COMPARATIVE EVALUATION OF EVAPOTRANSPIRATION PARAMETERS IN A NATURALLY VENTILATED POLYHOUSE AND OPEN FIELD

By

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(2015 -18- 008)

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DECLARATION

I hereby declare that this thesis entitled **"Comparative Evaluation of Evapotranspiration Parameters in a Naturally Ventilated Polyhouse and Open field"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

Place: Tavanur **MADHAVI TULLURU**

Date : **(2015 -18- 008)**

CERTIFICATE

Certified that this thesis, entitled **“Comparative Evaluation of Evapotranspiration Parameters in a Naturally Ventilated Polyhouse and Open field”** is a record of research work done independently by **Mrs. Madhavi Tulluru (2015- 18- 008)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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EXTERNAL EXAMINER

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Date:

Madhavi Tulluru

Dedicated to
My husband
Mr.S. Sudheer Kumar

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SYMBOLS AND ABBREVIATIONS

CWR : Crop Water Requirement
% : Percentage
& : And
” : Second
‟ : Minute
= : equal to
° : Degree
°C : Degree Celsius
Atm : Atmosphere
Cu : Consumptive use
Dept. : Department
ET : Evapotranspiration
et al. : and others
ETc : Crop evapotranspiration
ETo : Reference evapotranspiration
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/ha.mm : kilogram per hectare millimeter

km/day : kilometer per day
L : Litre
l/day/plant : Liter per day per plant
L_1 : Lysimeter-1
L_2 : Lysimeter-2
L_3 : Lysimeter-3
LDPE : low density polyethylene
LEPA : Low energy precision application
Lph : Litre per hour
M : Metre
m^2 : Square metre
m^3 : Cubic metre
MAE : Mean absolute error
MJ/m^2/day : Mega joules per square meter per day
ML : Mini-Lysimeter
Mm : Millimeter
MSL : Mean sea level
PVC : Poly vinyl chloride
R^2 : Coefficient of determination
RH : Relative humidity
RMSE : Root mean square error
RRMSE : Relative root mean square error
S : Second
Sci. : Science
TDR : Time domain reflectometer
UV : Ultraviolet
viz. : Namely
WUE : Water use efficiency
M : Micron
Mm : Micrometer

Introduction

CHAPTER 1

INTRODUCTION

Water being a scarce resource, it is necessary to scientifically manage and judiciously use this natural resource to sustain life on earth. It is the greatest pre-requisite for developing the social and economical conditions of different sectors of the society. 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. Irrigation is the major contributor towards increasing the agricultural production at profitable level. It is necessary to optimize irrigation practices by applying water in the right quantities to suit to the crop water needs, thus avoiding wastage.

Irrigation scheduling is the process of determining when to irrigate and how much quantity of water to apply per irrigation. To schedule irrigation effectively, a farmer must know the atmospheric demand for surface water. In order to obtain profitable level of crop yield, soil water depletion level should not exceed the predetermined levels mainly during critical periods of crop. Application of excess or deficit amounts of water at the crop development stage causes crop damage and yield reduction.

Evapotranspiration is the major component of the hydrologic cycle, by which, most precipitation that falls on land surface returns back to the atmosphere. Globally, about 60 percent of yearly precipitation falling over the land surface is used by ET (Irmak, 2009). The evapotranspiration requirements of agricultural crops is an important component in irrigation planning, water resources management, and environmental assessment. Accurate estimation of evapotranspiration is considered a most important part of irrigation system planning and designing, and accurate spatial determination of ET is crucial to achieving sustainable agriculture.

Evapotranspiration requirements at critical stages of growth of crops are important to decide when irrigation is to be applied to the crops. Transpiration may stop when evapotranspiration value exceeds the plant water availability through precipitation or irrigation. Therefore, accurate measurement of ET, knowledge of precipitation and soil moisture storage capacity can provide an insight to the correct quantity of water to be applied through irrigation.

Crop evapotranspiration (ET_c) is the most important component regarding water balance in arid and semi-arid areas and is a key factor for computing proper irrigation scheduling and for increasing water use efficiency in irrigated agriculture. ET_c differs from the reference crop evapotranspiration (ET_o), since the ground cover, canopy properties and aerodynamic resistance of the crop are different from grass. The actual rate of water uptake by the crop from the soil in relation to its crop evapotranspiration (ET_c) is influenced by whether, the available water in the soil is adequate or whether the crop will suffer from stress induced by water deficit.

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). The K_c value relates to evapotranspiration of a disease free crop grown in large areas under optimum soil water and fertility conditions and achieving full production potential under the given growing environmental conditions (Allen *et al.*,1998). It serves as a combination of the physical and physiological differences between crops and the reference grass. Differences between evaporation and transpiration of field crops and the reference grass surface can be integrated in a single K_c value. Factors affecting K_c include crop type, crop growth stage, climate and soil moisture. Crop coefficient is normally expressed as a function of time. Therefore, most of the authors have reported values of K_c as a function of days after transplanting which helps to denote K_c for different crop development stages. The K_c values represent the crop specific water use and are required for exact estimation of irrigation requirements of various crops.

One of the challenges of determining crop water requirement and other output components of the soil water balance are that the parameters are very volatile and difficult to measure at field level under rain-fed condition. However, this challenge can be overcome by the use of lysimeters. The first report on the use of lysimeters was from France in 1668 where, La Hire used lead containers filled with soil to observe water loss (Aboukhaled *et al.*, 1982). A lysimeter is a device which enables the isolation of a soil column for the purpose of studying water inflow and outflow in the system. Field studies using lysimetric data acts as an accurate tool in the determination of water balance variables, representing the existing field conditions. Lysimeters if designed to adequately approximate the physical system, can be used as a research tool to study plant-water relationships.

Mini- Lysimeters are characterized by reduced soil volume (less than 1 m^3), and have been recently adopted due to reduced installation and management costs and good accuracy of measurement. Mini-lysimeters have the advantages that they permit the measurement of the evaporative flux from smaller areas. It creates fewer disturbances to the cropped area during installation. Non-weighing mini-lysimeters are used to estimate ET by computing the water balance. The water balance involves measuring all the water inputs and outputs to and from the lysimeter and the change in storage over a stipulated period of time. The lysimeters provide viable estimates of ET_c for longer periods such as weekly or monthly.

Reference evapotranspiration can be estimated by several methods. Class A pan method is the one of the most important method worldwide because of its simplicity, relatively low cost, and provides daily evapotranspiration estimates. Greater precision can be obtained when it is used for periods of at least five days. However, its application inside greenhouses is still a matter of controversy. There is no conclusive result of Pan Coefficient (K_p) prediction studies inside greenhouse. In addition, some producers consider leaving an unproductive area of approximately 10 m^2 occupied by the class A pan inside the greenhouse, not viable. Because of the large area occupied by a class A pan, alternative methods have been sought to estimate ET_o inside greenhouses. Among these methods, the reduced size Class A Pan deserves special attention. Small pans have been developed and evaporation from smaller pans is generally highly correlated with Class A pan.

Previous studies have illustrated the linear relationship between crop water requirement and pan evaporation both inside and outside greenhouses. Difference between the variations of crop evapotranspiration and pan evaporation inside the greenhouse is caused by the shading of pan in the later period when the crops grow taller than the location of pan. Hence it is required to assess the applicability of pan evaporation data for ET_o determination in poly houses.

To calculate crop evapotranspiration (ET_c) indirectly from metrological data, we should estimate ET_o and K_c. There are several theoretical and empirical equations developed of which the most common empirical equations are Penman-Monteith method, Radiation method, Hargreaves method, Thornthwaite method, Blaney-Criddle, Priestly-Taylor method, Makkink method and Artificial Neural Network method. Many of these have been derived empirically through field experiments, or from theoretical approaches. A major complication in modeling ET is the requirement for meteorological data that may not be easily available inside the polyhouse (eg. solar radiation).

The total area covered under protected cultivation in our country is 30,000 hectares (Shweta *et al.* 2014). Hi-tech horticulture is gaining momentum in recent years and most of the crops are grown under protected cultivation. Naturally ventilated polyhouses are specially recommended for Kerala conditions for horticultural crops. Optimal irrigation is quite essential for protected vegetable cultivation. Okra (*Abelmoschus esculentus)* or ladies finger is an important vegetable of the tropical countries and most popular vegetable crop in India. The total area under okra cultivation in India is reported to be 501 thousand ha and the production is estimated as 5783 thousand tons during 2016-2017 (Indian Horticultural data base, 2017).

Studies on the water requirement of horticultural crops in polyhouses are scarce and irrigation is mainly scheduled according to farmer's experience, despite the water scarcity. Canopy development and management of some polyhouse horticultural crops is quite different from that outdoors. Difference in plant spacing, crop height and aerodynamic properties may affect the crop coefficient values. Moreover, the measure of diffuse radiation in polyhouse is higher than that outdoors.

Complete data on meteorological parameters inside poly houses is very rarely obtained and it causes lot of limitations in applying indirect ET_0 estimation methods based on climatological data. Hence investigations into the direct determination of evapotranspiration and crop coefficients of vegetables under greenhouse cultivation are essential.

Therefore, this study is proposed to use lysimetric data to determine the evapotranspiration parameters inside naturally ventilated poly house and open field and to compare the values with indirect methods. The study also attempts to compare poly house and open field evapotranspiration.

The specific objectives of the study are:-

1. Determination of ET_0 and ET of Okra in naturally ventilated polyhouse and open field using lysimeters.
2. Development of crop coefficient curves for okra.
3. Comparison of direct measurement by lysimeters with indirect methods of ET estimation.
4. Comparison of evapotranspiration parameters in polyhouse and open field conditions.

Review of Literature

CHAPTER 2

REVIEW OF LITERATURE

The most significant factor in agriculture is the water availability. Through precipitation and irrigation, water is provided to the crops naturally but farmers must resort to irrigation when these supplies prove to be inadequate for crop use. Determination of evapotranspiration (ET) is a major component of agricultural water management, in local and regional water balance studies and hydrological modelling. Experimentally determined crop coefficient values and crop water requirement are important for proper irrigation scheduling, efficient water management, optimum yield and profit. In polyhouses, micro climate and canopy development vary significantly from open field and ET estimation is important for climate and irrigation control. Non-weighing mini-lysimeters are used to estimate ET by computing the water balance and have been used for many years to determine and study water use, to calibrate reference ET methods for a local area, and to develop crop-coefficient curves for specific crops.

Some of the literature relevant to the study are reviewed and presented under the following sub headings.

2.1 SIGNIFICANCE OF EVAPOTRANSPIRATION (ET)

Evapotranspiration (ET), also known as consumptive use or actual evapotranspiration (AET), is the sum of the amount of water returned to the atmosphere through the process of evaporation and transpiration (Hansen *et al*., 1980). It is the most important processes in the hydrological cycle for irrigation planning and water management (Allen *et al*., 1998). 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). Though it is vital that the ET used by growers is as accurate as possible for both economic and environmental purposes, its determination is difficult in practical field situations.

The efficient use of water in any sector of human life has become more and more important in our daily lives, particularly in arid and/or semi-arid condition where water resources have become gradually scarce. In irrigated agriculture this part becomes more important because worldwide, agriculture is the primary user of diverted water, reaching a quantity that exceeds 70–80 per cent of the total water capital in the arid and semiarid zones (Fereres and Soriano, 2007).

Er-Raki *et al*. (2007) had eported that one of the most important concepts regarding water balance in arid and semi-arid areas is crop evapotranspiration (ET_c) which is a key factor for determining proper irrigation scheduling and for improving water use efficiency in irrigated agriculture. Accurate determination of evapotranspiration component is considered as a major part of irrigation system planning and designing but, accurate spatial determination is crucial to reach sustainable agriculture.

Irmak (2009) had explained that evapotranspiration (ET) is the major component of the hydrologic cycle, given that most precipitation that falls on land is returned to the atmosphere. Worldwide, about 60 per cent of yearly precipitation falling over the land surface is consumed by ET. Determination of ET is used for crop production, water resources management, and environmental assessment. In agriculture, accurate estimation of ET is important for effective and efficient irrigation management.

2.2 REFERENCE CROP EVAPOTRANSPIRATION (ET_o)

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. Allen *et al*. (1994) had 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_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 (Dingman, 1994; Allen *et al*., 1998). It is important to provide accurate amount of water through irrigation. More or less water at the incorrect stage of crop development can damage the crop and reduce yield.

Allen *et al*. (1998) had reported that reference crop evapotranspiration is independent of crop type, crop development, and management practices. Relating evapotranspiration to a specific surface provides a reference to which evapotranspiration from other surfaces can be related. ET_o values computed from different locations or in different seasons are comparable as they refer to the evapotranspiration from the same reference surface. As a result, ET_o is a climatic parameter and can be computed from weather data. ET_o expresses the evaporating power of the atmosphere at a specific surface and time of the year and does not consider the crop characteristics and soil factors.

Reference crop evapotranspiration (ET_o) is one of the major hydrological component for scheduling irrigation systems, preparing input data for hydrological water balance models, and computing actual evapotranspiration for a region. It is a measure of evaporative demand of atmosphere and dependent on climatic factors, but independent of crop type, crop development and management practices (Xu and Singh, 2005).

According to Michael (2008), the profitable value associated by irrigating with the proper amount of water at the right time is significant. Consumptive crop water use is a function of the crop growth stage and reference evapotranspiration (ET_o). Consumptive crop water use for a particular crop is determined from the reference evapotranspiration, requirement of a standard crop under the applicable climatic conditions, and a crop factor relating to the growth stage of that particular crop. As the quantity of water used by plants for metabolic processes is insignificant (less than 1 per cent), seasonal Cu values are useful in scheduling irrigation, and are obtained by adding the daily ET values of entire crop season. Peak period Cu is particularly useful for irrigation system design, as ET, K_c and Cu are also affected by crop type, plant growth stage and weather conditions. A good estimate of crop evapotranspiration plays an important role in accurate determination of crop water requirements for proper irrigation scheduling (Rowshon *et al.*, 2013).

2.3 FACTORS EFFECTING EVAPOTRANSPIRATION

Plant factors affecting transpiration are the crop size, shape, surface characteristics as well as stomata aperture of leaf, leaf density and spatial structure (Hirasawa, 1995). The most important weather parameters affecting evapotranspiration are radiation, air temperature, humidity and wind speed. Several methods have been developed to compute the evaporation rate from these parameters.

The crop type, variety and development stage should be considered when computing the crop evapotranspiration from large, well-managed fields. Differences in resistance to transpiration, crop height, crop roughness, ground cover and crop rooting habits result in different ET rate in different types of crops under unique environmental circumstances. Crop evapotranspiration under standard conditions (ET_c) refers to the evaporating demand from crops that are grown in large fields under optimum soil water, excellent management and environmental conditions, and achieve full production under the given climatic conditions (Allen *et al.*, 1998).

Alexandris and Kerkides (2003) had reported that the process of water vapour removal largely depends on wind speed which transfers great quantities of air from and to the evaporating surface. When vaporizing water, the air above the evaporating surface becomes steadily saturated with water vapor. If this air is not continuously replaced with drier air, the gradient water vapour and thus evapotranspiration rates decrease. They also reported that the combined influence of meteorological factors affects evapotranspiration rate.

An accurate estimation of ET includes integration of a number of factors such as crop characteristics and development stage, weather parameters, environmental conditions and management practices (Kjaersgaard *et al*., 2008). Shekhar (2012) had explained evapotranspiration (ET) more broadly as a need of hour because in context of climate change, as the average temperature is rising, certainly the evaporative demand is shooting up. The different models for estimating ET differs in the effect of specific meteorological parameters on ET demand. The change in temperature causes change in other parameters such as humidity, wind speed, and vapour pressure which directly changes ET. In this study, ten years (2002-2011) weather data taken from Ozone unit, Indian meteorological Department, Banaras Hindu University (BHU), Varanasi, has been analyzed for the change in temperature, wind speed and solar radiation.

