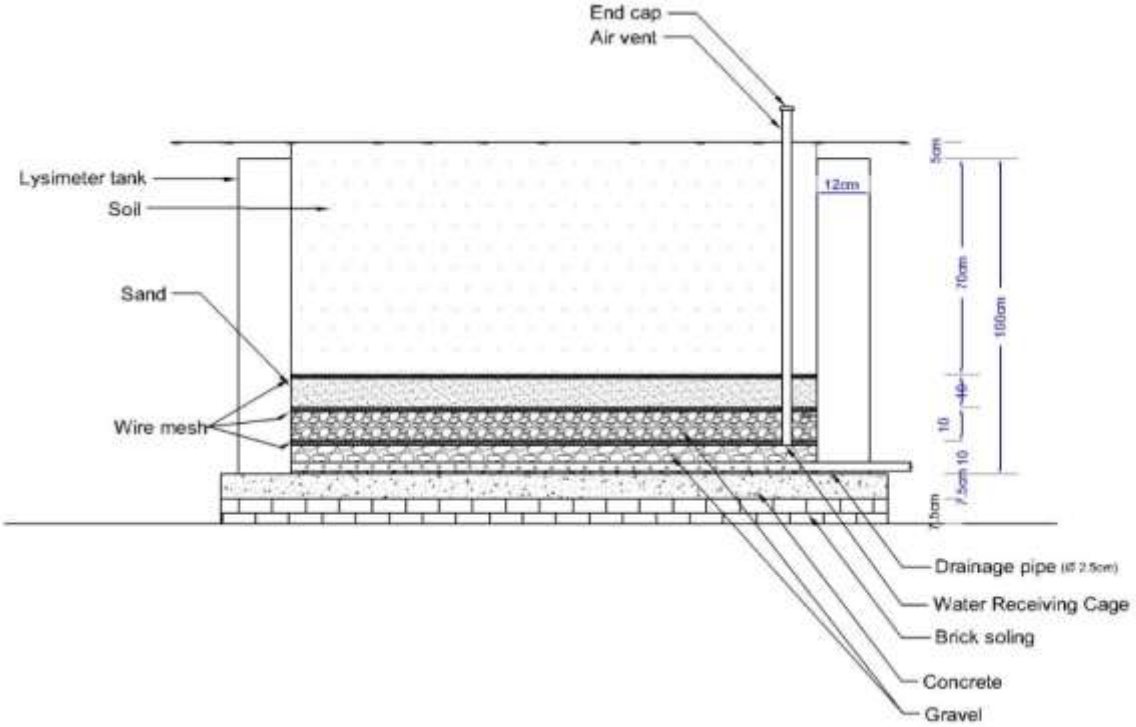

Fig 3.1 Cross sectional view of lysimeter

Plate 3.4 A view of lysimeter tank

Plate 3.5 Drainage media filling- part 1

Plate 3.6 Drainage media filling-part 2

Plate 3.7 Lysimeter in filled condition

3.4.2 Field Preparation

Land preparation was done inside the lysimeter as well as the area around the lysimeter. The plot was tilled up to a required depth and removed all other unwanted plants around the lysimeter before preparing the beds. Four raised beds of 13 m length, 0.5 m width and 0.25 m height were made for cultivating Okra as shown in Plate 3.8.

Plate 3.8 Experimental field after land preparation

3.4.3 Irrigation system

Irrigation was applied using drip system. The PVC pipe of diameter 30mm was used as the main and 25mm pipe was used as the sub main, to which, Low density polyethylene laterals of 12 mm diameter were connected. End caps were provided at the end of laterals. Drippers of 4 lph were used for applying water. The lysimeter of 5m^2 area comprises of 2 laterals with 10 drippers as shown in Plate 3.9. The evapotranspiration from a reference surface not short of water is called reference crop evapotranspiration. Hence irrigation was applied daily until an appreciable quantity of water has obtained as drainage. At the initial stage the crop was irrigated daily with an application rate of 1.5 l/day/plant against the standard value of 0.65 l\day\plant. During the mid-season stage the plant requires more water than initial stage. So the water applied was increased from 1.5 to 2.0 l/day/plant. In the late season stage water application rate was reduced to 1.5 l/day/plant.

Plate 3.9 Drip irrigation in lysimeter

3.4.4 Sowing of Okra

Okra variety *Varsha Upahar* was chosen for this study to estimate crop evapotranspiration in lysimeter. Sowing was done on 13th October. Seeds were directly sown in the lysimeter as well as the area around the lysimeter. In the lysimeter, ten seeds were sown at a spacing of 50x50 cm. Plate 3.10 shows an overall view of the field with emerging Okra.

Plate 3.10 Overall view of the field with emerging Okra

3.5 DETERMINATION OF ACTUAL CROP EVAPOTRANSPIRATION (ET_C)

Field studies using lysimetric data act as an accurate tool in the determination of water balance variables, representing the existing field conditions. Non weighing lysimeters also known as Drainage lysimeters or Percolation lysimeters was used in this study. Drainage lysimeters work on the principle (of water balance) that evapotranspiration is equal to the amount of rainfall and irrigation added to the system, minus percolation, runoff and soil moisture change, assuming that the water flow is mainly vertical and occurrence of lateral flow components are negligible (Zupanc *et al*., 2005).

Here the crop is grown in a totally controlled environment and the system is not affected by any other parameters such as surface runoff, interflow, deep percolation and groundwater contribution. Moreover lysimeter imitated the natural field conditions. Hence, it is recommended that no further replication is necessary (Mila *et al*., 2016).

3.5.1 Water Balance Model

Water balance is defined by the general hydrologic equation, which is basically a statement of the law of conservation of mass as applied to the hydrologic cycle (Ridder and Boonstra, 1994).

The following formula is used to calculate the crop evapotranspiration for the specific period:

$$ETc = Wa - (Dw \pm \Delta Ss) \qquad \ldots..(1)$$

Where,

ETc = Crop evapotranspiration in mm for time, t

Wa = Applied water + rainfall, mm, for time, t

Dw = Drainage water, mm, for time, t

ΔSs = Change in soil moisture, mm, for time, t

3.5.2 Recording data pertaining to various components of water balance equation

Water applied: The crop was irrigated in excess of the actual crop water demand. Measured quantity of water was applied daily to the lysimeter tank ensuring drainage. The surrounding area of lysimeter with Okra crop was also well irrigated. The quantity of water applied during irrigation was calculated as follows.

$$\text{Water applied (mm)} = \frac{\text{No of drippers X Each dripper capacity (lph)} \times \text{ Applied time (min)}}{\text{Area of lysimeter } (\text{m}^2) \text{ X } 60}$$

Effective rainfall: The rainfall falling over a given area was measured by a rain gauge and 75 per cent of that was taken as the effective rainfall.

Drainage water: Drainage water from the lysimeter was collected in a plastic container with lid which prevents evaporation from the container and measured using a graduated cylinder weekly.

Change in soil moisture storage: Soil moisture storage is the total amount of water stored in the soil within the plant's root zone in a specified time. Change in soil moisture was determined by gravimetric method on weekly basis. Soil moisture samples were collected at two different depths, one at 10cm depth and, next from 20cm before irrigation to determine the change in soil moisture storage. Measured soil moisture in weight basis was converted into volume basis by using the following formula.

$$\Delta S_s = \sum_{i=1}^{n} \frac{M_{1i} - M_{2i}}{100} \times A_i \times D_i$$

Where,

ΔS_s = Change in soil moisture storage, mm, for time, t,

n = Number of soil layers in the root zone,

M_{1i} = Moisture content at the time of first sampling in the i^{th} layer,

M_{2i} = Moisture content at the time of second sampling in the i^{th} layer,

A_i = Apparent specific gravity of i^{th} layer and

D_i = Depth of i^{th} layer of the soil with root zone (mm).

3.6 DETERMINATION OF REFERENCE CROP EVAPO-TRANSPIRATION (ET_O)

Reference crop ET (ET_o) is the potential evapotranspiration which is defined as “the rate of evapotranspiration from an extensive surface of 8 to 15cm tall, green grass cover of uniform height, actively growing, completely shading the ground and not short of water” (Doorenbos and Pruitt, 1977). ET_o can be estimated by using local atmospheric boundary condition such as temperature, humidity, sunshine, and wind speed. It is the potential evaporation of a well-watered grass crop and a set of surrounding (advective) conditions.

3.6.1 Weather data

Weather data was collected from the meteorological observatory RARS Pattambi, KAU from October 2017 to December 2017. Daily data was collected and it was converted into weekly average values. The meteorological data comprises the following parameters: maximum and minimum temperature, maximum and minimum relative humidity, wind speed, sunshine hours and pan evaporation. By incorporating this data in the different models the reference crop evapotranspiration (ET_o) was estimated. The climatic data collected from RARS Pattambi shown in Table 3.1 was used to estimate the potential evapotranspiration (ETo).

Table 3.1 Mean weekly weather data for the period October-December 2017

Weeks	Max Temp (˚C)	Min Temp (˚C)	Max RH (%)	Min RH (%)	Wind speed (km/h)	Sunshine hours	Pan evaporation (mm)
1	30.3	23.9	96	71	2.8	2.5	1.9
2	31.3	24.6	91	66	3.4	4.8	3.3
3	30.4	23.1	95	75	2.4	4.4	1.9
4	32.2	22.3	90	60	2.2	6.8	2.5
5	32.4	23.4	87.6	61.9	3.4	6.7	4.5
6	31.9	23.4	86.8	67.7	4.2	4.9	2.7
7	32	21.9	93.1	56.1	1.8	7.1	2.7
8	33.2	22.9	91.1	55.6	3.2	6.7	3.4
9	31.1	22.6	86.3	61.1	6.2	4.2	2.5
10	32	21.9	88.3	59.7	4.4	8.4	2
11	31.7	22.2	90.1	53.3	3.4	4.7	2.5
12	32	19.6	71	40.4	12.1	8.8	4.3
13	32.1	19.7	77.1	38.1	9	8.7	3.8

3.6.2 *Empirical Models used in this study*

Three different empirical models which were found most suitable for Tavanur region from earlier studies and widely used for the estimation of reference crop evapotranspiration (ETo) in Indian conditions were used in this research work. They were:

1. FAO 56 Penman-Monteith (1991) model (combination model)
2. FAO-24 Open Pan (1977) model (Evaporation model)
3. Christiansen (1968) Pan evaporation model (Evaporation model)

In recent years FAO-56 Penman-Monteith model which is more physically based provides superior results in both arid and humid regions and has been recommended as a new standard for reference crop evapotranspiration estimates (Allen *et al*., 1998). They also recommended FAO-24 Open pan (1977) model and Christiansen (1968) pan evaporation model for estimation of ETo in conditions where sufficient climatic data is not available. Hence, in this study the ETo obtained from the above models was used for calculating the crop coefficient values.

3.6.2.1 Description of the Models Used in the Study (Source: FAO, 1992)

FAO 56 Penman-Monteith Model (PMM)

The equation is expressed as:

$$\text{PET}=\frac{0.408\Delta\,(Rn-G)+\gamma\frac{900}{T+273}U2\,(ea-ed)}{\Delta+\gamma\,(1+0.34U2)}$$

Where,

ETo = Reference crop evapotranspiration (mm/day),

R_n = Net radiation at crop surface (MJ m^{-2} day^{-1}),

G = Soil heat flux (MJ m^{-2} day^{-1}),

T = Average temperature at 2 m height (^{o}C),

U_2 = Wind speed measured at 2 m height ($m\ s^{-1}$),

$(e_a\text{-}e_d)$ = Vapour pressure deficit for measurement at 2 m height (K Pa),

Δ = Slope vapour pressure curve (K Pa $^oC^{-1}$),

Υ = Psychrometric constant (K Pa $^oC^{-1}$),

900 = Coefficient for the reference crop ($1\ j^{-1}\ Kg\ K\ d^{-1}$) and

0.34 = Wind coefficient for the reference crop ($s\ m^{-1}$).

The various components of the above relation are derived as

i) When solar radiation is available

$$Rn = 0.77\ Rs - \left(a_c \frac{Rs}{Rso} + b_c\right)\left(a_1 + b_1\sqrt{ed}\right)\ \sigma\ \frac{(T_{Kx}^4 + T_{Kn}^4)}{2}$$

Where, T_{kx} and T_{kn} is both set equal to mean hourly air temperature for hourly calculations. This is not employed in the present study as very few stations have the data on solar radiation.

ii) When only sunshine data is available

$$R_n = 0.77\left(0.25 + 0.50\,\frac{n}{N} + R_s\right) - 2.45 \times 10^{-9}\left(0.9\,\frac{n}{N} + 0.1\right)\left(0.34 - 0.14\sqrt{e_d}\right)\left(T_{Kx}^4 + T_{Kn}^4\right)$$

$$G = 0.38\left(T_{day\ i} - T_{day\ i-1}\right)$$

Where, $T_{day\ i}$= Mean daily air temperature and

$T_{day\ i-1}$= Mean daily air temperature of preceding day.

iii) Vapour Pressure Deficit (VPD)

$$VPD = (e_a - e_d) = \frac{e^o(T_{max}) + e^o\ (T_{min})}{2} - e_d$$

Where, VPD = Vapour Pressure Deficit (K Pa),

$e^o(T_{max})$ = Saturation vapour pressure at T_{max} (K Pa),

$e^o (T_{min})$ = Saturation vapour pressure at T_{min} (K Pa),

e_d = Actual vapour pressure (K Pa) and

$$e_a = e^o \text{ (T)} = 0.611 \exp \left(\frac{17.27T}{T+237.3}\right).$$

Where,

e_a = Saturation vapour pressure (K Pa),

e^o (T) = Saturation vapour pressure function (K Pa),

T = Air temperature (°C) and

$$e_d = e^o\ (T_{min})\frac{RH_{max}}{100}.$$

iv) Δ is slope of vapour pressure, computed as

$$\Delta = \left(\frac{e_a}{T_m+273}\right)\left(\frac{6791}{T_m+273} - 5.03\right)$$

FAO-24 Open Pan (1977) model (OPM)

The equation is expressed as: $ETo = K_p E_p$

Where, K_p = Pan coefficient, E_p = Measured open pan evaporation (mm).