2.4 POLYHOUSE MICROCLIMATE AND EVAPOTRANSPIRATION

Mears (1990) had stated that it is essential to provide a warm atmosphere in cold climate inside the polyhouse which is possible with correctly designed climate control system. It is able to get better plant growing conditions under extensively warm climatic conditions. Implementation of modern technology in arid conditions will lead to increased potential for production of high value plants and materials. Protection cultivation is also used for the potential benefit of increasing plant productivity per unit water consumption which is significant in many areas where water sources are inadequate.

The main aim of a polyhouse is to raise plants, and therefore high transmission of solar radiation in the wave band 400-700 nm is necessary to increase the photosynthesis rates. The amount of structural material and the properties of the cladding material will control the rate of incident radiation transmitted to the plants. All the radiation trapped inside the greenhouse will add to the possible elevation of the greenhouse temperature above that of the outside air. The better the insulation properties of the polyhouse, better will be the elevation, although as universal rule, those cladding material that may be chosen for good quality thermal resistance will also tend to be less good at admitting radiation for plant growth (Day and Bailey, 1999).

The use of greenhouses in arid regions decreases crop water requirement by reducing evapotranspiration. The plastic cover utilized on these structure changes locally the radiation balance and creates an obstacle to moisture losses. As a result evapotranspiration is decreased by 60 to 85 per cent compared to outside the greenhouse (Fernandes *et al*., 2003) which may lead to clear reduction in water demand when compared to open field farming. Thus greenhouse farming provides a way of increasing crop water use efficiency.

According to Singh and Kalia (2005) every protected structure has its own limitations and advantages. The basic benefit is the extra protective shelter restricting or minimizing the exposure of crops to various adverse factors, which are high in open conditions. The application of chemicals for controlling biotic pressure is also low under protected structures which results in production of high quality vegetables for human use. Naturally ventilated greenhouses are the protected structures where no heating or cooling devices are provided for climate control. They are simple and medium cost greenhouses, and can be efficiently used for growing year round crops of 8–9 months duration. These structures are having a hand operated normal ventilation system when it is essential (Singh and Kumar, 2006).

Neelam *et al*. (2010) had carried out a study to analyze the effects of climatic variability on evapotranspiration. The objective was achieved through the use of internet based technology. The polyhouse has a direct effect on air temperature, and relative humidity and an indirect effect on soil temperature and soil moisture inside the polyhouse. Web enabled automatic weather station having sensors for real time on line measurement of soil temperature, soil moisture, ambient temperature, humidity, leaf wetness and solar insulation was installed inside the polyhouse. Capsicum was transplanted inside the polyhouse and crop evapotranspiration was estimated. The system also allows transmission of process parameters, including sending SMS on a mobile phone. The conception compasses data acquisition through a sensor network, data storage, post processing and online transmission of data to multiple users logged on to web-browsers. Further, managing of process parameters of a polyhouse, control of pumps, accessories and ventilators in real time was also feasible. From, this study it was concluded that the total crop water prerequisite of capsicum inside polyhouse was about 20-40 per cent less than outside the polyhouse.

Production of vegetable crops under protected conditions provides high water and nutrient use efficiency under varied agro climatic conditions. This technology has good potential especially in peri-urban areas adjoining to the major cities which are fast growing markets of the country, since it can be profitably used for growing high value vegetable crops like, tomato, cherry tomato, colored peppers, parthenocarpic cucumber, healthy and virus free seedlings in agri-entrepreneurial models (Singh *et al*., 2010).

The basic prerequisite for implementing polyhouse technology is to depend on the selection of appropriate design based on the climatic conditions, market availability and the type of vegetable crop. Under arid and semi arid conditions maximum ventilation up to 40–50 per cent is required to make the structure efficient and successful to raise vegetable crops. Under extreme hot periods rooftops of the greenhouses should be covered with shade nets allowing a space between the shade net and roof surface for air movement. Such greenhouses can be equipped with low-pressure drip irrigation system to make them energy efficient ecofriendly model (Singh and Hasan, 2011).

By using protected structures, it is also possible to raise an offseason and long duration vegetable crop of high quality (Sabir and Singh, 2013). The total area covered under protected cultivation in our country is 30,000 hectares (Shweta *et al.,* 2014). Hi-tech horticulture is gaining momentum in recent years and most of the crops are grown under protected cultivation.

2.5 ROLE OF LYSIMETERS IN WATER BALANCE STUDIES

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 (Chow, 1964).

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 (Aboukhaled *et al*., 1982).

In a Lysimeter, a soil column can be separated from the adjoining fields using a container of normal shape and planted with crop. The water input to grow the crop can be calculated and the crop water use and other output variables of the soil water balance (runoff, deep percolation and moisture retained in the soil column) can also be computed. The lysimeter tank could be of any dimension, but

Clark and Reddell (1990) had noted that depth and the surface area of the lysimeter tanks are to be large enough adequately to minimize plant root limitations.

Mini-lysimeters have greater advantages in that they permit the measurement of the evaporative flux from smaller areas, create fewer disturbances to the environment during installation, and are considerably cheaper to construct and install. Mini-Lysimeters (ML), characterized by reduced soil quantity (less than 1 m^3), have been recently accepted due to the reduced installation and managements costs and good accuracy of measurements (Oke, 2004).

Field studies using lysimetric data acts as an accurate tool in the determination of water balance variables, representing the existent 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).

2.6 COMPUTATION OF ET_o AND ET_c USING LYSIMETERS

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).

Orgaz *et al*. (2005) had conducted a study to determine the water requirement of four most important horticultural crops grown in an unheated plastic greenhouse using drainage lysimeter in Almeria, Spain. Drainage lysimeters were used to compute the seasonal evapotranspiration (ET) of four crops and it was associated with reference evapotranspiration (ET_o). Crop evapotranspiration (ET) and grass or reference evapotranspiration (ET_o) were calculated on weekly basis in the lysimeters using the soil water balance approach. TDR probes were installed in each crop lysimeter at 4 locations for measuring the volumetric soil water content in the lysimeters. Soil water content was also measured in four locations in the grass lysimeter. Drainage from the lysimeters was collected daily and applied irrigation water was calculated with a water meter. From the ratio between ET and ET_o values the Crop coefficient values (K_c) were calculated for weekly periods.

Ali and Rehman (2016) had conducted a study on the design and construction of low-cost raised-bed drainage lysimeter for crop water hydrological studies and relations. Collection of complete data of all the parameters of water balance equation was possible for one week or 10 days duration with the help of a non-weighing lysimeter. ‘Bangladesh Institute of Nuclear Agriculture’, Bangladesh has designed and constructed a non-weighing gravity type lysimeter system with eighteen boxes at the experimental farm. Each lysimeter box is equipped with percolate collector. The percolation collector (bottom runoff outlet pipe) was placed at the bottom of the lysimeter box maintaining a slope of 5 per cent towards the outlet. The percolation amount (subsurface runoff) can be collected and measured. Evapotranspiration was determined from water balance equation by accounting effective rainfall, run-off, irrigation, storage and deep percolation.

2.7 DEVELOPMENT OF CROP COEFFICIENT CURVES

Haman *et al*. (1997) had used drainage lysimeters to compute ET and develop K_c for two varieties of young blueberries at Florida. They used cylindrical tanks as lysimeters (1.6 m diameter and 1.8 m deep) equipped with permeable plates to remove drainage water. The ET_c in their study integrated transpiration and evaporation as that from the surface wetted by the irrigation system, but did not contain water loss from the grassed alleys. They noted that the computed K_c was different from the standard K_c but it provides the actual crop water use. Although K_c for both the varieties followed the same common trend, K_c values for the two varieties were dissimilar from each other. Differences in K_c values of the two varieties were attributed to the differences in plant development.

The K_c values represent the crop specific water use and is required for accurate estimation of irrigation requirements of different crops in a specific area. Development of K_c curves `involves determination of total growing period of the crop, identifying the length of different growth stages, and determination of K_c values for each growth stage. However, K_c cannot be measured directly, but is estimated as a ratio. While ET_o can be estimated using one of several available methods, ET_c can be estimated by a lysimeter study (Gratten *et al*., 1998).

Simon *et al*. (1998) had conducted a study to develop crop K_c values 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 K_c were also discussed. They found that K_c during a wet season (K_c =1.13 to 1.41) was superior than during a dry season. (K_c = 0.73 to 0.94). They reported that the differences between the wet and dry season K_c is due to the lower ET_o during the wet season. Mean K_c for maize was found to be greater than the reported values by Doorenboss and Pruitt. As a result, the authors pointed out on the importance of developing regional K_c values for proper irrigation scheduling.

Ko *et al*. (2009) had conducted a study to determine the growth-stage-specific Kc and crop water use for cotton (*Gossypiumhirsutum*) and wheat (*Triticumaestivum*). Lysimeters were used to measure crop water use and local weather data were used to compute the reference evapotranspiration (ET_o). Six lysimeters were located in the center of a 1ha field beneath a linear-move sprinkler system equipped with low energy precision application (LEPA). Seventh lysimeter was installed to measure reference grass ET_o. Determination of crop water requirements, K_c, and comparison to existing FAO K_c values were done over a 2-year period on cotton and a 3-year period on wheat. Seasonal total amounts of crop water use ranged from 689 to 830mm for cotton and 483 to 505 mm for wheat. The K_c values determined over the growing seasons varied from 0.2 to 1.5 for cotton and 0.1 to 1.7 for wheat. Some of the values corresponded and some did not correspond to those from FAO-56. Development of regionally based and growth-stage-specific K_c helps in irrigation management and provides precise water applications for Uvalde region

Fisher (2012) had conducted experiments on lysimeters to measure and study water use, and to develop crop-coefficient functions necessary in estimating ET. Lysimeter data were used for computing crop-water use of Cotton under local environmental conditions, and it ranged from 2mm/d to 8 mm/d. For each year, K_c values in the early season ranged from 0.2 to 0.6 and from 1.1 to almost 1.3 during the peak period. The K_c curves varied greatly among years, indicating large differences in crop growth patterns among years.

Fifteen non-weighing reinforced concrete lysimeters were used to grow alfalfa (*Mcdicago sativa*) and grass *Cynodondactylon*) as reference crops, and date palm (*Phoenix dactylifera*) as an experimental crop to obtain the daily water requirements and crop coefficient throughout the productive cycle of date palm. The experimental site was located at the experimental station of the Centre for Date Palm and Dates in Al-Hassa, Saudi Arabia in a sandy loam textured soil. 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 per 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 reduced to 5.42 mm/day in September at the end of harvest. The date palm crop coefficient was not constant throughout its productive cycle and it ranged from 0.74 to 0.91 according to crop growth stages. The average crop coefficient for the date palm productive cycle through the whole year was 0.83 (Dewidar *et al*., 2015).

2.8 COMPARISON OF EVAPOTRANSPIRATION MEASURED BY LYSIMETERS WITH INDIRECT METHODS

Green *et al*. (1984) had conducted a study to compare evapotranspiration (ET) data computed using two independent measurement techniques, and to compare measured ET with ET estimates computed using a commonly-applied formula. The measurements were made in a mixed-pasture paddock near Palmerston North. One set of ET measurement was made using a lysimeter with surface area $2m^2$ and a soil depth of 1 m. The lysimeter had a suction-operated drainage method at its base. Other set of ET data was obtained using the Bowen ratio-energy balance technique. Daily ET estimates were made with the Priestley-Taylor formula, using measured net radiation and air temperature values. The daily ET for well watered full-cover pasture measured by the lysimeter on rain-free days was in good arrangement with the ET measured using the Bowen ratio-energy balance technique. Daily measured ET values by the lysimeter highly correlated with Priestley-Taylor estimates, the agreement was even improved over longer periods.

Kashyap and Panda (2001) had conducted a study to evaluate the performance of the climatologic methods such as Penman, FAO-Penman, FAO-Corrected-Penman, 1982-Kimberly-Penman, Penman-Montieth, True Radiation, Priestly-Taylor, FAO-Radiation,Hargreaves and FAO-Bleny-Criddle in estimating the ET_o values as compared to the lysimeter-measured values .Root mean square error and coefficient of determination was estimated to compare the methods adopted. The Penman-Montieth equation gave the best result, with the highest value of coefficient of determination (R2 =0.91).

Xu and Chen (2005) conducted study to evaluate seven evapotranspiration models and their performance in water balance studies by using lysimeter measured data. Out Of the seven evapotranspiration models, three models calculate actual evapotranspiration directly using the balancing relationship approach, i.e. the CRAE model of Morton, the advection–aridity (AA) model of Brutsaert and Stricker, and the GG model of Granger and Gray. Four models calculated initial potential evapotranspiration and then actual evapotranspiration by considering the soil moisture condition. Two of the four potential evapotranspiration models belong to the temperature-based category, i.e. the Thornthwaite model and the Hargreaves model, and the other two models are radiation-based category, i.e. the Makkink model and the Priestley–Taylor model. The results show that, for the calculation of actual evapotranspiration, the GG model and the Makkink are highly correlated with lysimeter measurements than the other models.

Lopez-Urrea *et al*. (2006) had conducted a study to test evapotranspiration models with lysimeter observations in a semiarid climate. FAO-56 Penman–Monteith, FAO-24 Corrected Penman (I) and (II), FAO-24 Blaney–Criddle, FAO-24 Radiation and Hargreaves method were used in the study. It was concluded, that FAO-56 Penman–Monteith method was the most accurate, when compared to lysimeter measurements. The Hargreaves equation was the second most precise, even in its simplicity. The FAO-24 Radiation method also gave good performance, although it produced a small overestimation. The FAO-24 Penman (I) and (II) methods, and especially the FAO-24 Blaney–Criddle method significantly overestimated the lysimeter measurements, while the Penman equation considerably underestimated ETo.

Mini-Lysimeters (ML) were 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 micrometeorological algorithm of Penman –Monteith. Data produced by the ML has been compared with Penman-Monteith equation. Results indicated that the two methods are closer throughout March than August though all the numerical indexes, as root mean square error (RRMSE), mean absolute error (MAE) and correlation R^2 gave similar results in August and March. The good results of statistical indices represent the same results of lysimeters and Penman-Monteith to different daily meteorological factors (Parisi *et al.*, 2009).

Lysimeters are considered for standard evapotranspiration (ET) measurements. The Bowen ratio-energy balance (BREB) is a micrometeorological technique used to estimate ET due to its simplicity, robustness, and cost. The

Bowen ratio-energy balance technique accurately measured ET in semiarid conditions compared with lysimeter measurements. However, Bowen ratio-energy balance method overestimated daily and hourly ET got from the lysimetric measurements by 15 and 14 per cent, respectively (Unlu *et al*., 2010).

Accurate estimates of reference evapotranspiration (ET_o) is essential for irrigation design and scheduling. Numerous empirical methods for computing ET_o exists, but their correctness under different environmental circumstances is undefined. Greater uncertainty occurs under greenhouse conditions because these approaches were designed to relate to field situations, and greenhouses have an effect on the temperature, moisture and wind, etc. In this study, the results of 13 different common daily ET_o estimation methods, namely FAO56 Penman – Monteith, Hargreaves-Samanı, FAO-24 Blaney-Criddle, FAO-24 Radiation, Priestley-Taylor, Makkink, Turc, Linacre, Jensen-Haise, Copais, Pan Evaporation, Rn-radiation and Rs-radiation were associated with lysimetric measurements. Performances of ET_o methods were assessed by four statistical criteria laterally with reversion guides. The results indicated that FAO Penman-Monteith and Linacre are the most and the least appropriate methods for estimating daily ET_o with lysimetric data in greenhouse respectively (Moazed *et al*., 2014).

Modaberi *et al*. (2014) had conducted study in a greenhouse to evaluate five methods of estimating evapotranspiration over a reference crop at the agricultural study centre, Tehran, Iran. Micro-lysimeter and a reduced pan were located inside the greenhouse to compute reference evapotranspiration. FAO-Blaney-Cridle, Priestley-Taylor, Makkink, penman-monteith and Artificial Neural Network methods are empirical formulas relating to climatological measurements. ET_o estimates from five methods were compared with the lysimetric data using simple error analysis and linear regression. Results indicated that the evapotranspiration values estimated by Atrificial Neural Network has suitable correlation with values measured by a Micro-lysimeter.