Pan coefficient as computed by Allen and Pruitt (1991) for green and dry fetch is adopted in this study which is

Green Fetch

$K_p = 0.108 - 0.000331\ U_2 + 0.0422 \ln (\text{Fetch}) + 0.1434 \ln (RH_{mean}) - 0.000631\ [\ln (\text{Fetch})]^2\ [\ln (RH_{mean})]$

Dry Fetch

$K_p = 0.61 + 0.00341\ RH_{mean} - 0.00000187\ U_2 RH_{mean} - 0.000000111\ U_2\ (\text{Fetch}) + 0.0000378$

$U_2 \ln(\text{Fetch}) - 0.0000332\, U_2 \ln(U_2) - 0.0106\, [\ln(U_2)]\, [\ln(\text{Fetch})] + 0.00063\, [\ln(\text{Fetch})]^2\, [\ln(U_2)]$

In the present study, green fetch coefficients were used during southwest monsoon and northeast monsoon seasons and dry fetch coefficients during winter and summer periods. A fetch of 10m during southwest monsoon and northeast monsoon periods and 100m during winter and summer periods were assumed.

Christiansen (1968) Pan Evaporation model (CHM)

The equation is expressed as:

$$ET_O = 0.755\, E_O\, C_{T2}\, C_{W2}\, C_{H2}\, C_{S2}$$

Where, E_O = Open pan evaporation (mm),

$$C_{T2} = 0.862 + 0.179\, (Tm / 20) - 0.041\, (Tm / 20)^2.$$

Where,

Tm is the mean temperature in ^oC,

$$C_{W2} = 1.189 - 0.240\, (W / 6.7) + 0.051\, (W / 6.7)^2.$$

Where,

W = Mean wind speed 2m above ground level in km per hour,

$$C_{H2} = 0.499 + 0.620\, (Hm / 0.60) - 0.119\, (Hm / 0.60)^2.$$

Where,

Hm = Mean relative humidity, expressed decimally,

$$C_{S2} = 0.904 + 0.0080\, (S / 0.8) + 0.088\, (S / 0.8)^2.$$

Where, S is the percentage of possible sunshine, expressed decimally.

3.7 DEVELOPMENT OF CROP COEFFICIENT VALUES (Kc) FOR OKRA

Evapotranspiration rates of various crops are related to ET rate from the reference crop by means of crop coefficients (Allen *et al.*, 1998). The K_c value relates to evapotranspiration of a disease free crop grown in large fields under optimum soil water and fertility conditions and achieving full production potential under the given growing environment. Differences in evaporation and transpiration between field crops and the reference grass surface can be integrated in a K_c value.

Factors affecting K_c include crop type, crop growth stage, climate, soil moisture. K_c is normally expressed as a function of time. Steps for computing of K_c include determination of total growing period of the crop and determination of K_c values for each growth stage. The growing period was divided into three distinct growth stages: initial, midseason and late-season. Weekly values of ET_c were estimated using lysimeter by the soil water balance approach. The Crop coefficient values at each crop stages were calculated for weekly periods by using the equation:

$$\mathbf{Kc=ETc/ETo}$$

Where,

ETc = Actual crop evapotranspiration

ETo = Reference crop evapotranspiration

The duration of crop with respect to different growth stages are shown in Table 3.2. The total length of crop growth stages were 93 days. The different growing stages of Okra were shown in Plates 3.11, 3.12 and 3.13.

Table 3.2 Length of growing stages (days) of Okra

Growth stages	**Duration**
Initial stage	First 3 Weeks (0-21 DAS)
Midseason stage	Next 8 Weeks (22-78 DAS)
Late season stage	Last 2 Weeks (79-93 DAS)

Plate 3.11 Initial stage of Okra

Plate 3.12 Midseason stage of Okra

Plate 3.13 Late season stage of Okra

3.8 OBSERVATION ON CROP YIELD

Plants from lysimeter were selected for observations on yield. Harvesting was started 40 days after sowing and continued at an interval of two days. The weights of fruits harvested were recorded and the total yield was expressed as kg/m^2. A close view of the yielding crop in final harvest stage is shown in Plate 3.14.

Plate 3.14 Close view of the yielding crop in final harvest stage

3.9 COMPUTATION OF CROP WATER USE EFFICIENCY AND WATER PRODUCTIVITY

3.9.1 Crop Water Use Efficiency

Crop water use efficiency is defined as the ratio of crop yield to the amount of water depleted by the crop in the process of evapotranspiration (ET).

$$Crop\ water\ use\ efficiency = Y/ET$$

Where,

Y = Crop yield

ET = Evapotranspiration

Water use efficiency is influenced by crop and soil management practices. The numerator of this formula, namely, crop yield can be changed appreciably by management practices. The evapotranspiration or denominator of the formula is more difficult for man to control because it is dependent on climate and availability of water for the crop.

3.9.2 Water productivity

The term water productivity denotes the production (of Okra) per unit of water applied.

Hence water productivity was calculated as;

$$water\ productivity = \ yield/water\ applied$$

Results and Discussion

CHAPTER IV

RESULTS AND DISCUSSION

For a particular region, reference crop evapotranspiration (ETo) estimation has a critical role in crop planning, water management and irrigation design. There are a number of methods available for estimation and measurement of ET. But only a very few scientific studies related to water management have been taken up in this humid tropical region. Hence this study estimated reference crop evapotranspiration using three empirical models which were found most suitable for Tavanur region in earlier studies and widely used in Indian conditions. A lysimetric water balance study was conducted in the field for determination of actual crop evapotranspiration (ETc). The crop coefficient (Kc) was estimated as the ratio of actual crop evapotranspiration to reference crop evapotranspiration. The results relevant to these aspects were discussed in the following subheads.

4.1 DETERMINATION OF PHYSICAL PROPERTIES OF SOIL

The physical properties of soil required for the lysimeter water balance study were determined and presented in Table 4.1.

Table 4.1 Physical properties of soil

Sl. No.	**Soil Properties**	**Values**
1	Coarse sand (%)	99.4
2	Fines (%)	0.6
4	Bulk density (g/cc)	1.63
5	Dry bulk density (g/cc)	1.52
6	Field capacity (%)	21.01
7	Permanent wilting point (%)	15.74
8	Available soil moisture content (%)	5.26

4.2 MEASUREMENT OF ACTUAL EVAPOTRANSPIRATION BY LYSIMETER (ETc)

A lysimeter water balance experiment was conducted at the eastern block of instructional farm, KCAET during 13thOctober - December 2017. The results obtained from the water balance study were given in Table 4.2. ETc represents the actual crop evapotranspiration measured weekly by using lysimeter.

Table 4.2 Actual evapotranspiration of Okra by lysimeter (ETc)

Weeks	**Applied water (mm)**	**Effective rainfall(mm)**	**Drainage (mm)**	**Change in soil water storage (mm)**	**ETc (mm)**	**ETc (mm/day)**
1st Week	21	4.8	8	11.41	6.39	0.91
2nd Week	21	0	5	4.18	11.81	1.68
3rd Week	21	6.3	5	10.75	11.54	1.64
4th Week	28	4.65	11	3.61	18.03	2.57
5th Week	28	0	9	-8.68	27.69	3.96
6th Week	28	0	0	3.26	24.74	3.53
7th Week	28	0	0	4.89	23.11	3.30
8th Week	28	0	0	8.15	19.85	2.83
9th Week	28	0	0	9.7	18.30	2.61
10thWeek	28	0	0	9.86	18.13	2.59
11thweek	28	0	0	11.54	16.46	2.35
12thweek	21	0	0	5.77	15.23	2.17
13thweek	21	0	0	7.4	13.6	1.94

The negative sign in column 5 of the above table indicates that the plants depleted water from the initial soil moisture content. On the other hand, the positive sign indicates that more water was stored in soil in excess of initial water content. From table it was found that ETc was highest during mid-season stage and the lowest during initial stages. A curve was constructed with cumulative ETc against crop growth period as shown in Fig.4.1.

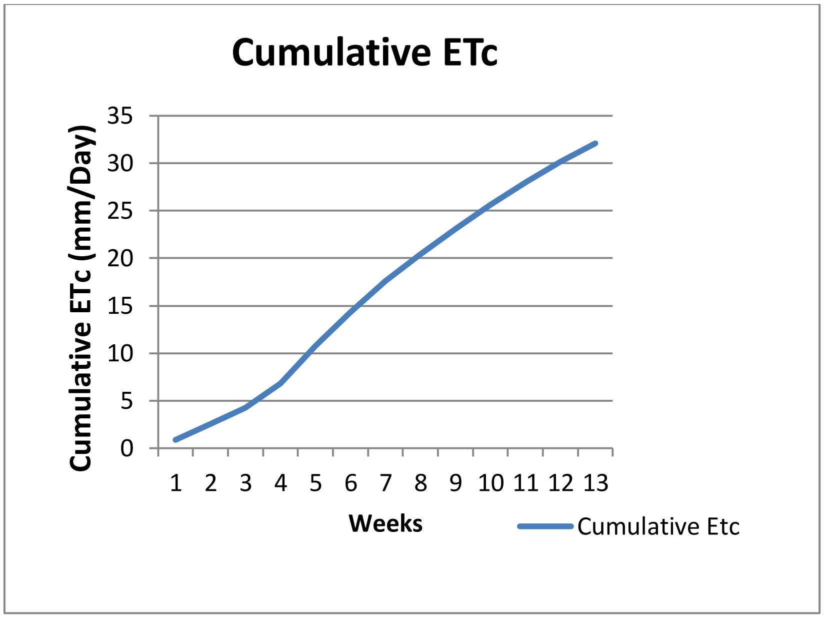

Fig.4.1 Cumulative ETc curve of Okra during crop growth period

It is evident from the above figure that initially ETc was low due to small size of crop, after that ETc increased with the increase of crop growth and development up to 75 days after sowing. After that crop growth was not occurred considerably. As a result, ETc trend was gradually increased. Finally, the total cumulative ETc was found 32.08 mm/day.

4.3. ESTIMATION OF REFERENCE CROP EVAPOTRANSPIRATION (ETo) USING EMPIRICAL MODELS

Reference evapotranspiration (ETo) is commonly computed from weather data since, the direct measurements are often very expensive and complicated. In this research reference crop evapotranspiration (ETo) was calculated using three empirical models which are most suitable for Tavanur region (Pravalika, 2017) and widely used in Indian conditions. They are Christiansen pan evaporation model (1968), FAO-24 Open pan model (1977) and FAO-56 Penman-Monteith model (1991).These three models are here after represented as CHM, OPM and PMM respectively for convenience. Out of the above models, one was combination model (PMM) and two were evaporation models (CHM and OPM). The weekly ETo estimated using the meteorological data for the period October – December 2017 by the three empirical models were presented in Table 4.3.

Table 4.3 ETo values obtained from different empirical models in mm/day

WEEKS	ETo CHM	ETo PMM	ETo OPM
1st Week (01-10-17 to 07-10-17)	1.66	2.55	1.57
2nd Week (08-10-17 to 14-10-17)	2.79	3.51	2.70
3rd Week (15-10-17 to 21-10-17)	1.69	3.40	1.57
4th Week (22-10-17 to 28-10-17)	2.14	4.20	2.02
5th Week (29-10-17 to 04-11-17)	3.74	4.29	3.64
6th Week (05-11-17 to 11-11-17)	2.22	3.82	2.19
7th Week (12-11-17 to 18-11-17)	2.33	4.08	2.18
8th Week (19-11-17 to 25-11-17)	2.82	4.35	2.74
9th Week (26-11-17 to 02-12-17)	1.93	3.90	2.01
10th Week (03-12-17 to 09-12-17)	1.61	4.51	1.71
11th Week (10-12-17 to 16-12-17)	2.03	3.37	2.14
12th Week (17-12-17 to 23-12-17)	2.77	5.60	3.31
13th week (24-12-17 to 31-12-17)	2.53	3.02	2.95

From the Table 4.3, it is clear that highest ETo values were obtained during the mid-season stage for all the three models and the lowest were obtained during the initial and late season stages. The maximum ETo values obtained were 3.74, 5.60 and 3.64 mm/day from CHM, PMM and OPM respectively. Christiansen and Open pan models gave nearly same values. The PMM method gave relatively higher value than those of other two methods. This is because calculation of ETo by using PMM method requires many climatic data, while in other methods ETo calculation is possible with the application of limited data. Variation of weekly ETo values determined by different empirical models were shown in Fig.4.2.