Daily lysimetric data for two years (2012 to 2013) from April to July in each year were used to assess nine different grass evapotranspiration models including FAO-56 Penman–Monteith, Penman-Kimberly 1996, FAO-Penman equation, Blaney–Criddle, FAO- 24 Radiation, Makkink, Turc, Priestley–Taylor, and Hargreaves in Kermanshah western part of Iran with semi-arid climate. They reported that the FAO - Penman-Monteith, Makkink and Hargreaves are the most appropriate models for the region under study. (Ghamarnia *et al.,* 2015).

Obioma *et al.* (2015) in their study aimed at estimating reference evapotranspiration using climatological models *viz* Pan Evaporation, Blaney – Morin Nigeria, Blaney – Criddle and Modified Hargreaves – Samani methods and comparing with weighing lysimetric data. All methods were used to estimate crop evapotranspiration of waterleaf in Umudike, Southeast Nigeria. Test of hypothesis using z-Test indicated that there was no significant variation between the mean of the ET by lysimeter and other four methods (Blaney - Criddle, Pan Evapotranspiration, Modified Hargreaves - Samani and Blaney - Morin Nigeria) as z-cal < z-critical at 5 per cent level of significance for the crop growth period of 8th November to 12th December, 2013.

Hirschi *et al.* (2016) had reported that the accurate determination of evapotranspiration is required for many meteorological, climatological, ecological, and hydrological research and developments. They measured and compared two well recognized approaches to decide evapotranspiration at the site level based on lysimeter-based measurements (EL) and eddy-10 covariance (EC) flux capacities (EEC). The measurements were compared on several time scales, and with respect to lysimeter-based evapotranspiration time series. Overall, the lysimeter and EC measurements were highly correlated, particularly on the annual time scale.

Mila *et al.* (2016) had 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 methods were used to compare the lysimeter values. Among these methods, Penman-Monteith method gave relatively higher value than the other methods.

Jackeline *et al*. (2016) conducted study to compare methods for estimating reference evapotranspiration models for water management purposes in the Brazilian Cerrado. They estimated daily reference evapotranspiration over a certain period (1982 - 2012) through different empirical models like Blaney-Criddle (BC), Hargreaves & Samani (HS), ASCE Penman-Monteith (ASCE- PM), Penman (1948/1963) (PO)and Priestley-Taylor (PT). All these models were compared to the FAO-56 Penman-Monteith method. Based on statistics,it was observed that ASCE- PM and BC methods should be recommended for cerrado areas, either in rainy or dry seasons.

2.9 ET ESTIMATES USING CROPWAT MODEL

During the nineties, CROPWAT, a computer program for irrigation planning and management developed by FAO (Smith *et al*., 1992), had been gaining particular importance among irrigation engineers. CROPWAT provided the link with climatic data from 3261 meteorological stations of 144 countries worldwide and represented a unique practical tool for approximation of crop water necessities, replication of irrigation scheduling situations and estimation of specific nonstop discharge either for one or more crops grown in nearly any part of the world.

CROPWAT program was introduced based on the methodologies presented in FAO Irrigation and Drainage Papers No.24 (Crop Water Requirements) and No.33 (Yield response to water) using the Penman-Monteith formula for crop evapotranspiration estimates. In recent years, FAO Irrigation and Drainage paper No.24 was revised and substituted with No.56. (Allen *et al*., 1998) introduced a new technique based on the Penman-Monteith equation as a standard method for reference evapotranspiration estimate and dual K_C concept for better consideration of soil evaporation and plant transpiration components.

Bouraima *et al*. (2015) had estimated reference and crop evapotranspiration (ET_o and ET_c) of rice using CROPWAT model. Climatic data, crop and soil data from 1942 to 2012 were computed with the CROPWAT model which is based on the United Nations Food and Agricultural Organization (FAO) paper number 56 (FAO 56). The Penman-Monteith technique was used to estimate ET_o. Crop coefficients (K_c) from the phenomenological stages of rice were applied to estimate the crop evapotranspiration ET_c. The crop evapotranspiration ET_c and the crop water requirement were estimated at 651 mm and 383 mm during rainy season and 920 mm and 1148 mm during dry period. Irrigation schemes of these periods could then be scheduled for crop water requirement based on these findings.

Patel *et al*. (2017) had conducted a study to estimate reference crop evapotranspiration in Ludhiana, Punjab (India) using CROPWAT model. Evapotranspiration (ET) is important in irrigation design, irrigation scheduling and water resource management. The Penman–Montieth method is a good estimator for different climatic conditions. The United Nations Food and Agricultural Organization (FAO) adopted the Penman–Montieth method as the standard method to estimate reference evapotranspiration (ET_o) from meteorological data. Based on this study, daily meteorological data recorded from 1970 to 2012 were used to obtain the result. The ET_o data were calculated for each constraint and the obtained results were compared. Reference evapotranspiration (ET_o) and monthly rainfall were calculated using CROPWAT model. The study revealed that Penman–Montieth method is the finest method to estimate ET_o because of the inclusion of all climatic variables in the calculation.

2.10 COMARISON OF LYSIMETER AND PAN EVAPORATION METHODS

The Class A pan coefficient (K_p) has been used to convert pan evaporation to grass-reference evapotranspiration (ET_o) as it is an important component for water management of irrigated crops. There are several methods to determine K_p values, using wind speed, relative humidity and fetch length conditions. The estimated and the observed values of K_p, obtained from the relationship between ET_o measured in a lysimeter and Convert pan coefficient measured in a Class A pan, were compared by regression analysis. The results showed that estimated K_p did not predict ET_o well compared to the value measured by lysimeter and gave very low correlation (Sentelhas *et al*., 2003).

Junzeng *et al*. (2008) had conducted lysimeter experiments to investigate tomato and cowpea crop evapotranspiration inside the greenhouse in Eastern China. The experiments were conducted in bottomed steel lysimeters with three replicates for each variety of crops. Lysimeters were surrounded by the same types of vegetables in the same density in order to avoid border effects. Water was applied to the lysimeters through drip irrigation. The applied water volumes were noted. Soil water potential in the root zone both inside and outside the lysimeters were checked using tensiometers installed at 10-cm, 20-cm, and 30-cm depths. Variation of pan evaporation inside the greenhouse did not agree with the variations of cowpea and tomato ET_c measured by lysimeter, particularly at later stages. This was attributed to the influence of shading when the vegetables were taller than the pan level.

Amiri *et al.* (2011) had reported that the class A pan method has been one of the most popular methods due to its simplicity, relatively low cost, and ability to compute daily evapotranspiration estimates. Because of the large area occupied by a class A pan, alternative methods have been sought to estimate ET_o inside greenhouses. With the objective of evaluating the possibility of using evaporation pan in estimating the water consumption in greenhouse, one class A pan and one reduced pan was installed inside the greenhouse and another class A pan was installed outside. In this investigation three drainage micro-lysimeters were installed inside and outside the greenhouse to compute the reference evapotranspiration. Monthly evaporation values measured by the class A pan and reduced pan, (both inside the greenhouse) were compared with the data of the lysimeters. R^2 values obtained from class A pan and reduced pan were 0.974 and 0.982 respectively, thus indicating that reduced pan was highly correlated with lysimetric data.

Tagliaferre *et al.* (2013) had conducted studies to assess the performance of the mini-evaporimeter, operating with water at a 30 mm border level, to estimate ET_o in relation to the lysimeter with continuous monitoring of groundwater table. The mini-evaporimeter consists of a tube with interior diameter of 244 mm and 320 mm height. The evaporation data from evaporimeter was related to the ET_o obtained by the lysimeter and was used to compute mini-evaporimeter coefficients. During the study period, the mini-evaporimeter presented better ET_o estimate than the other methods studied. These results reflected the applicability of mini-evaporimeters in evapotranspiration estimates for better water management.

2.11 COMPARISON OF EVAPOTRANSPIRATION IN A NATURALLY VENTILATED POLYHOUSE AND OPEN FIELD

For similar levels of production, crop water requirements are less in greenhouses than in open fields (FAO, 1991). This is a consequence of the lower evapotranspiration inside greenhouses on account of less wind, reduced solar radiation, and higher atmospheric humidity (Fernandez *et al.*, 2000). Consequently, greenhouse crops have noticeably higher water use efficiency (WUE). Additionally, the autumn to spring growing season of crops in the plastic greenhouses will significantly modify the pattern of crop growth, which is likely to effect the water requirement for crop growth.

Cheema *et al.* (2004) had reported that the early and higher yield of different vegetable crops inside the polyhouse was mainly because of better microclimate such as higher temperature (4-9°C more than the open field). Study was conducted to determine crop water requirement of drip irrigated tomato grown in greenhouse in tropical environment. Greenhouse farming system performed better than open field system in terms of crop yield, water use efficiency and fruit quality. The results showed that the crop evapotranspiration inside the greenhouse matched 75-85 per cent of the crop evapotranspiration computed from the climatic factors observed in open environment. Harmato *et al.* (2005) also reports that greenhouse farming can save about 20-25 per cent of water compared to the open field crops.

Drainage lysimeters were used to determine the seasonal evapotranspiration of four crops (melon, green beans, watermelon and pepper), which ranged from 170 to 371mm and it was related with the reference ET. Compared to outdoors, the seasonal ET of the greenhouse horticultural crops is relatively low due to the lower evaporative demand inside the greenhouse and reduction in solar radiation transmission by blanching in late spring and summer. Additionally, off-season greenhouse crops are grown during low evaporative demand periods, thus reducing the water requirements (Orgaz *et al*., 2005).

Polyhouse relative humidity was always 5-10 per cent lower compared to open field conditions. Parvej *et al.* (2010) had reported that inside the polyhouse, crop growth, development and yield were better than open field due to higher temperature and lower relative humidity. This positively influenced the morpho - phenological and physiological events.

Rajasekar *et al.* (2013) had conducted experiment to cultivate ten varieties of vegetables at the Department of Horticulture, Agricultural College and Research Institute, Tamil Nadu Agricultural University under shade net house (33 per cent shade) and open field for year round production of vegetables. Tomato, eggplant, chilli, cucumber, cluster bean, radish, amaranthus, coriander, bhindi and capsicum were grown in the summer and winter. Relative humidity was always higher under shade net house than in open field during both seasons. Light intensity in the shade net house was lower than in the open field. Mean weekly temperature during summer and winter were higher under open field conditions than in the shade net house. Lower temperature caused plant height, number of branches, inter nodal length, average fruit weight and yield per plant to be higher in the shade net house than in the open field. Hence, the growing of tomato, eggplant, chilli, cucumber, radish, amaranths and coriander under shade house conditions will be more economical irrespective of the seasons.

Materials and Methods

CHAPTER 3

MATERIALS AND METHODS

One of the key factors for enhancing agricultural production is the precise and timely application of the available water. Estimation of evapotranspiration (ET) is an important part of agricultural water management, in local and regional water balance studies and in hydrological modelling. At the field scale ET is important in irrigation planning and scheduling and is an integral part of field management decision support tools. Availability of experimentally determined crop coefficient and crop water requirement data is important for proper irrigation scheduling, efficient water management, optimum yield and profit. Evapotranspiration rate is an important component of canopy energy and water balance. The values may vary for open field and protected cultivation as influenced by the changes in micro climatic parameters.

Many studies have been conducted over the years to develop the Crop Coefficient ($K_{c)}$ for different agricultural crops. K_c for any crop may vary from one place to another, depending on factors such as climate, soil, crop type, crop variety and irrigation methods. For an accurate estimation of the crop water use, it is important to develop a regional K_c. In the present study, Non-Weighing Mini-Lysimeters were used to determine evapotranspiration parameters and to develop crop-coefficient curves for okra. Comparison with indirect methods is also done in order to assess the dependability of climatic data in evapotranspiration estimates. The study compares data for open field and poly house conditions in order to quantify the effect of micro climatic variations. The materials utilized and the methodology adopted for achieving the objectives of the study are enumerated under the following sub headings in this chapter.

3.1 LOCATION OF THE STUDY AREA

The site is situated on the cross point of 10^{o} 51’18” N latitude and 75^{o} 59’ 11” E longitude at an altitude of 8.54 m above mean sea level. The field experiment was conducted in a naturally ventilated polyhouse and open field in the research plot of the Department of Irrigation and Drainage Engineering, in KCAET campus, Tavanur, Kerala.

3.2 CLIMATE

Agro - climatically, the area falls within the border line of northern zone and central zone of Kerala. Most part of the rainfall received in this region is from south- west monsoon. The average annual rainfall varies from 2500 mm to 2900 mm. The average maximum temperature of the study area is 31ºC and the average minimum temperature is 26ºC.

3.3 PHYSICAL PROPERTIES OF SOIL

3.3.1 Bulk density and particle density

Bulk density and dry density of the soil filled in the Lysimeters were measured using core cutter method by standard procedure (Punmia, 1987).

Equipment 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 105ºC and constant weight was recorded (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

3.3.2 Soil texture

Soil texture was determined by using sieve analysis (Punmia, 1987).

Procedure:

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

Sieving was performed by arranging the various sieves one over the other in the order of their mesh openings. A receiver was kept at the bottom and a cover was kept at the top of the whole assembly. The soil sample was put on the top sieve, and shaking was done by hand. 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.

3.3.3 Soil moisture constants

Soil moisture characteristics were determined using the pressure plate apparatus (Plate 3.2) developed primarily by Richards. 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 metric potential (>1 bar) which is not possible on suction plates.

The procedure for determining soil metric potential and water content relation involves in first saturating the porous plates and then the soil sample (undisturbed or disturbed) is placed on these plates. The soil samples were also saturated and then 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 1/3 atm & 15 atm which were applied to get field capacity and permanent wilting point. 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 is achieved. After that the soil samples were taken out and oven dried for determining moisture content on volume basis. Calculations are shown in Appendix III (Michael, 2008).

Plate 3.2 Soil moisture constants by Pressure plate apparatus

3.4 EXPERIMENTAL DETAILS

The experiment was conducted inside the naturally ventilated poly house during February 18th to April 23rd 2017 and the crop duration was three months. The poly house was oriented east–west with an overall area of 213 m^2 (26 m length and 8 m width). The open field experiment was conducted in the nearby area in front of the naturally ventilated polyhouse. View of the poly house and open field are shown in Plate 3.3.

Plate 3.3 View of the experiment site

3.4.1 Field Preparation

Land preparation was done inside the naturally ventilated polyhouse and open field. Polyhouse was divided into two parts for cultivating okra crop and grass reference crop. Four raised beds of 10 m length, 1.0 m width and 0.25 m height were made for cultivating okra. A reduced pan was installed in the middle of the polyhouse leaving an area of 48 m^2 without crop. The beds of the same dimensions were continued in the other half for planting grass. (Plate3.4).

Plate 3.4 Poly house after land preparation

3.4.2 Preparation of Non weighing Mini Lysimeters

Twelve sets of mini non-weighing lysimeters were fabricated and used for this study. (Plate 3.5).

Plate 3.5 Non-weighing Mini lysimeter with drainage system

The drainage lysimeters were plastic containers of 42 cm diameter and 30 cm depth. Drainage provisions were provided at the sides at a height of 5 cm above the bottom. A hole was made in each lysimeter and drain pipe of 75mm was connected from the bottom of the tank to the drainage system to ensure free drainage of excess water. Drainage system consisted of a plastic bucket of 22 cm diameter and 20 cm depth with a lid provided to prevent evaporation.

3.4.3 Experiment setup

Six mini lysimeters were used inside the poly house and open field respectively, of which, three were planted with okra and three with grass. Lysimeters were placed randomly on the raised beds in the naturally ventilated Polyhouse. Gravel was filled at the bottom of the lysimeter to a height of 5cm to ensure proper drainage. Each lysimeter was filled with sandy soil collected from the field. Three okra plants were planted in each lysimeter. Other three identical lysimeters were planted with grass. Lysimeters were surrounded by the same crop in grow bags (40×24 cm) in the same density in order to avoid the border effect. The grow bags were made of UV stabilized polyethylene. Drainage holes were provided on both sides of the grow bag, towards the bottom to allow drainage. The trails were replicated outside the polyhouse in the selected area with an identical set up. Fig. 3.1 shows layout of the experiment set up and Plate 3.6 shows the experimental set up of lysimeters and grow bags, before sowing inside the poly house.

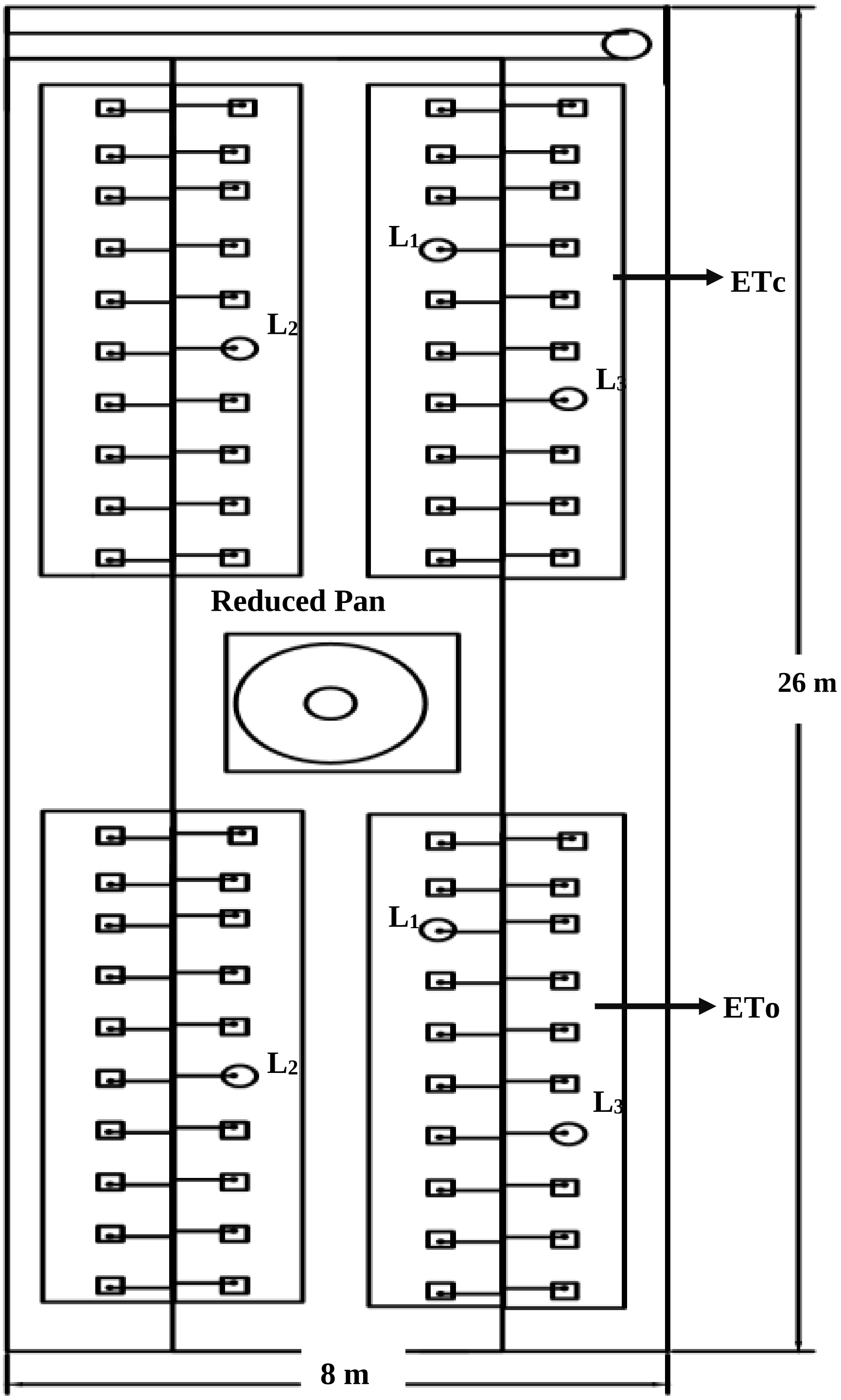

Fig. 3.1 Layout of experiment setup inside poly house

Plate 3.6 Grow bags ready for planting

3.4.4 Crop details

Okra variety *Varsha Upahar* was chosen for this study to estimate crop evapotranspiration. Sowing was done on 23rd February. Seeds were directly sown in the Lysimeters and grow bags. In each Lysimeter or grow bag, three seeds were sown. Plate 3.7 shows the view of the field in the initial stage of Okra.

Kango signal grass was selected as reference crop for this study. Grass seedlings were procured from the research station at Thiruvanzenkunnu under the Kerala Veterinary Animal science university. Planting was done on 23rd February. Seedlings were planted in Lysimeters and grow bags, in such a way that it completely covered the area. Plate 3.8 gives an overall view of grass after Planting.

a) Overall view-poly house b) Lysimeter with Okra

Plate 3.7 Overall view of okra three weeks after sowing

a) Overall view-poly house b) Lysimeter with Grass

Plate 3.8 Overall view of grass after planting

3.4.5 Irrigation system

Water source is a filter point well from which water was pumped to an over head tank and conveyed through the main line of 63 mm diameter PVC pipes. PVC sub main of 50 mm diameter was connected to the main line to which, low density polyethylene laterals of 12 mm diameter were connected. End caps were provided at the end of laterals. Each lateral was provided with individual cutoff valve for controlling irrigation. Along the laterals, microtube of 6 mm diameter and length of 75 cm were connected using thin connectors and online drippers of 4 lhr^{-1} were fixed at the other end of the microtube. Plate 3.9 and Plate 3.10 depicts the irrigation system layout in the poly house and open field.

Plate 3.9 Poly house -Irrigation layout

Plate 3.10 Open field -Irrigation layout

The irrigation applied to the plant was in a higher rate than the actual requirement in order to ensure drainage and to allow maximum evapotranspiration. At the initial stage (3 weeks) the crop was irrigated daily with an application rate of 0.65 l/day/plant against the standard value of 0.6l\day\plant. During the mid season stage (8 weeks) the plant requires more water than initial stage. So the water applied was increased from 0.65 to 1 l/day/plant. In the late season stage (2 weeks) water application rate was reduced to 0.8 l/day/plant. Irrigation applied to the grass was at a rate of 1.5 l/day throughout the growing period.

3.4.6 Fertigation

Macro nutrients were applied as water soluble fertilizers through fertigation system with venturi both in poly house and open field. The dosage of fertilizers as per the KAU package of practices recommendations is 55, 35 and 70 kg ha^{-1} of N, P_2O_5 and K_2O respectively at the time of sowing and additional 55 kg ha^{-1} of N, one month after sowing. But in this study, reduced quantity of fertilizers than the recommended dose was applied as it was grow bag cultivation. The total quantity was given in three split doses during crop period in the ratio of 1:0.7:0.5. Neem cake was applied in two dosages during crop period in poly house and open field at a rate of 2 g/plant.

3.4.7 Pest and disease management

Okra yield is usually reduced due to sucking insects and pests. Common problem for polyhouse okra are aphids mealy bugs, scale, thrips, and white flies. Confidor was sprayed twice during the crop period at a rate of 2ml/ 5 liters of water on the leaves for controlling sucking insects.

3.5 DETERMINATION OF ET_o AND ET_c

Field studies using lysimetric data acts as an accurate tool in the determination of water balance variables, representing the existing field conditions. Non weighing lysimeters are also known as Drainage lysimeters or Percolation lysimeters. The soil column is isolated from the surroundings using lysimeter to prevent seepage of the adjoining fields and also to study the water inflow and outflow in the system. Drainage lysimeters work on the principle 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).

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 Lysimeter water balance equation used in the study was

$$\mathbf{ET = I + R - D - \Delta S}$$

Where,

I and D are respectively, the total volumes of applied irrigation water and collected drainage water, measured weekly.

R is effective rainfall measured with rain gauge near the site

ΔS is the change in volumetric soil moisture content measured weekly at two depths.

3.5.1 Water balance data collection

Applied irrigation water (l) was measured daily. Drainage from the lysimeters (D) was collected manually on daily basis and measured. Volume of water was converted to depth in mm of water using the following formula. Data are presented in Appendix IV.

$$\text{Depth in mm of water} = \frac{\text{Volume of water (l)}}{\text{Cross sectional area of the lysimeter } (\mathrm{m}^2)}$$

The volumetric soil moisture content data used in water balance calculations was derived from the gravimetric soil moisture content data. Soil sampling was done in each lysimeter at two sampling points 0-10 and 10-20 cm depth on a weekly basis. Soil moisture content was determined gravimetrically using oven drying method. Change in soil moisture storage was calculated layer wise using the following formula. Data are presented in Appendix V.

$$\Delta S = \sum_{i=1}^{n} \frac{M_{1st} - M_{2nd}}{100} \times (A \times D_i)$$

Where,

ΔS - change in soil moisture storage in mm

M_{1st} - moisture content at the time of 1_{st} sampling in the i^{th} layer

M_{2nd} - moisture content at the time of 2_{nd} sampling in the i^{th} layer

A - apparent specific gravity of the soil

D_i - depth of the i^{th} layer of the soil in mm

n - no. of soil layers in the root zone

ETc from okra and ETo were measured on weekly basis throughout the crop period inside polyhouse and open field using water balance approach. Results are given in section 4.2

3.6 DEVELOPMENT OF CROP COEFFICIENT VALUES 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 and 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, identifying the length of different growth stages, 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 and grass or ET_o were estimated using lysimeters by the soil water balance approach for polyhouse and open field. The Crop coefficient values at each crop stages were calculated for weekly periods by using the equation:

$$\mathbf{K_c = ET_c / ET_o}$$

Crop coefficient curves were plotted for Poly house and open field. Results are presented in section 4.3

3.7 INDIRECT METHODS OF ET ESTIMATION

3.7.1 ET$_o$ from reduced pan data

The class A pan method has been one of the most accepted method due to its simplicity, relatively low cost, and computes daily evapotranspiration estimates. Because of the large area occupied by a class A pan, alternative methods have been sought to estimate ET_o inside polyhouse. Reduced pan method was effectively used inside the polyhouse to compute ET_o (Amiri *et al.,* 2011).

3.7.1.1 *Fabrication of Reduced Pan*

Two reduced pans of dimensions, 60 cm diameter and 25 cm depth were fabricated with 22 mm galvanized iron sheet, and painted white. A, stilling well was provided in the center of the Pan to prevent wave effects and a stainless steel scale was placed inside of the stilling well to monitor the water levels in the Pan. It was placed on a level wooden platform of height 15cm on the soil surface in order to avoid the crop shading effect. Plate 3.11 shows the view of the reduced pan.

Plate 3.11 View of reduced pan

3.7.1.2 *ET_o from reduced Pan data*

One reduced pan was installed in the naturally ventilated Poly house at the center position, and the other pan with identical dimensions was installed outside in the Meteorological observatory nearby. Daily Pan Evaporation (E_p) was obtained by monitoring the water level in the stilling well. Depth of water level maintained in the stilling well was 15cm. Water level in the pan was measured daily and the amount of evaporation was calculated as the difference between observed water levels. A pan coefficient of 0.4564 was taken for conversion of reduced pan evaporation data to data from free water surface (Modaberi *et al*., 2014). Pan based ET_o was estimated by using following equation.

$$\mathbf{ET_o = K_p \times E_p}$$

Where,

ET_o - Reference evapotranspiration in mm

K_p - Pan coefficient

E_p - Pan Evaporation in mm

3.7.2 ET_o computation using CROPWAT

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. It is a computer program that uses the FAO Penman-Monteith model to calculate ET_O (FAO 1992). Computer model simulation is an emerging trend in the field of water management.

3.7.2.1 *Penman-Monteith method*

To calculate ET_O using the Penman-Monteith method, monthly mean data are required, including maximum and minimum temperatures (°C), sunshine hours (hour), wind speed (km/day) and relative humidity (%).

The penman Monteith form of combination equation is,

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

Where,

ET_o : The reference evapotranspiration [mm/day]

R_n : The net radiation [MJ m^{-2} /day]

G : The soil heat flux density [MJ m^{-2} /day]

T : The mean daily air temperature at 2m height [^oC]

U_2 : The wind speed at 2m height [km/day]

Es : The saturation vapour pressure [KPa]

Ea : The actual vapour pressure [KPa]

(es-ea) : The vapour pressure deficit of the air [KPa]

Δ : The slope vapour pressure curve [KPa $^oC^{-1}$]

γ : The psychometric constant [KPa $^{o}C^{-1}$]

3.7.2.2 Data Requirements for CROPWAT

In this study climate data is given as input to the CROPWAT. The climatic data include maximum and minimum temperatures (ºC), mean daily relative humidity (%), daily sunshine (hours) and wind speed (km/day).

3.7.2.3 Climate data

Climate module window is presented in Fig. 3.1. The daily data of rainfall, minimum temperature, maximum temperature, humidity, sunshine hours, and wind speed for twelve months were used to calculate radiation and ET_o. Minimum temperature, maximum temperature and relative humidity were measured inside the polyhouse from May 2016 to April 2017 using the Equinox Digital Temperature and Humidity meter at 7.30 am and 2.30 pm everyday at crop canopy level based on IMD recommendations. .

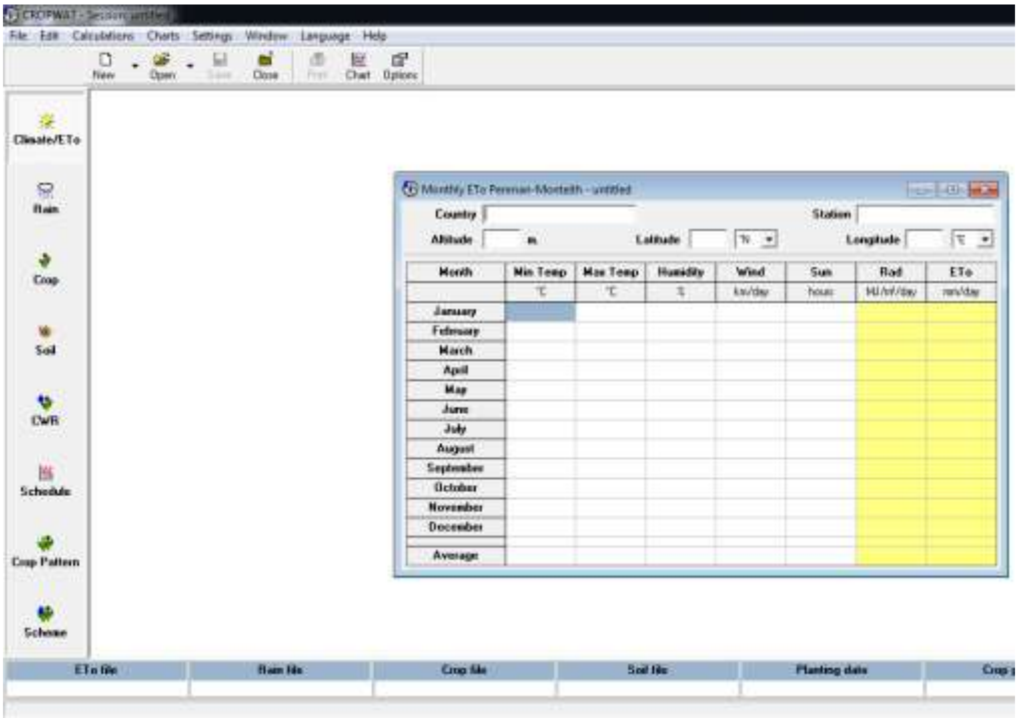

Fig. 3.2 Climate module window of CROPWAT model

For open field conditions, rainfall, minimum temperature, maximum temperature, humidity, sunshine hours, and wind speed were taken from the Meteorological observatory at RARS, Pattambi for the period 2016 January to 2017 May. For sunshine hours and wind speed data in poly house, suitable correction factors were applied to open field data based on literature due to lack of yearly measured data. Wind velocity value was reduced by 10% and sunshine hours was assumed to be the same (Neelam *et al.*, 2009). Radiation and ET_O were calculated for Polyhouse and open field conditions by using CROPWAT model