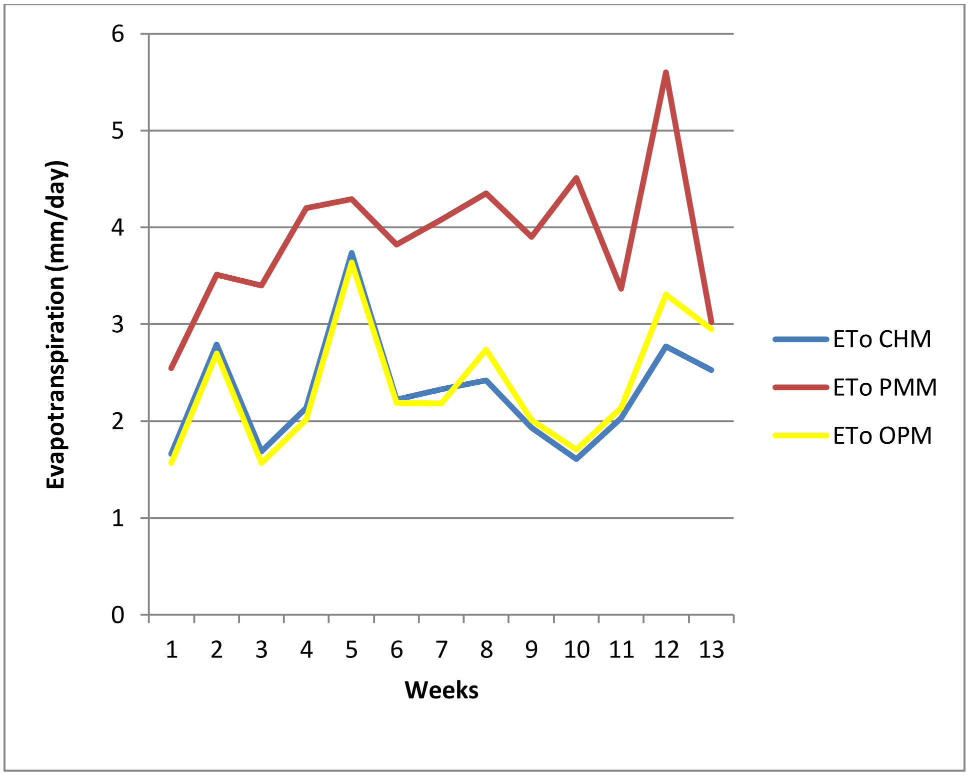

Figure 4.2 Variation of weekly ETo values by different empirical models

4.4 ETc AND ETo DURING CROP GROWING PERIOD

Reference evapotranspiration (ETo) and crop evapotranspiration (ETc) during the growing season for different empirical models were presented in the Fig. 4.3. In ETc curve, the fluctuation is regulated by crop growth and development, while in ETo curve the fluctuation is regulated by weather parameter values.

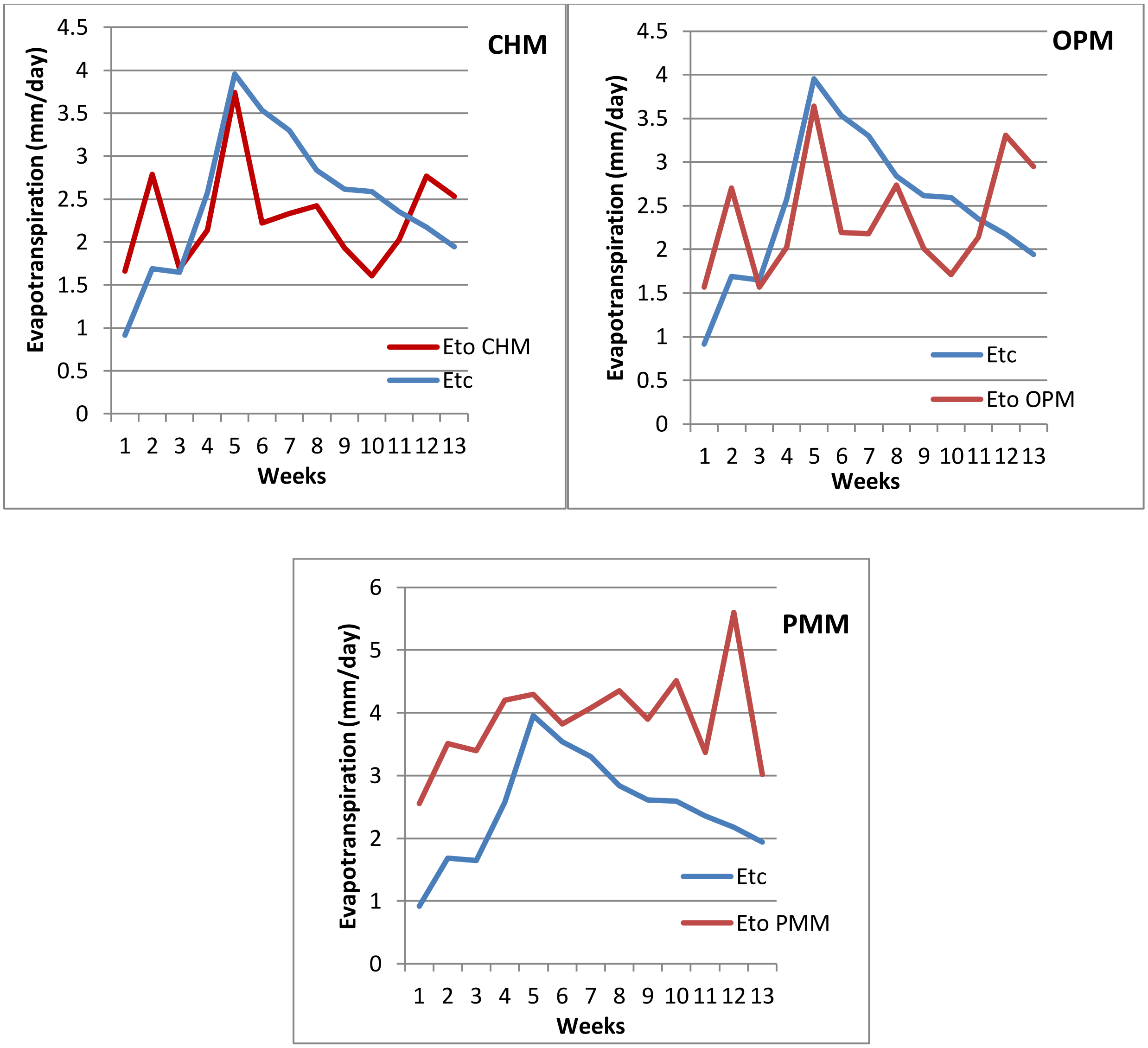

Fig.4.3 ETc and ETo during crop growing period

From the Fig 4.3, it could also be concluded that the methods CHM and OPM provided closer values with evapotranspiration obtained by direct measurements with lysimeter. However, PMM little bit deviated from the actual measured value. According to Smith (2002), Droogers and Allen (1992), FAO Penman-Monteith gives more consistent ETo estimates and has shown to perform better than other ETo methods in most of the regions. In this study PMM showed little bit variability.

4.5. DETERMINATION OF CROP COEFFICIENT (Kc) ACCORDING TO GROWTH STAGES

The crop growth stages were identified as initial, mid-season and late season stages for the calculation of crop coefficient (Kc). Table 4.4 presents crop evapotranspiration, reference evapotranspiration and crop coefficient values of Okra for different ETo methods.