3.7.3 Computing ET_o using FAO – Blaney- Criddle (1977) method

Blaney and Criddle in 1950 developed a model for use in arid farmlands to calculate reference evapotranspiration. Several revisions of the Blaney-Criddle model have been proposed, but the one used in this study is based on the FAO 24 Paper (Doorenbos and Pruitt 1977). This method required only temperature and sunlight hours as data input. The Blaney- Criddle model was designed to use monthly values only and produces invalid results for any period shorter than one month. This limitation was due to the use of temperature as the sole climatic variable (Hansen *et al.*, 1980). The FAO 24 version of the model uses humidity and wind speed, thus minimizing this limitation. Monthly ETo was calculated by the following equation,

$$PET = a + b.f$$

$$f = p\ (0.46T+8.13)$$

$$a = 0.0043\ RH_{min} - \frac{n}{N} - 1.41$$

$$b = a_o + a_1\ RH_{min} + a_2 \frac{n}{N} + a3\ U_d + a_4\ RH_{min} \frac{n}{N} + a_5\ RH_{min}\ U_d$$

Where,

P - Mean daily % of annual daytime hours (monthly p/ (days/month))

T_m- Mean air temperature (^oC)

$\frac{n}{N}$ - Ratio of possible sun shine hours

RH_{min}- Minimum daily relative humidity in %

U_d - Day time wind at 2 m height (ms^{-1})

$a_o = 0.81917$

$a_1 = 0.0040922$

$a_2 = 1.0705$

$a_3 = 0.065649$

$a_4 = 0.0059684$

$a_5 = 0.0005967$

The data on mean temperature, humidity, sunshine hours, and wind speed collected as explained before in were used to compute ETo by this method and results are presented in 4.4

3.7.4 ET_o by Thornthwaite (1948) method

Thornthwaite(1948) developed model for estimating potential evapotranspiration from climatological data. To estimate potential evapotranspiration in this method, mean monthly temperature of the site and latitude of the site are required. Monthly Potential evapotranspiration was calculated by the following equation,

$$PET = 1.6\, l\, (10\, T_m / l)^a$$

Where,

PET = Adjusted potential evapotranspiration in cm (12 hrs, day time)

Tm = Mean temperature in ^{o}C

I = Annual heat index = $\Sigma (t_1/5)^{1.514}$

Ti = Maximum temperature in ^{o}C of ith month

a = an empirical exponent = $6.75 \times 10^{-7} I^3 - 7.71 \times 10^{-5} I^2 + 1.792 \times 10^{-2} I + 0.49239$

l = day length factor, = (n/12) (D/30), where D is no. of days in a month

The data on mean temperature, maximum temperature and sunshine hours collected as explained before in were used to compute ETo by this method and results are presented in 4.4

3.7.5 Statistical analysis

ET_o estimated from the models was compared with the lysimeter data using simple error analysis including RMSE and MAE and correlation was obtained by using linear regression analysis.

3.8 COMPARISON OF EVAPOTRANSPIRATION INSIDE POLY HOUSE AND OPEN FIELD

ETo and ETc measured by using lysimeters inside polyhouse and open field and estimated by using indirect methods were compared and results are presented in section 4.5.1 and 4.5.2 respectively.

3.9 CROP GROWTH AND YIELD PARAMETERS

One plant from each lysimeter was selected and tagged for observations on growth and yield parameters.

3.9.1 Plant height

Plant height from base level of shoot to the tip was measured at initial, mid and late season and expressed in centimeters.

3.9.2 Number of leaves and branches

Number of leaves and branches per plant was noted at initial, mid and late season stage in selected plants.

3.9.3 Yield parameters

Harvesting was started 40 days after sowing and continued at an interval of two days. The number of fruits and weight of fruits harvested were noted from tagged plants for each harvest. Results are presented in section 4.6

Results and Discussion

CHAPTER 4

RESULTS AND DISCUSSION

Results obtained from the field study on the comparative evaluation of evapotranspiration parameters in a naturally ventilated polyhouse and open field were analyzed and details are discussed under various headings in this chapter.

4.1 PHYSICAL PROPERTIES OF SOIL

4.1.1 Bulk density and Dry density

Bulk density and dry density of the soil filled in the Lysimeters were measured using core cutter method. The value of bulk density and dry density were observed as 1.63 g/cc and 1.52 g/cc respectively.

4.1.2 Soil Texture

Soil Texture was determined by using sieve analysis. From the analysis, it was found that 99.4 per cent of the soil was sandy and the remaining 0.6 per cent comprised of fines. Out of this 99.4 per cent sand, the percentage of coarse, medium and fine sand were 66, 30.4 and 2.9 per cent respectively. From the results, it could be concluded that the soil texture was sandy.

4.1.3 Soil moisture constants

The values of field capacity, permanent wilting point and available moisture range for the soil were measured using pressure plate apparatus and the results on volumetric basis are as follows.

Field capacity : 34.84 %

Permanent Wilting point : 26.09 %

Available water : 8.7 %

4.2 DETERMINATION OF ET_o AND ET_c

The amount of irrigation water applied, drainage from non weighing mini lysimeters, effective rainfall and change in soil moisture storage were observed to measure the ETo and ETc in poly house and open field conditions using soil water balance approach. The total volumes of applied irrigation water and collected drainage water were measured daily and converted to weekly values. Effective rainfall was measured with rain gauge near the site. The change in volumetric soil moisture content was observed for two layers of soil in the root zone on a weekly basis.

4.2.1 Determination of ETo in polyhouse

Measurements from non weighing mini lysimeters planted with grass were used to estimate ET_0 by water balance approach. Table 4.1 gives sample calculations for ET_0 estimated by water balance. The detailed data are presented in Appendix VI.

Table 4.2 gives weekly values of ETo for three lysimeters inside the poly house. Minimum and maximum ETo values were recorded during the 1st and 8th week of crop growing period as 30.08mm and 36.01mm for lysimeter-1. For lysimeter-2, 27.33mm and 37.01mm were recorded in the 1st and 11th week and 26.01mm and 37.48mm were recorded during the 6th and 12th week for lysimeter-3. Average weekly values of ETo for three lysimeters were 33.28, 33.30 and 33.17mm respectively implying that there was no much variation among the three lysimeters. The average daily ETo values of the reference crop varied from 4.30 to 5.18 mm/day with a seasonal average of 4.74 mm/day. ET_0 was lesser in the initial stages and increased towards the late season stages when the crop height exceeded the reference height. The average ETo inside poly house was obtained as 4.74 mm/day.

Table 4.1 Water balance computation for lysimeter 1- polyhouse

Growing period	**Applied water (I) mm**	**Drainage (D) mm**	**Soil moisture Storage change (Δs) mm**	**ETo=I-D±Δs (mm)**
1st week	75.81	37.55	8.17	30.08
2nd week	75.81	38.84	6.68	30.28
3rd week	75.81	37.40	6.69	31.72
4th week	75.81	36.10	7.23	32.48
5th week	75.81	36.53	6.29	32.98
6th week	75.81	37.18	3.86	34.77
7th week	75.81	37.04	5.21	33.56
8th week	75.81	36.82	2.98	36.01
9th week	75.81	34.08	8.28	33.45
10th week	75.81	33.14	11.62	31.05
11th week	75.81	32.27	8.73	34.81
12th week	75.81	30.76	9.18	35.88
13th week	75.81	30.69	9.52	35.60

Table 4.2 Weekly values of ET$_0$ – polyhouse

Growing period	**Weekly ETo (mm)**			**Mean weekly ETo (mm)**	**Average daily ETo (mm/day)**
	Lysimeter (1)	**Lysimeter (2)**	**Lysimeter (3)**		
1st week	30.08	27.33	32.8	30.07	4.3
2nd week	30.28	28.91	32.98	30.72	4.39
3rd week	31.72	30.37	33.25	31.78	4.54
4th week	32.48	31.13	31.01	31.54	4.51
5th week	32.98	33.28	26.07	30.78	4.4
6th week	34.77	35.36	26.06	32.06	4.58
7th week	33.56	34.87	34.01	34.15	4.88
8th week	36.01	33.99	35.33	35.11	5.02
9th week	33.45	37.15	33.18	34.59	4.94
10th week	31.05	33.43	34.14	32.87	4.7
11th week	34.81	36.77	34.97	35.51	5.07
12th week	35.88	35.42	37.48	36.26	5.18
13th week	35.6	34.88	36.7	35.73	5.1
Average	**33.28**	**33.3**	**32.92**	**33.17**	**4.74**

4.2.2 Determination of ETo for open field conditions

ETo was calculated by water balance approach using Non Weighing Mini Lysimeters placed in the open field. Table 4.3 gives water balance sample calculations for lysimeter placed in the open condition outside the polyhouse. The detailed data and calculations are presented in Appendix VII.

Table 4.3 Water balance computation for lysimeter 1– open field ETo

Growing period	**Applied water (I) mm**	**Rainfall (R) mm**	**Drainage (D) mm**	**Soil moisture Storage change (Δs) mm**	**ETo=I+R-D±Δs (mm)**
1st week	75.81	0.00	33.50	10.52	31.79
2nd week	75.81	0.00	32.92	11.16	31.73
3rd week	75.81	0.00	31.62	12.27	31.91
4th week	75.81	0.00	32.56	8.31	34.93
5th week	75.81	0.00	34.37	10.40	31.04
6th week	75.81	0.00	33.94	8.85	33.02
7th week	75.81	0.00	33.57	7.18	35.05
8th week	75.81	0.00	33.79	5.61	36.41
9th week	75.81	0.00	31.55	8.43	35.83
10th week	75.81	0.00	30.76	6.67	38.38
11th week	75.81	0.00	29.60	7.89	38.32
12th week	75.81	0.00	28.30	7.59	39.92
13th week	75.81	2.80	29.69	12.91	36.01

Table 4.4 shows mean values of ETo for three lysimeters outside the poly house. Minimum and maximum ETo values were recorded during the 2nd and 12th week of crop growing period as 31.73mm and 39.92mm for lysimeter-1, For lysimeter-2, 31.62mm and 39.48mm were recorded in the 3rd and 6th week and 38.56mm and 31.20mm were recorded during the 3rd and 9th week for lysimeter-3. Average weekly values of ETo for three lysimeters were 34.95, 35.29 and 35.11mm respectively implying there was not much variation among the three lysimeters. The daily ETo values of the reference crop varied from 4.58 to 5.16 mm/day with a seasonal average of 5.02 mm/day. ET_0 was lesser in the initial stages and increased towards the late season stages when the crop height exceeded

the reference height. The average ETo for open field was obtained as 5.02 mm/day.

Table 4.4 Weekly values of ET_0 – open field

Growing period	**Weekly ETo (mm)**			**Mean weekly ETo (mm)**	**Average daily ETo (mm/day)**
	Lysimeter (1)	**Lysimeter (2)**	**Lysimeter (3)**		
1st week	31.79	32.07	32.33	32.07	4.58
2nd week	31.73	32.28	32.88	32.29	4.61
3rd week	31.91	31.62	31.2	31.58	4.51
4th week	34.93	32.49	33.1	33.51	4.79
5th week	31.04	33.64	34.96	33.21	4.74
6th week	33.02	39.48	36.51	36.34	5.19
7th week	35.05	35.23	36.17	35.48	5.07
8th week	36.41	36.22	36.65	36.43	5.2
9th week	35.83	38.83	38.56	37.74	5.39
10th week	38.38	37.01	34.21	36.53	5.22
11th week	38.32	34.57	36	36.3	5.19
12th week	39.92	38.75	38	38.89	5.56
13th week	36.01	36.53	35.82	36.12	5.16
Average	**34.95**	**35.29**	**35.11**	**35.11**	**5.02**

4.2.3 Determination of ETc of okra inside polyhouse

ETc was measured for okra crop inside the poly house using water balance approach by Non Weighing Mini Lysimeters. Table 4.5 gives water balance sample calculations for one lysimeter to determine ETc and the data and calculations for the remaining two lysimeters are presented in Appendix VIII. Table 4.6 and Fig. 4.1 shows seasonal mean values of ETc for three lysimeters inside the polyhouse. Minimum and maximum ETc values of okra crop were 2.23 and 4.77 mm/day during the 1^{st} and 10^{th} week of crop period with a seasonal average of 3.90 mm/day. The average daily ETc values of the Okra crop were 2.56, 4.5 and 3.47 mm/day during the initial stage, mid season stage and late season stage respectively. It implied that lowest seasonal ETc was observed in the initial stage and highest ETc was observed in mid season stage. ETc increased from initial stage to mid season stage and then decreased in late season. This trend agreed with the characteristic pattern of ETc (water use) of crops as explained by Igbadun (2012) in his study on estimation of crop water use of maize and ground nut crops using Mini Lysimeters.

Table 4.5 Water balance computation for lysimeter 1 – polyhouse ETc

Growing period	**Applied water (I) mm**	**Drainage (D) mm**	**Soil moisture Storage change (∆s) mm**	**ETc=I-D±∆s (mm)**
1st week	101.08	50.11	5.17	45.80
2nd week	101.08	44.40	7.02	49.66
3rd week	101.08	43.18	-9.85	67.76
4th week	151.62	58.63	12.14	80.86
5th week	151.62	57.33	-2.80	97.09
6th week	151.62	53.43	-3.67	101.86
7th week	151.62	50.76	3.42	97.45
8th week	151.62	47.51	13.17	90.95
9th week	151.62	47.00	6.99	97.63
10th week	151.62	43.32	10.57	97.73
11th week	151.62	41.95	20.29	89.38
12th week	126.35	41.59	4.05	80.71
13th week	126.35	47.44	13.91	65.01

Table 4.6 ETc of okra for different growth stages - polyhouse

Growing period	**Growth stages**	**Weekly ETc mm**	**Total ETc-stage wise mm**	**Average daily ETc mm**	**Average daily stage wise ETc mm/day**
1st week	Initial stage	15.60	53.82	2.23	2.56
2nd week		17.42		2.49	
3rd week		20.80		2.97	
4th week	Mid season stage	27.96	252.12	3.99	4.5
5th week		30.70		4.39	
6th week		32.20		4.60	
7th week		32.49		4.64	
8th week		31.01		4.43	
9th week		33.29		4.76	
10th week		33.40		4.77	
11th week		31.07		4.44	
12th week	Late season stage	26.02	48.61	3.72	3.47
13th week		22.59		3.23	

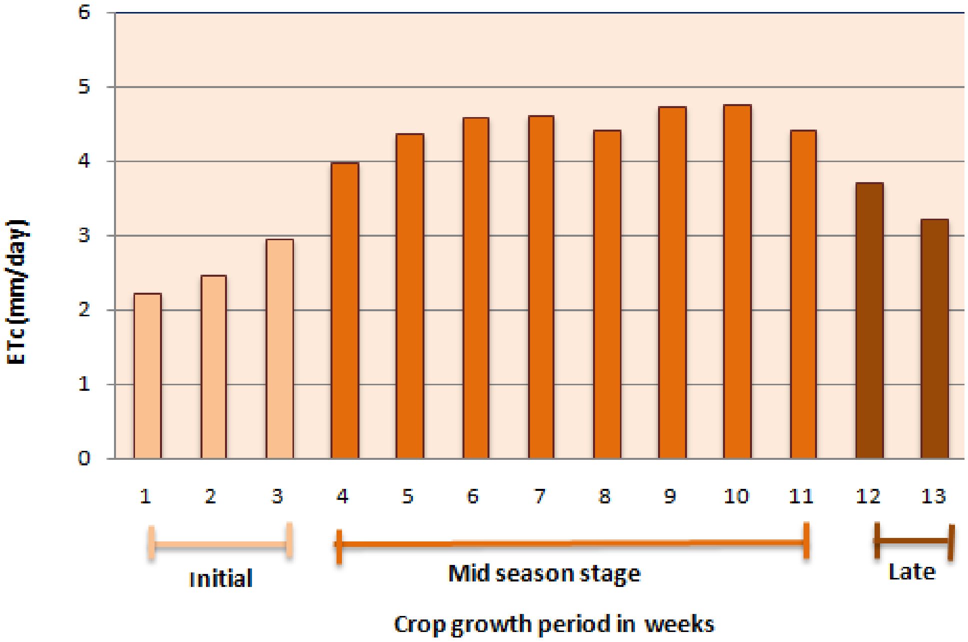

Fig.4.1.Average daily stage wise ETc of okra inside polyhouse

4.2.4 Determination of ETc of Okra-Open Field

Applied irrigation water, drainage, effective rainfall and change in soil moisture storage were observed in open field to compute ETc of okra. ETc was computed using water balance approach by Non Weighing Mini Lysimeters. Table 4.7 gives sample water balance calculations for one lysimeter in the open field and remaining two lysimeter data and calculations are presented in Appendix IX.