Table 4.4 Crop coefficient values of Okra under different ETo methods

Weeks	Growth Stages	Weekly ETc (mm)	ETo For different method			Kc for different method			Weekly Avg. Kc	Avg. Kc
			CHM	PMM	OPM	CHM	PMM	OPM		
1	Initial season stage	0.91	1.66	2.55	1.57	0.55	0.35	0.58	0.49	0.63
2		1.68	2.79	3.51	2.70	0.60	0.48	0.62	0.57	
3		1.64	1.69	3.40	1.57	0.97	0.48	1.05	0.83	
4	Midseason stage	2.57	2.14	4.20	2.02	1.20	0.61	1.27	1.03	1.1
5		3.95	3.74	4.29	3.64	1.06	0.92	1.09	1.02	
6		3.53	2.22	3.82	2.19	1.59	0.92	1.61	1.37	
7		3.30	2.33	4.08	2.18	1.41	0.80	1.51	1.24	
8		2.83	2.82	4.35	2.74	1.17	0.65	1.03	0.95	
9		2.61	1.93	3.90	2.01	1.35	0.67	1.30	1.11	
10		2.59	1.61	4.51	1.71	1.60	0.57	1.51	1.23	
11		2.35	2.03	3.37	2.14	1.15	0.69	1.09	0.97	
12	Late season stage	2.17	2.77	5.60	3.31	0.78	0.38	0.66	0.61	0.65
13		1.94	2.53	3.02	2.95	0.76	0.64	0.65	0.69	

The trend of crop coefficient values of Okra for different ETo methods were shown in Fig.4.4. It is clear that at the initial stage crop coefficients was minimum, rose steeply to the point and continued and after that sharply fall to a certain point. The maximum kc value was found during the mid- season stage and the lowest was found during initial stages for all the three methods. This was because of the highest ETc value at midseason stage compared to respective ETo. The average Kc values obtained from CHM for intial, midseason and late season were 0.71, 1.31 and 0.77 respectively. The average Kc values obtained from PMM were 0.43, 0.73 and 0.51 and from OPM were 0.75, 1.3 and 0.66 for intial, midseason and late season respectively. The average Kc values of Okra obtained from different ETo models for initial, midseason and late season stages ranged from 0.43-0.75, 0.73-1.30 and 0.51-0.77 respectively. The average Kc values of Okra under different ETo methods for initial, midseason and late season were 0.63, 1.1 and 0.65 respectively.

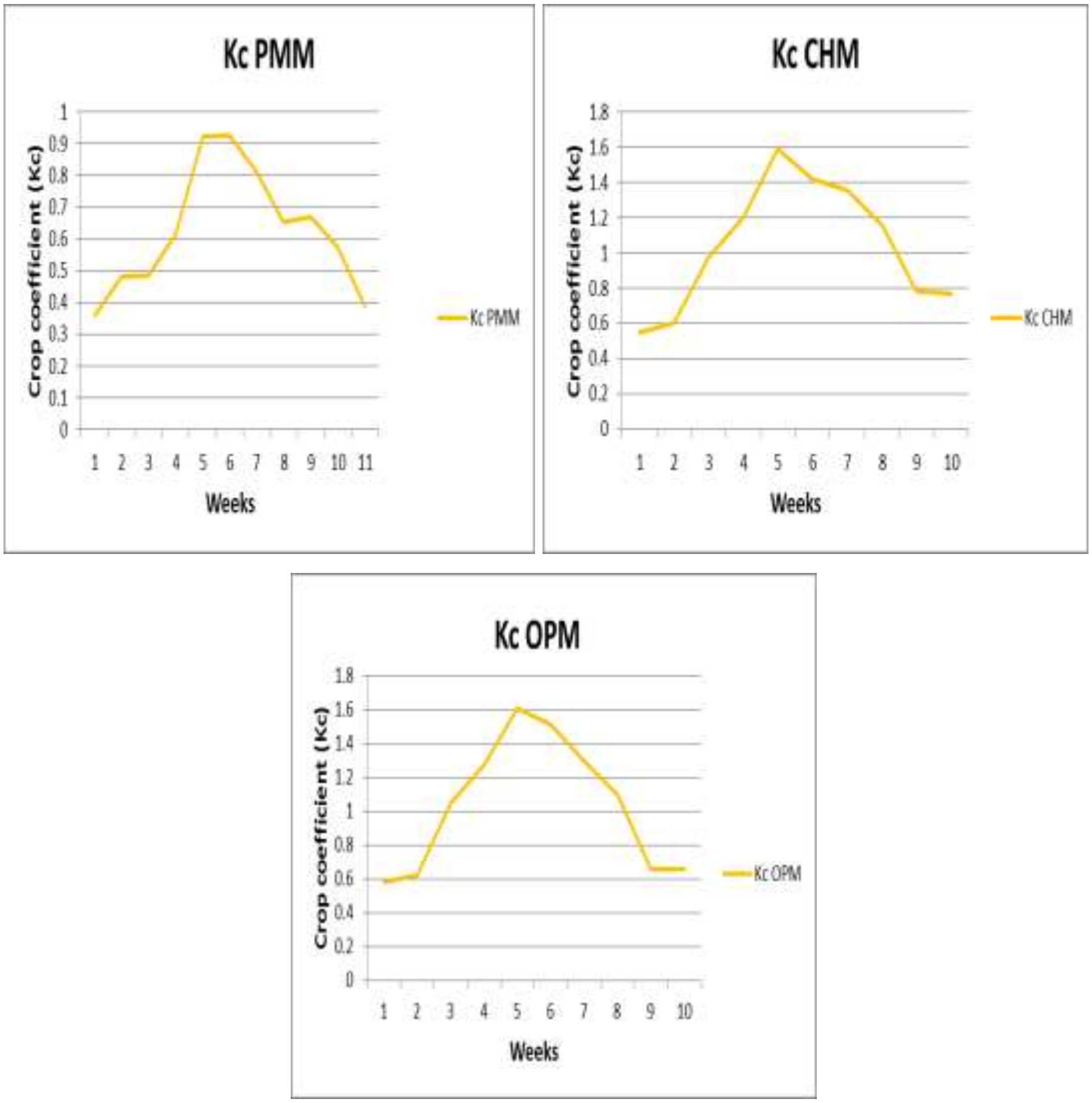

Fig.4.4 Crop coefficient values of Okra during crop growing period

The PMM method gave relatively lower kc value than those of other methods. This may be due to calculation of ETo by using PMM model requires many climatic data. The crop co-efficient values determined by this experiment, were found to vary to some extent from those recommended by FAO (Doorenbos and Pruitt, 1977). The FAO recommended values are, 0.38, 0.74 to 0.98, and 0.49 for initial, midseason, and late season stages of Okra respectively. FAO values are the generalized ones and recommended for use worldwide but those determined by this study are location specific. Another reason for this variation of K_c values might be the use of specific variety of hybrid Okra used in this experiment. However, locally determined K_c values are preferable to generalized standard values to estimate location specific crop evapotranspiration.

The crop coefficient values of Okra obtained from this study could be adopted as standard values for computation of water requirements of Okra for humid tropical regions. This will ensure better water use efficiency rather than depending on values available in literature for alternate locations.

4.6 CROP YIELD, WATER PRODUCTIVITY AND CROP WATER USE EFFICIENCY

4.6.1 Crop Yield

The data on crop yield was recorded for plants inside the lysimeter tank and is shown in Table 4.5. The total crop yield per unit area was recorded as 2.619 kg (Plates 4.1and 4.2).