Table 4.8 and fig.4.2 shows seasonal mean values of ETc for three lysimeters outside the poly house. Minimum and maximum ETc values of okra crop were 2.57 and 5.19 mm/day during the 1st and 10th week of crop period with a seasonal average of 4.31 mm/day for open field condition. The average daily ETc values of the okra crop were 2.78, 4.99 and 3.87 mm/day during the initial stage, mid season stage and late season stage respectively. The results imply that lowest ETc was observed in the initial stage and highest ETc was observed in the mid season stage respectively. ETc increased from initial stage to mid season stage and then decreased in the late season stage.

Table 4.7 Water balance computation for lysimeter 1– open field ETc

Growing period	**Applied water (I) mm**	**Effective Rainfall (R) mm**	**Drainage (D) mm**	**Soil moisture Storage change (Δs) mm**	**ETc=I+R-D±Δs (mm)**
1st week	101.08	0.00	42.60	5.29	53.19
2nd week	101.08	0.00	39.71	6.07	55.30
3rd week	101.08	0.00	38.99	-7.77	69.87
4th week	151.62	0.00	50.47	2.58	98.58
5th week	151.62	0.00	44.71	0.73	106.18
6th week	151.62	0.00	44.55	-4.68	111.76
7th week	151.62	0.00	43.25	-0.82	109.20
8th week	151.62	0.00	40.07	3.72	107.83
9th week	151.62	0.00	38.34	17.65	95.63
10th week	151.62	0.00	39.35	2.42	109.85
11th week	151.62	0.00	37.91	4.57	109.15
12th week	126.35	0.00	37.91	8.53	79.92
13th week	126.35	2.80	45.34	7.11	76.70

Table 4.8 ETc of okra for different growth stages - open field

Growing period	**Growth Stages**	**Weekly ETc mm**	**Total ETc-stage wise mm**	**Average daily ETc mm**	**Average Daily stage wise ETc mm/day**
1st week	Initial stage	17.96	58.28	2.57	2.78
2nd week		18.29		2.61	
3rd week		22.03		3.15	
4th week	Mid season stage	32.15	279.5	4.59	4.99
5th week		33.37		4.77	
6th week		35.86		5.12	
7th week		35.53		5.08	
8th week		35.68		5.1	
9th week		34.94		4.99	
10th week		36.36		5.19	
11th week		35.61		5.09	
12th week	Late season stage	27.49	54.13	3.93	3.87
13th week		26.64		3.81	

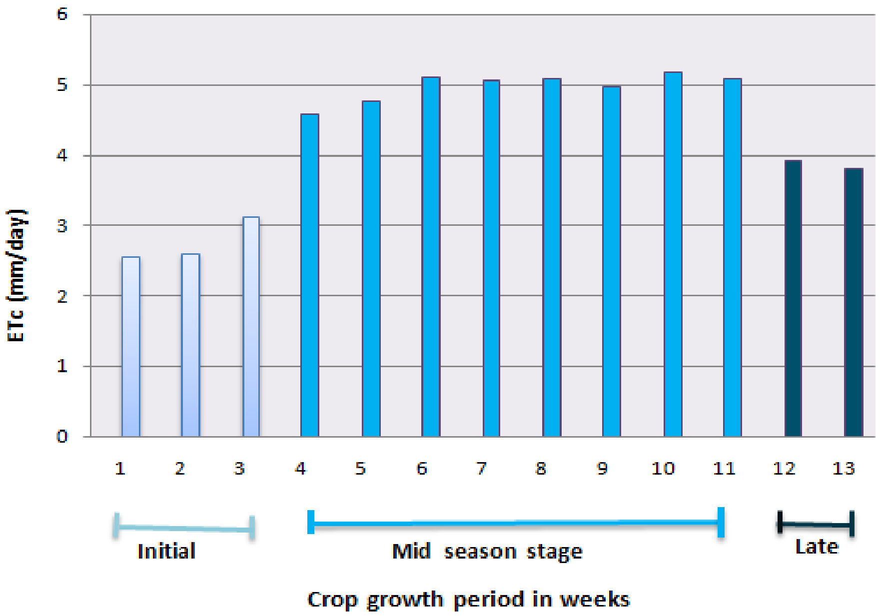

Fig.4.2 Average daily stage wise ETc for open field

4.3 CROP COEFFICIENT VALUES OF OKRA

Crop coefficient values of Okra were calculated as the ratio of ETc and ETo. Weekly values of ET_c and ET_o were estimated by the soil water balance approach using lysimeters for polyhouse and open field, as explained in the section 4.2.

Tables 4.9 and 4.10 shows crop coefficient values of Okra inside the polyhouse and open field for each crop growth stage calculated from weekly data. Inside the polyhouse Kc was around 0.58 during the crop establishment stage or initial stage and then Kc increased gradually, reaching a maximum value of 0.94 in the mid season stage and finally, Kc declined to 0.67 in the late season stage. Outside field values were 0.61, 0.98 and 0.72 during initial, mid and late season stages respectively. During initial stage Kc values were lower compared to mid season stage in both conditions since the leaf area and transpiration was low during the initial stage. Kc values were higher until early harvesting time and slightly declined towards the end of the crop growth period. These observed Kc values are in agreement with the values proposed by Panigrahi and Sahu (2013).

Table 4.9 Crop coefficient values of okra- poly house

Growing period	**Growth stages**	**Weekly ETc (mm)**	**Weekly ETo (mm)**	**KC = ETc/ETo**	**Growth stage wise Kc**
1st week	Initial Stage	15.60	30.07	0.52	0.58
2nd week		17.42	30.72	0.57	
3rd week		20.80	31.78	0.65	
4th week	Mid season stage	27.96	31.54	0.89	0.94
5th week		30.70	30.78	1.00	
6th week		32.20	32.06	1.00	
7th week		32.49	34.15	0.95	
8th week		31.01	35.11	0.88	
9th week		33.29	34.59	0.96	
10th week		33.40	32.87	1.02	
11th week		31.07	35.51	0.87	
12th week	Late season	26.02	36.26	0.72	0.67
13th week		22.59	35.73	0.63	

Table 4.10 Crop coefficient values of okra- open field

Growing period	**Growth stages**	**Weekly ETc (mm)**	**Weekly ETo (mm)**	**KC = ETc/ETo**	**Growth stage wise Kc**
1st week	Initial season stage	17.96	32.07	0.56	0.61
2nd week		18.29	32.29	0.57	
3rd week		22.03	31.58	0.70	
4th week	Mid season stage	32.15	33.51	0.96	0.98
5th week		33.37	33.21	1.00	
6th week		35.86	36.34	0.99	
7th week		35.53	35.48	1.00	
8th week		35.68	36.43	0.98	
9th week		34.94	37.74	0.93	
10th week		36.36	36.53	1.00	
11th week		35.61	36.30	0.98	
12th week	Late season stage	27.49	38.89	0.71	0.72
13th week		26.64	36.12	0.74	

4.3.1 Crop Coefficient curves for okra – polyhouse vs. open field

Fig.4.3 shows Kc curves of Okra for polyhouse and openfield conditions with respect to crop growth period. Kc values were not constant through the crop period and increaseds from initial stage to mid season stage and then decreased in the late season stage in both conditions, which implies that during mid season water requirement is more than the initial stage. From the figure it is understood that Kc for open field was higher than that inside the polyhouse, which results in lesser water requirement inside the polyhouse than open field mainly in the crop maturity stage. These results agree with the observations for Lettuce crop by Shahindian *et al.*, 2014 for poly house and open field conditions.

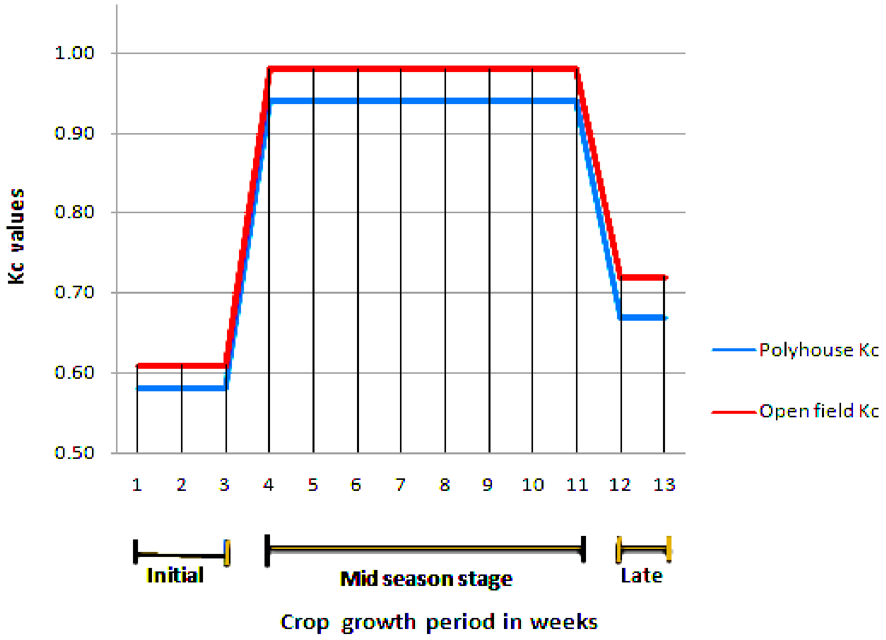

Fig. 4.3 Kc curves of okra for polyhouse and open field conditions

4.4 INDIRECT METHODS OF ET ESTIMATION

ETo was estimated using Pan evaporation method, FAO Penman-Monteith, Blaney- Criddle and Thornthwaite models for polyhouse and open field conditions. Calculations are presented in Appendix X.

4.4.1 Estimation of ETo by Pan evaporation method

4.4.1.1 *ETo from reduced pan* data

Daily pan evaporation and pan coefficient were used to estimate the ETo from reduced pan inside polyhouse and open field. Daily Pan Evaporation (E_p) was obtained by monitoring the water level in the stilling well. A pan coefficient of 0.4564 was taken for conversion of reduced pan evaporation data to data from free water surface (Modaberi *et al*., 2014).

Table 4.11 and 4.12 shows ETo from reduced pan inside polyhouse and open field. Minimum and maximum daily ETo values were recorded during 1st and 4th week of the crop growing period as 2.15 to 3.10 mm/day with a seasonal average of 2.48 mm/day inside the polyhouse. For open field conditions also, minimum and maximum daily ETo values were recorded during 1st and 4th week of crop growing period as 2.61 to 3.79 mm/day with a seasonal average of 2.92 mm/day.

Table 4.11 ETo from reduced pan data – polyhouse

Period	**E_p in mm**	**ETo = E_p * K_p (mm)**	**ETo mm/day**
1st week	33.00	15.06	2.15
2nd week	38.20	17.43	2.49
3rd week	43.40	19.81	2.83
4th week	47.60	21.72	3.10
5th week	38.90	17.75	2.54
6th week	38.90	17.75	2.54
7th week	36.40	16.61	2.37
8th week	36.50	16.66	2.38
9th week	37.40	17.07	2.44
10th week	35.20	16.07	2.30
11th week	34.90	15.93	2.28
12th week	37.80	17.25	2.46
13th week	36.00	16.43	2.35
Average	**38.02**	**17.35**	**2.48**

Table 4.12 ETo from reduced pan data –open field

Period	**E_p in mm**	**ETo = E_p * K_p (mm)**	**ETo mm/day**
1st week	40.10	18.30	2.61
2nd week	43.90	20.04	2.86
3rd week	49.10	22.41	3.20
4th week	58.10	26.52	3.79
5th week	45.20	20.63	2.95
6th week	47.20	21.54	3.08
7th week	42.70	19.49	2.78
8th week	42.80	19.53	2.79
9th week	43.60	19.90	2.84
10th week	41.50	18.94	2.71
11th week	45.20	20.63	2.95
12th week	41.30	18.85	2.69
13th week	41.20	18.80	2.69
Average	**44.76**	**20.43**	**2.92**

4.5 ETo estimated using climatological models

ETo was estimated by FAO-56 Penman-Monteith method for polyhouse and open field conditions using daily values of minimum temperature, maximum temperature, humidity, sunshine hours, and wind speed data for twelve months as input. For polyhouse conditions, climate data were measured daily at site and for open field conditions, climate data collected from the observatory was used.

Table 4.13 shows calculated ETo for polyhouse and open field conditions. Inside the polyhouse, maximum and minimum daily average ETo recorded in the 1st and 7th week of crop period were 4.49 and 3.23 mm/day respectively. For open field conditions, maximum and minimum ETo was recorded during 1st and 7th week of crop period and values obtained were 5.10 and 3.52 mm/day respectively.

ETo was estimated by FAO-Blaney- Criddle method for polyhouse and open field conditions using daily values of mean temperature, humidity, sunshine hours, and wind speed as input data.

Table 4.13 shows calculated ETo for polyhouse and open field conditions. Maximum and minimum of weekly average ETo were recorded in the 3rd and 12th week of crop period and values obtained were 8.82 and 6.03 mm/day respectively inside the polyhouse. For open field condition, maximum and minimum ETo was recorded during 3rd and 13th week of crop period and obtained values were 10.22 and 7.04 mm/day respectively.

ETo was estimated by Thornthwaite method for polyhouse and open field conditions using monthly average values of mean temperature, maximum temperature and sunshine hours data for twelve months as input.

Table 4.13 shows calculated ETo for polyhouse and open field conditions. Maximum and minimum of weekly average ETo was recorded in the 3rd and 1st week of crop period and values obtained were 8.53 and 4.09 mm/day respectively inside the polyhouse. For open field condition, maximum and minimum ETo was recorded during 7th and 13th week and obtained values were 10.07 and 3.68 mm/day respectively.

In recent years, FAO-56 Penman-Monteith method gained more importance to estimate reference evapotranspiration. It provides better results in both arid and humid regions because it takes into account all climatological parameters. Hence, this model has been recommended as a standard method for estimating reference evapotranspiration (Gotardo *et al.,* 2016).

Taking FAO-56 Penman-Monteith method as standard, ETo estimated by other methods was compared. Fig. 4.4 shows variation of ETo estimated from climatological models. From the results it is understood that FAO-Blaney- Criddle and Thornthwaite methods over estimated the ETo values compared to FAO-56 Penman-Monteith method. The variation between poly house and open field ETo was almost similar in all models with less value in poly house compared to open field. The difference was higher in Blaney Criddle method as is obvious from the figure. This may be due to the variation of temperature between poly house and outside field and the dependence of this method on temperature data alone. The graphs showed similar trend in other models though Thornthwaite method over estimated the values.

Table 4.13 Average daily ETo from climatological methods

ETo (mm)						
Crop growth period	**FAO-56 Penman-Monteith**		**FAO Blaney-Criddle**		**Thornthwaite**	
	Polyhouse	**Open field**	**Polyhouse**	**Open field**	**Polyhouse**	**Open field**
1st week	3.23	3.52	6.52	7.79	4.09	4.68
2nd week	3.88	4.56	7.61	10.18	7.45	8.69
3rd week	4.33	4.71	8.82	10.22	8.53	9.03
4th week	3.83	4.33	7.55	9.68	6.52	7.08
5th week	4.13	4.62	7.61	9.28	6.97	7.61
6 th week	4.12	4.85	7.14	9.73	7.53	9.06
7 th week	4.49	5.1	7.99	9.92	8.16	9.32
8th week	3.9	4.74	6.41	9.11	6.19	7.27
9 th week	4.25	4.95	7.14	9.33	6.62	7.95
10 th week	4.48	5.06	7.7	9.51	7.63	8.51
11th week	4.12	4.58	6.93	8.38	5.88	6.47
12th week	3.78	4.07	6.03	7.25	4.12	4.37
13th week	3.73	3.99	5.84	7.04	4.13	4.19
Average	**4.02**	**4.54**	**7.18**	**9.03**	**6.45**	**7.25**

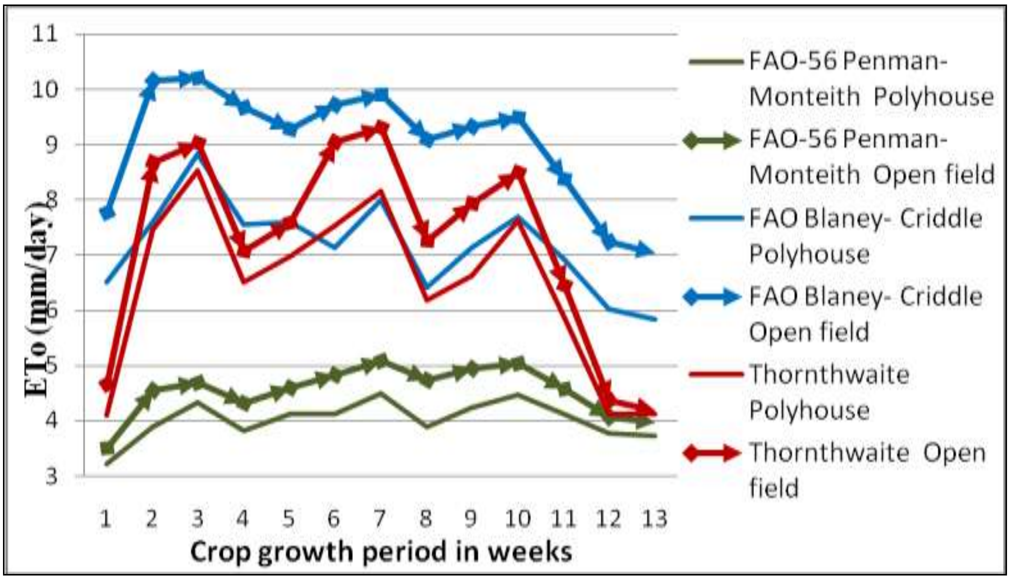

Fig. 4.4 Variation of average daily ETo estimated from climatological models

4.4.6 Comparison of direct and indirect methods of ET estimation

ETo estimated using five indirect methods *viz* Pan evaporation,FAO-56 Penman-Monteith, FAO Blaney- Criddle and Thornthwaite were compared with measured lysimetric data using simple error analysis and linear regression. For each method, coefficient of determination (R^2) Root Mean Square error (RMSE), Relative root mean square error (Rel RMSE) and Mean Absolute Error (MAE) were calculated for inside poly house and open field conditions.

Measured and estimated ETo were compared by linear regression analysis as shown in figs.4.5 and 4.6 for polyhouse and open field conditions. From the results, it was observed that reduced pan and FAO -56 Penman-Monteith methods under estimated the data where as Blaney- Criddle and Thornthwaite methods over estimated ETo compared to lysimetric data. Out of these methods, FAO-56 Penman- Monteith correlated well with lysimetric data with higher R^2 value.

Summary of statistics of comparison between ET methods is shown in Tables 4.14 and 4.15.From the results, FAO-56 Penman-Monteith method obtained higher R^2 value and least RMSE, RelRMSE and MAE. Least R^2 value, higher RMSE, RelRMSE and MAE were obtained for Blaney- Criddle and Thornthwaite methods inside polyhouse and open field conditions. This may be because the two methods use minimum climatic parameters for the estimation of ETo. It can be concluded that the FAO -56 Penman-Monteith provides quite good agreement with evapotranspiration obtained by lysimetric data.

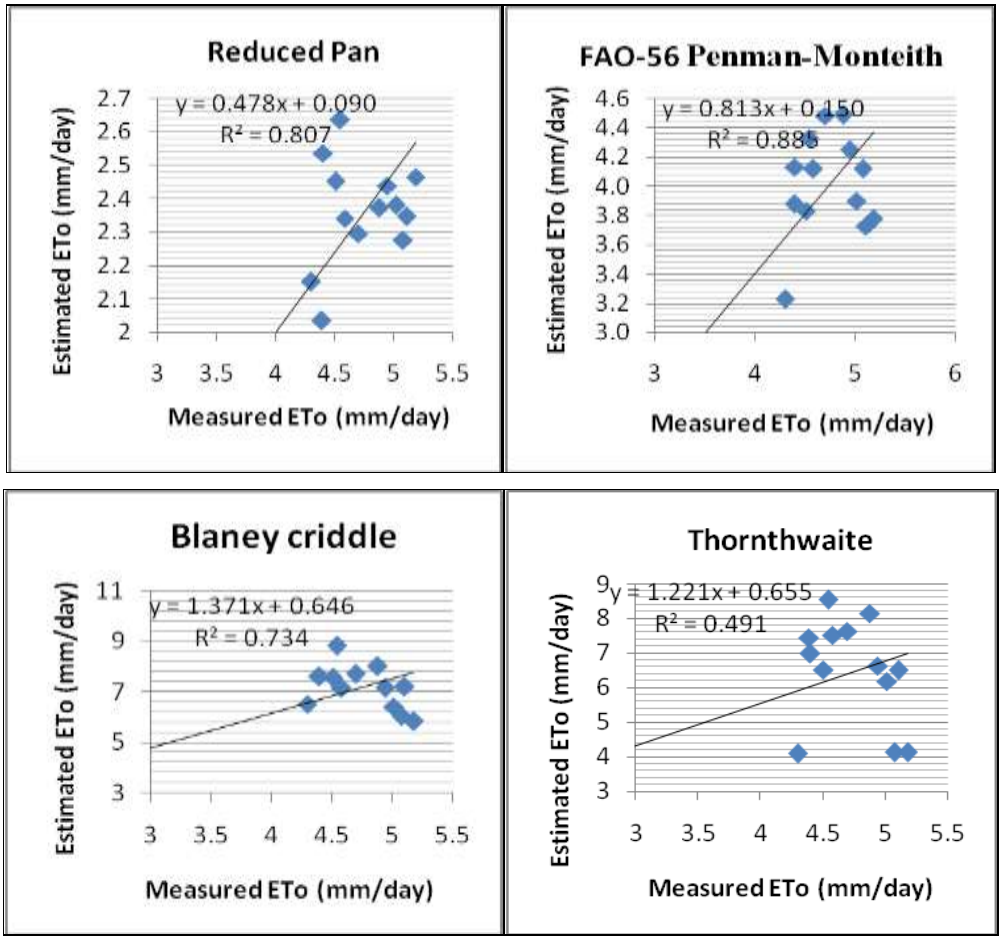

Fig. 4.5 Comparison between measured and estimated ETo -polyhouse

Table 4.14 Summary of statistical comparison of ET methods -polyhouse

	Reduced pan	**FAO -56 Penman-Monteith**	**FAO- Blaney-Criddle**	**Thornthwaite**
RMSE	1.39	0.81	2.61	2.35
MAE	1.37	0.72	2.45	2.01
Rel RMSE	0.5	0.17	0.55	0.49
R^2	0.8	0.88	0.73	0.49

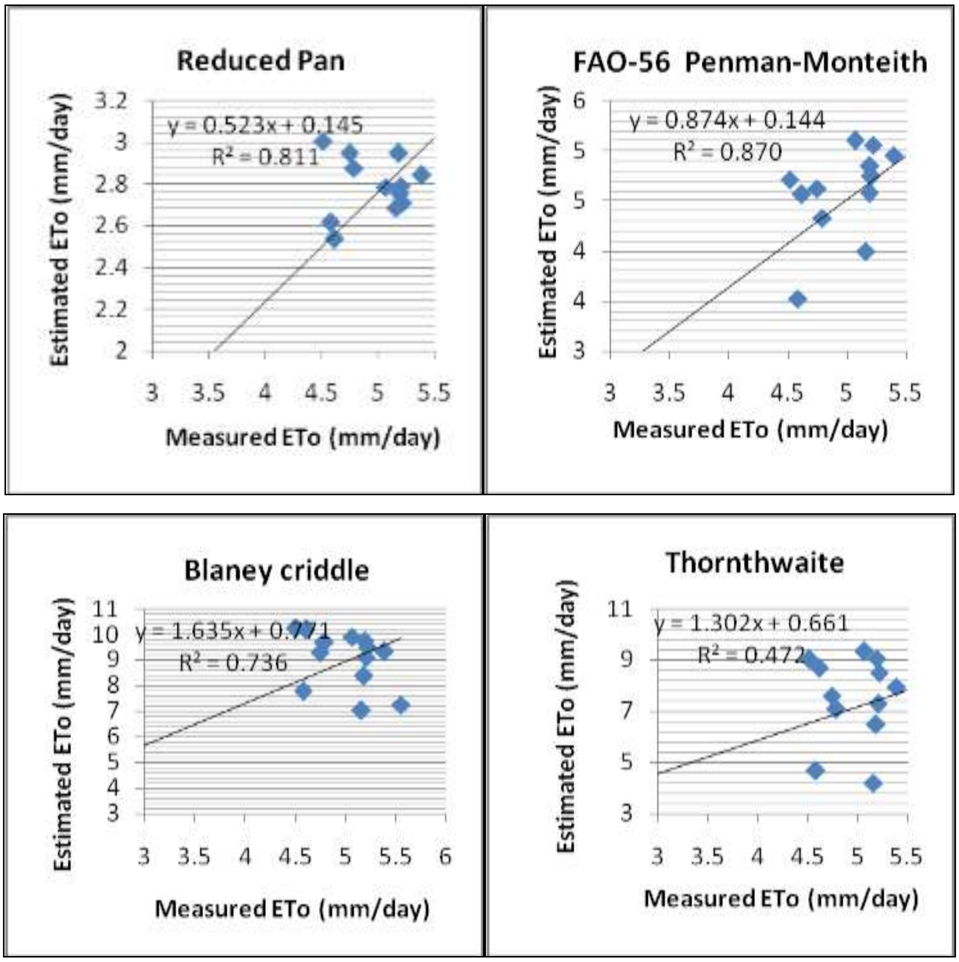

Fig. 4.6 Comparison between measured and estimated ETo –open field

Table 4.15 Summary of statistical comparison of ET methods -open field

	Reduced pan	**FAO -56 Penman Monteith**	**FAO- Blaney Criddle**	**Thornthwaite**
RMSE	1.26	0.67	4.14	2.81
MAE	1.23	0.5	4.01	2.56
Rel RMSE	0.45	0.133	0.835	0.39
R^2	0.81	0.87	0.71	0.47

In humid climate conditions, Yoder *et al*., (2005) compared eight reference evapotranspiration models with measured ETo by lysimetric data. Based on their results, FAO-56 PM performed better among other models for estimating ETo. For semiarid regions, Trajkovic and Gocic, (2010) evaluated seven ETo models against

ETo measured by lysimeters. They reported that the performance of the FAO-56 PM on a daily basis was the best among other models.

4.5 COMPARISON OF DIRECT MEASURED ET PARAMETERS FOR POLYHOUSE AND OPEN FIELD CONDITIONS

4.5.1 Climatic parameters -Polyhouse vs Open field

During crop growth period, microclimate inside the polyhouse was recorded. Temperature and relative humidity were observed as per the procedure detailed in section 3.7.2.3. For open field conditions temperature and relative humidity data were taken from the meteorological observatory.

Fig. 4.7 shows weekly mean values of temperature inside polyhouse as compared to open field conditions during the crop growing season. For polyhouse conditions, maximum and minimum temperature recorded values were 31.86 and 29.32^{o}C during 9th and 13th week of crop period respectively, whereas 30.06 and 26.51^{o}C were observed during 12th and 2nd week for open field conditions.

From the data it is seen that higher temperature was recorded inside the polyhouse than open field conditions. Maximum temperature was recorded in the ninth week inside poly house. The values of maximum and minimum temperature varied by about 2^{o}C between poly house and open field conditions. Higher temperature is helpful to attain early maturity and yield. Cheema *et al*. (2004) reported that the early and higher yield of different vegetable crops inside the polyhouse was mainly because of better microclimate such as higher temperature (4-9^{o}C more than the open field).

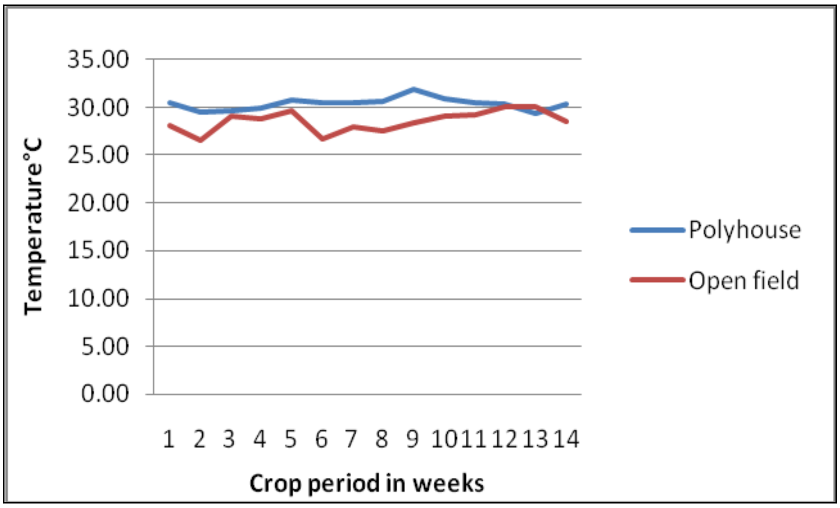

Fig. 4.7 Weekly temperature variation between polyhouse and open field

Fig. 4.8 shows variation of weekly mean relative humidity between polyhouse and open field during crop growing season. For polyhouse conditions, maximum and minimum relative humidity values were 83.29 and 71.71 per cent during 3rd and 6th week of crop period respectively, whereas 81.86 and 72.57 per cent were observed during 2nd and 6th week for open field conditions. Results indicated that the relative humidity inside the polyhouse was higher than that of open field conditions almost throughout the crop period.

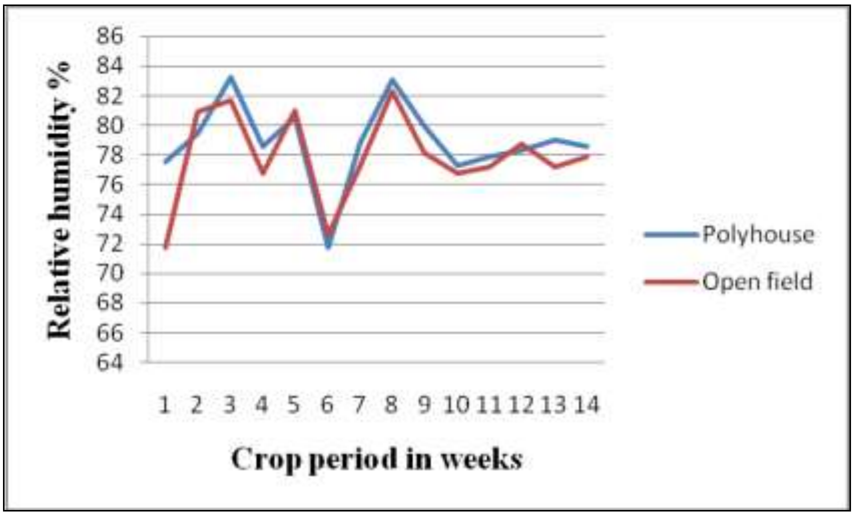

Fig. 4.8 Variation of weekly relative humidity between polyhouse and open field

Fernandez *et al.* (2000) had reported that the lesser evapotranspiration inside greenhouses may be due to the less wind, reduced solar radiation, and higher atmospheric humidity. Consequently, greenhouse crops have noticeably less water requirement and higher water use efficiency. Additionally, the autumn to spring growing season of crops in the plastic greenhouses will significantly modify the pattern of crop growth, which is likely to effect the water requirement.