Plate 4.1 Harvested Okra

Plate 4.2 View of Okra at maturity stage

Table 4.5 Yield of Okra per kg/m^2

Sl. No	Harvest date	Yield (kg/m^2)
1	01-12-17	0.162
2	03-12-17	0.171
3	05-12-17	0.168
4	07-12-17	0.170
5	09-12-17	0.154
6	11-12-17	0.18
7	13-12-17	0.162
8	16-12-17	0.150
9	18-15-17	0.137
10	20-12-17	0.175
11	22-12-17	0.164
12	23-12-17	0.151
13	24-12-17	0.133
14	26-12-17	0.180
15	28-12-17	0.187
16	30-12-17	0.175
Total Yield		**2.619**

4.6.2 Water Productivity

Water productivity refers to the fresh weight of fruit per unit of applied water.

Water productivity = Yield per m^2/Applied water (mm)

Yield of Okra = 2.619 kg/m^2

Water applied = 32.9 cm

Water productivity = 2.619/32.9

= 0.08 kg/m^2.cm

4.6.3 Crop Water Use Efficiency

Crop water use efficiency is defined as the ratio of crop yield to the amount of water depleted by the crop through the process of evapotranspiration (ET).

$$Crop\ water\ use\ efficiency = Y/ET$$

Where,

Y = Crop yield (kg/m^2)

ET = Evapotranspiration (cm)

$$\text{Yield of Okra} = 2.619\ kg/m^2$$

$$ET = 22.480\ cm$$

$$\text{Crop water use efficiency} = 2.619/22.48$$

$$= 0.116\ kg/m^2.cm$$

Summary and Conclusion

CHAPTER 5

SUMMARY AND CONCLUSION

The primary objective of the present research work was to develop crop coefficient data of Okra for the humid tropical region.Weekly water balance study was conducted in lysimeter to find the actual evapotranspiration (ETc) of Okra for the period October-December, 2017. The reference evapotranspiration (ETo) was estimated using the weekly values of meteorological data for the same period. ETo was estimated by three empirical models which were found most suitable for Tavanur region in earlier studies and were widely used in Indian conditions. They are Christiansen (1968) Pan Evaporation model, FAO-24 Open Pan (1977) model and FAO-56 Penman-Monteith (1991) model. The crop coefficient values of okra were calculated using the relation Kc=ETc/ETo. The water productivity and crop water use efficiency of Okra was also found in this study.

The average daily ETc values of the Okra crop were 1.41, 2.95 and 2.05 mm/day during the initial, midseason and late season stage respectively. The total ETc of Okra was found as 32.08 mm/day. The lowest seasonal ETc was observed in the initial stage and highest ETc was observed in the midseason stage. The ETc increased from initial stage to midseason stage and then decreased in late season stage. The average ETo values obtained from Christiansen model (CHM) were 2.05, 2.3 and 2.65 mm/day and those from Open pan model (OPM) were 1.95, 2.33 and 3.13 mm/day for the initial, midseason and late season stage respectively. The average ETo values from the Penman-Monteith for initial, midseason and late season were found as 3.15, 4.06 and 4.31 mm/day respectively. Among the three empirical models, Christiansen and Open pan models gave nearly same values, while ETo values obtained from PMM were little deviated from the other two models. However, PMM is considered to be the standard model for Indian conditions.

The crop coefficient values of Okra for PMM were 0.43, 0.73 and 0.51 for initial, mid-season and late season respectively. The Kc values for CHM were 0.71, 1.31 and 0.77 and for OPM were 0.75, 1.3 and 0.66 for initial, midseason and late season respectively. The maximum kc value was found during the mid- season stage and the lowest was found during initial stages for all the three models. The Kc values were increased from initial stage to midseason stage and then decreased in the late season stage. The average Kc values of Okra for initial, midseason and late season were found to be 0.63, 1.1 and 0.65 respectively. This estimated average Kc values of Okra vary considerably at all stages from those recommended by FAO (0.38, 0.74-0.98 and 0.49). The variations may be due to the location and environmental effects on crop growth and yield. However, the estimated location specific crop coefficient values are preferred to use in irrigation planning, estimation of crop water requirement and irrigation scheduling.

But it was also found that the Kc value obtained from FAO -56 Penman-Monteith model showed quite good agreement with the Kc values recommended by FAO. In the absence of direct measured data, the average crop coefficient value obtained in this study can be used for the estimation of evapotranspiration of Okra crop in the region. Thus it can be adopted as standard value for computation of water requirement of Okra in the humid tropical regions. This will ensure better water use efficiency rather than depending on values available in literature for alternate locations.

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Appendices

APPENDIX I

Physical properties of soil by core cutter method

Calculations

Weight of core soil (W) : 1480 g

Volume of core soil (V) : 908 cm^3

Weight of moisture container (W_1) : 334.5 g

Weight of moist soil + Moisture container weight (W_2) : 1806.5 g

Weight of dry soil + Moisture container weight (W_3) : 1704 g

Moisture content of soil (ω) : 7.48 %

Bulk density and particle density of soil were determined by using the following formulas

$$\text{Bulk density of the soil } (g/cm^3)\ \gamma = \frac{W}{V}$$

$$= 1480/908$$

$$= 1.63 \text{ g/cc}$$

$$\text{Particle density of the soil } (g/cm^3)\ \gamma_d = \frac{\gamma}{1+\omega}$$

$$= 1.63/(1+0.0748)$$

$$= 1.52 \text{ g/cc}$$

APPENDIX II

Sieve analysis calculations

IS Sieve	Particle size (mm)	mass of each sieve (g)	mass of each sieve + retained soil	mass of soil retained (g)	percentage on each sieve	cumulative percent retained	% finer
2 mm	2	359.5	1044.0	684.5	50.3	50.3	49.7
1mm	1	368.5	481.0	112.5	8.3	58.6	41.4
600 µ	0.6	332.0	433.0	101.0	7.4	66.0	34.0
425 µ	0.425	335.5	402.0	66.5	4.9	70.9	29.1
300 µ	0.3	344.5	476.0	131.5	9.7	80.6	19.4
212 µ	0.212	340.5	556.0	215.5	15.8	96.4	3.6
150 µ	0.15	333.5	351.0	17.5	1.3	97.7	2.3
75 µ	0.075	297.5	320.0	22.5	1.7	99.4	0.6
Final Sieve	<75 micron	256.0	264.5	8.5	0.6	100.0	0.0
Sum				1360.0			

APPENDIX III

Soil moisture constants using pressure plate apparatus

Samples	**Soil constants**	**Mass of container (g)**	**Mass of wet soil (g)**	**Mass of dry soil (g)**	**Moisture content (%)**	**Available water (%)**
1	FC	24.63	46.32	42.50	21.38	5.37
	PWP	27.48	55.60	51.72	16.01	
2	FC	22.50	51.14	46.24	20.64	5.16
	PWP	28.84	49.50	46.73	15.48	

APPENDIX IV

Soil moisture measurements

Weeks	Surface layer (10 cm)	((Mbi-Mei)/100)*(Ai*Di) (1)	Deep layer (10 cm)	((Mbi-Mei)/100)*(Ai*Di) (2)	Soil moisture storage (Δs)=(1)+(2)
1	16.93	0.15	11.10	-0.05	0.10
2	16.84	5.07	11.13	-3.05	2.02
3	13.73	3.76	13.00	-1.30	2.46
4	11.42	0.36	13.80	4.97	5.33
5	11.20	-3.89	10.75	-2.44	-6.33
6	13.59	4.11	12.25	0.36	4.47
7	11.07	1.22	12.03	1.68	2.90
8	10.30	0.81	11.00	1.63	2.44
9	9.80	1.91	10.00	1.63	3.54
10	8.63		9.00		

APPENDIX V

Estimated weekly average ETo by lysimeter

	Lysimeter								
Weeks	Applied water/ Grass (I) in mm	Drainage (D) in mm	Surface layer(10 cm)	$((M_{bi}-M_{ei})/100)*(A_i*D_i)$ (1)	Deep layer (10 cm)	$((M_{bi}-M_{ei})/100)*(A_i*D_i)$ (2)	Soil moisture Storage (Δs) Ly=(1)+(2)	ET=I-D±Δs	ETc Average
1	21	8	27	6.52	33	4.89	11.41	6.39	0.91
2	21	5	23	1.63	30	2.5591	4.1891	11.81	1.69
3	21	5	22	9.78	28.43	0.978	10.758	11.54	1.65
4	28	11	16	1.63	27.83	1.9886	3.6186	18.03	2.57
5	28	9	15	-16.3	26.61	7.6121	-8.6879	27.69	3.95
6	28	0	25	4.89	21.94	-1.63	3.26	24.74	3.53
7	28	0	22	3.26	22.94	1.63	4.89	23.11	3.30
8	28	0	20	4.89	21.94	3.26	8.15	19.85	2.83
9	28	0	17	4.89	19.94	4.8085	9.6985	18.30	2.61
10	28	0	14	4.89	16.99	4.9715	9.8615	18.14	2.59
11	28	0	11	3.3904	13.94	8.15	11.5404	16.46	2.35
12	21	0	8.92	-0.652	8.94	6.4222	5.7702	15.23	2.17
13	21	0	9.32	7.0416	5	0.3586	7.4002	13.59	1.94
14	21	0	5		4.78				

Estimated weekly average ETo by Christiansen Pan Evaporation model

		Christiansen (1968) Pan Evaporation model				
Weeks	Evaporation(mm)	CT2	CW2	CH2	CS2	PET
1	1.9	1.01	1.10	1.13	0.90	1.66
2	3.3	1.03	1.08	1.11	0.90	2.79
3	1.9	1.03	1.11	1.14	0.90	1.69
4	2.5	1.01	1.12	1.09	0.91	2.14
5	4.5	1.03	1.08	1.09	0.90	3.74
6	2.7	1.03	1.06	1.10	0.90	2.22
7	2.7	1.03	1.13	1.08	0.90	2.33
8	3.4	1.03	1.09	1.08	0.90	2.82
9	2.5	1.03	1.02	1.08	0.90	1.91
10	2	1.03	1.06	1.08	0.91	1.61
11	2.5	1.03	1.08	1.07	0.90	2.04
12	4.3	1.02	0.93	1.00	0.90	2.77
13	3.8	1.02	0.96	1.00	0.91	2.53

Estimated weekly average ETo by FAO-24 Open Pan method

	FAO-24 Open Pan (1977) Method		
Weeks	Evaporation (mm)	Kp	PET
1	1.9	0.825	1.57
2	3.3	0.816	2.69
3	1.9	0.827	1.57
4	2.5	0.810	2.02
5	4.5	0.809	3.64
6	2.7	0.814	2.10
7	2.7	0.809	2.18
8	3.4	0.806	2.74
9	2.5	0.807	2.01
10	2	0.858	1.71
11	2.5	0.859	2.15
12	4.3	0.770	3.31
13	3.8	0.777	2.95

Estimated weekly average ETo by FAO-56 Penman-Monteith model

		FAO-24 Penman-Monteith (1991) model					
Weeks	U2	Tmean	Δ	ϒ	e_a-e_d	Rn-G	ETo
1	0.715526934	27.1	0.282146506	0.067	0.14	11.36	2.55
2	0.868854135	27.95	0.288193935	0.067	0.34	15.56	3.51
3	0.613308801	26.75	0.279616503	0.067	0.18	15.86	3.40
4	0.562199734	27.25	0.283223633	0.067	0.36	19.86	4.20
5	0.868854135	27.9	0.28784197	0.067	0.46	19.36	4.29
6	1.073290402	27.65	0.286075111	0.067	0.49	16.26	3.82
7	0.459981601	26.95	0.281065089	0.067	0.25	19.76	4.08
8	0.817745068	28.05	0.288896464	0.067	0.34	19.46	4.35
9	1.584381069	26.85	0.280341755	0.067	0.48	15.56	3.90
10	1.124399468	26.95	0.281065089	0.067	0.42	21.06	4.51
11	0.868854135	26.95	0.281065089	0.067	0.36	14.56	3.37
12	3.092098538	25.8	0.272630139	0.067	0.96	19.56	5.60

CROP COEFFICIENT VALUES OF OKRA FOR THE HUMID TROPICAL REGION USING LYSIMETER

by

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ABSTRACT OF THE REPORT
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ABSTRACT

Local level calibration of crop coefficient (Kc) values is critical for regional level planning and allocation of water resources for irrigation. Hence, a research was conducted at the eastern block of instructional farm of Kelappaji College of Agricultural Engineering and Technology, Tavanur, during the month of October - December, 2017 to estimate the crop coefficient values of Okra for the humid tropical region. An improved crop variety - Varsha Upahar was used for the study. A lysimeter water balance study was conducted in the field for the determination of actual crop evapotranspiration (ETc). The reference crop evapotranspiration (ETo) was computed from the weather data using the three empirical models which were found most suitable for the humid tropical region of Tavanur in earlier studies and widely used in Indian conditions. The three models were FAO-56 Penman Monteith (1991) model, FAO-24 Open pan(1977) model and Christiansen pan evaporation (1968) model.

Among the three models, Penman-Monteith model gave higher ETo values than the other two models. However the other two models gave nearly same values. The seasonal cumulative ETc of Okra was found as 224.56 mm from the lysimeter water balance study. Then, crop coefficient values (Kc) were estimated as the ratio of actual crop evapotranspiration to reference crop evapotranspiration for different growth stages. The Kc values of Okra obtained from different ETo models for initial, mid-season and late season stages ranged from 0.43-0.75, 0.73-1.30 and 0.51-0.77 respectively. The maximum Kc value was found during the mid-season stage and the lowest was found during initial stage for all the three models. The Penman-Monteith model gave relatively lower Kc value than the other two methods. But it was found that the Kc value obtained from FAO-56 Penman-Monteith model (0.43, 0.73 and 0.51) showed quite good agreement with the Kc values recommended by FAO (0.38, 0.74-0.98 and 0.49). Therefore, the average crop coefficient values of Okra obtained in this study would be helpful for computing the water requirement and irrigation scheduling of Okra in the humid tropical region.