4.5.2 Comparison of measured ETo - polyhouse and open field

ETo estimated from Non weighing lysimeters inside polyhouse and open field were compared. Fig.4.9 and Table 4.16 shows comparison of ETo between polyhouse and open field. Seasonal ETo for polyhouse and open field were 4.74 and 5.02 mm/day. From the figure, it is evident that ETo values were low inside the polyhouse than open field conditions. This may be due to the lower wind speed and lower incidence of direct solar radiation inside polyhouse.

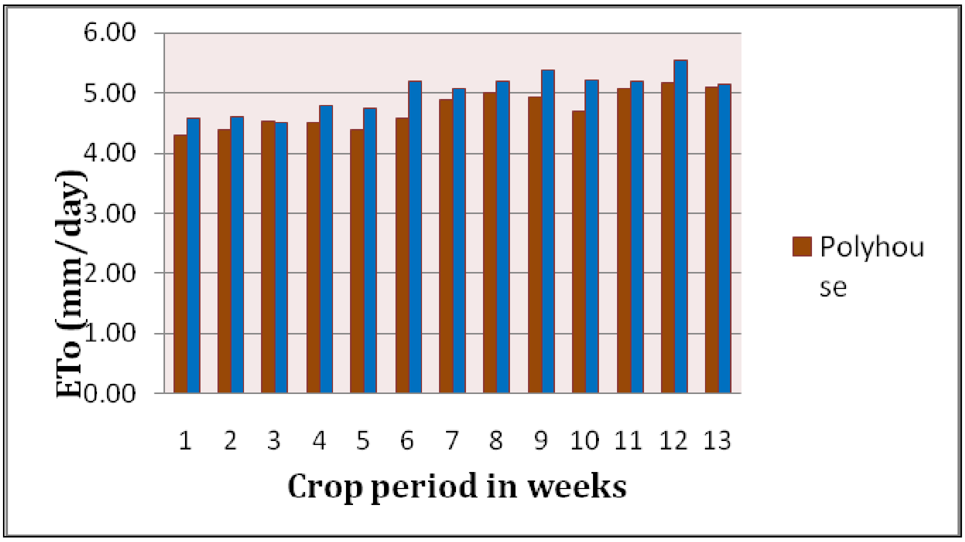

Fig.4.9 Comparison of ETo in polyhouse and open field

Table 4.16 Weekly mean values of measured ETo in polyhouse and open field

Growing period	**Measured ETo (mm/day)**	
	Polyhouse	**Open field**
1st week	4.30	4.58
2nd week	4.39	4.61
3rd week	4.54	4.51
4th week	4.51	4.79
5th week	4.40	4.74
6th week	4.58	5.19
7th week	4.88	5.07
8th week	5.02	5.20
9th week	4.94	5.39
10th week	4.70	5.22
11th week	5.07	5.19
12th week	5.18	5.56
13th week	5.10	5.16
Average	**4.74**	**5.02**

The plants inside the polyhouse received about 18-21 % less energy as net solar radiation than the outside conditions. The reduction of solar energy received by the plants also results in the reduced evapotranspiration inside polyhouse (Neelam *et al.*, 2009). Observed results were similar to the previous observations and they reported that polyhouse changes the radiation balance, usually with a reduction of at least 30 per cent in the incoming radiation. The reduced incoming radiation coupled with negligible wind results in reduced ETo inside the polyhouse, even though the temperatures are higher (Moller and Assouline, 2007).

4.5.2 Comparison of measured ETc for polyhouse and open field

ETc measured from the mini lysimeter inside the polyhouse and open field for Okra crop was compared. Fig.4.10 and Table 4.17 shows comparison of ETc between polyhouse and open field.

From the figure it is understood that the ETc increases from initial stage to mid season stage and then decreases in late season stage for polyhouse and open field conditions. Seasonal ETc values of okra for polyhouse and open field conditions were 3.90 and 4.31mm/day. It is evident that, ETc was lower inside the polyhouse than open field even though, applied irrigation water, fertilizer dosage and crop duration period were similar for both conditions. This may be due to the lesser values of weather parameter like wind speed and solar radiation inside polyhouse which might have contributed to lesser water requirement. The advantages of low wind speed include low evapotranspiration rate and consequent lesser water requirements (Abou-Hadid *et al.*, 1994).

Table 4.17 Weekly mean values of measured ETc in polyhouse and open field

Growing period	**Measured ETc (mm/day)**	
	Polyhouse	**Open field**
1st week	2.23	2.57
2nd week	2.49	2.61
3rd week	2.97	3.15
4th week	3.99	4.59
5th week	4.39	4.77
6th week	4.60	5.12
7th week	4.64	5.08
8th week	4.43	5.10
9th week	4.76	4.99
10th week	4.77	5.19
11th week	4.44	5.09
12th week	3.72	3.93
13th week	3.23	3.81
Average	**3.90**	**4.31**

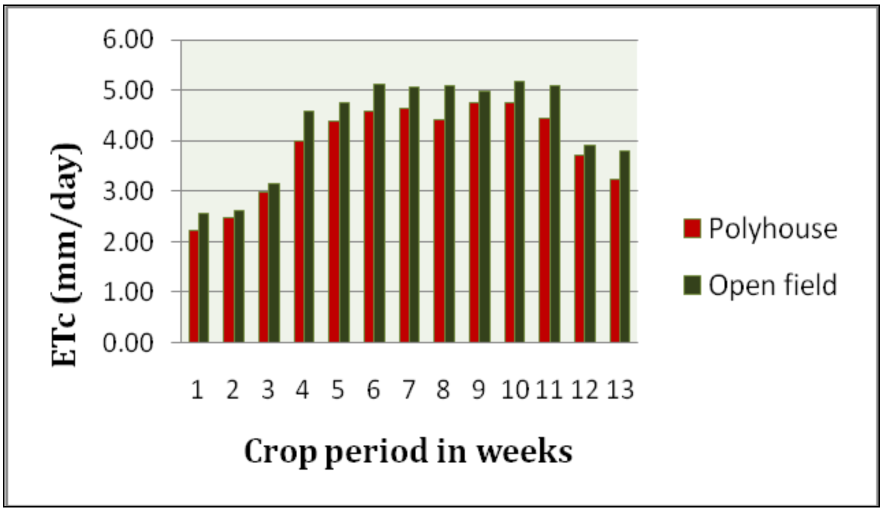

Fig.4.10 Comparison of ETc in polyhouse and open field

4.6 CROP GROWTH AND YIELD PARAMETERS

4.6.1 Plant height

The data on plant height at different stages of okra was recorded for selected plants inside the polyhouse and open field and the data are given in Table 4.18 and Fig.4.11. Plant height increased with respect to crop stage in both conditions. At the late season stage of the crop period inside the polyhouse, plant height was 163.3 cm, which was found higher than the open field conditions (129.3 cm). This may be attributed to the enhanced plant metabolic activities like photosynthesis and respiration due to favorable micro climatic conditions that prevailed in the polyhouse as compared to the open field conditions.

Table 4.18 Mean values of okra plant height in different crop stages

Plant height in cm			
Treatment	**Initial Stage**	**Mid season stage**	**Late season stage**
Polyhouse	24.6	118.8	163.3
Open field	17	96.6	129.3

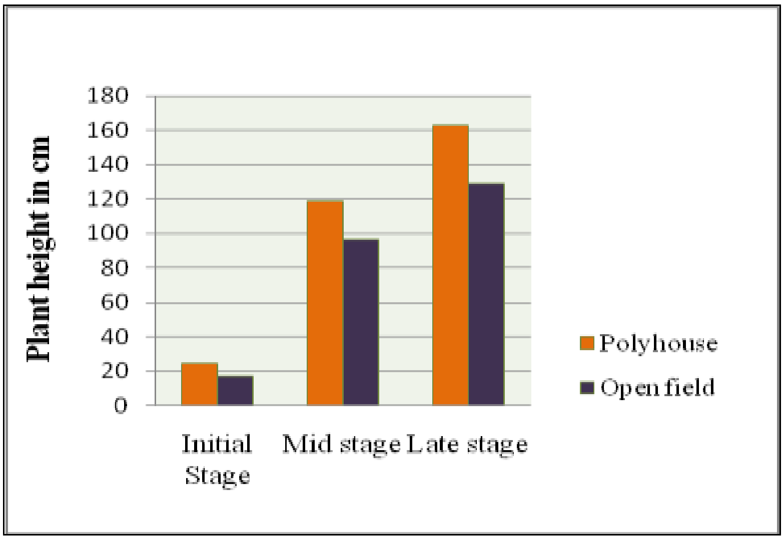

Fig.4. 11 Variation of plant height between polyhouse and open field

4.6.2 Number of branches

The data on number of branches at different stages of okra was recorded for selected plants inside the polyhouse and open field as shown in Table 4.19 and Fig.4.12. Number of branches increased with respect to crop stage in both conditions. At the late season stage of the crop period, the number of branches inside the polyhouse and open field were observed to be same.

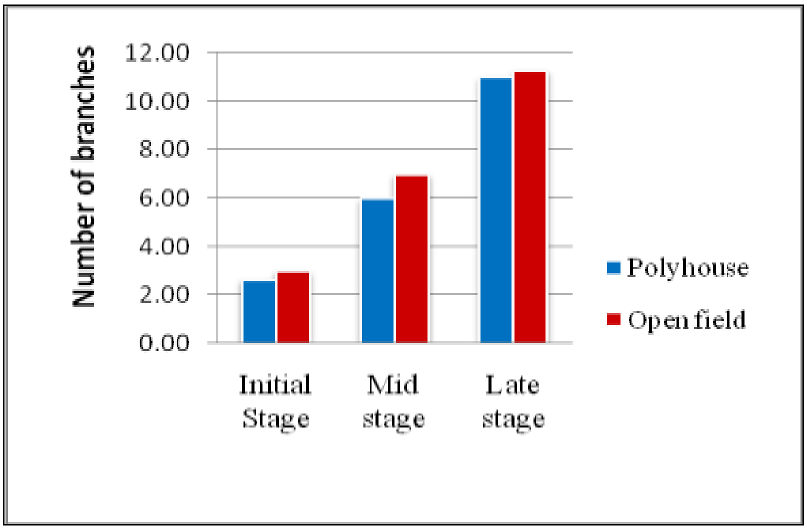

Fig. 4.12 Variation of no of branches between polyhouse and open field

Table 4.19 Mean of the number of branches in different crop stages

Number of branches			
Treatments	**Initial Stage**	**Mid stage**	**Late stage**
Polyhouse	2.66	6.00	11.00
Open field	3.00	7.00	11.00

4.6.3 Number of leaves

The data on number of leaves at different stages of okra were recorded for selected plants inside the polyhouse and open field as shown in Table 4.20 and Fig.4.13. Number of leaves increased with respect to crop stage in both conditions. At the late season stage of the crop period inside the polyhouse, number of leaves was 42, which was found to be higher than the open field conditions (38). Plate 4.1 and 4.2 shows okra crop during initial stage for polyhouse and open field conditions. Plate 4.3 and 4.4 shows okra crop during maturity stage for polyhouse and open field conditions.

Table 4.20 Number of leaves in different crop stages

Number of leaves			
Treatments	**Initial Stage**	**Mid stage**	**Late stage**
Polyhouse	16	39	42
Open field	16	36	38

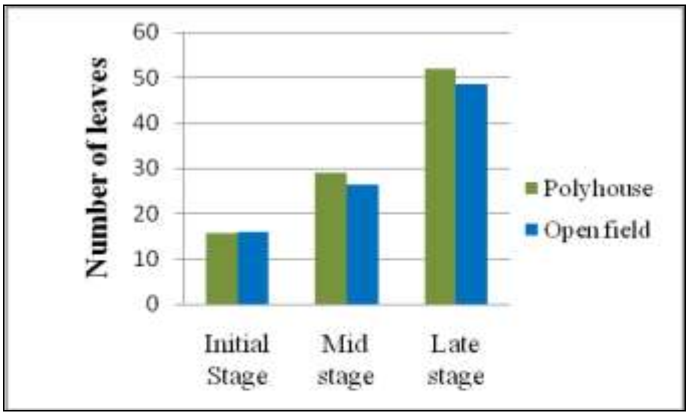

Fig. 4.13 Variation of no of leaves between polyhouse and open field

a) Okra crop in lysimeter during initial stage

b) Overall view of okra during initial stage

Plate 4.1 Okra crop during initial stage-polyhouse

a) Okra crop in lysimeter during initial stage

b) Overall view of okra during initial stage

Plate 4.2 Okra crop during initial stage-open field

a) Okra crop in lysimeter during maturity stage

b) Overall view of okra during maturity stage

Plate 4.3 Okra crop during maturity stage-polyhouse

a) Okra crop in lysimeter during maturity stage

b) Overall view of okra during maturity stage

Plate 4.4 Okra crop during maturity stage-open field

4.6.4 Crop yield

Plate 4.5 shows crop yield inside polyhouse and open field. The data on crop yield of Okra was recorded for selected plants inside the polyhouse and open field as shown in Table 4.21 and Fig.4.14. The total crop yield per plant was recorded as 0.54 and 0.55 kg respectively for polyhouse and open field conditions. Total yield per square meter was 2.57 and 2.62 kg respectively. No significant variation in yield was noted. But, for the same quantity of applied irrigation, evapotranspiration loss was lesser inside poly house compared to open field.

a) Polyhouse b) open field

Plate 4.5 Harvested okra

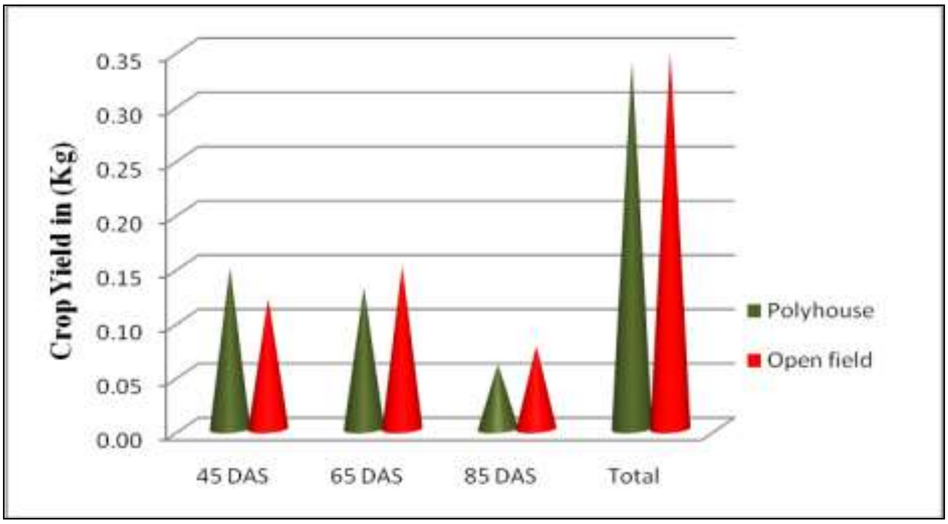

Fig.4.14 Comparison of crop yield per plant between polyhouse and open field

Table 4.21 Variation of crop yield between polyhouse and open field

Crop Yield (kg/m^2)				
Treatments	**45 DAS**	**65 DAS**	**85 DAS**	**Total**
Polyhouse	0.95	1.33	0.29	2.57
Open field	0.81	1.43	0.38	2.62

Table 4.22 and 4.23 shows consolidated data of evapotranspiration for polyhouse vs. open field. The study revealed that seasonal average daily ETc and Kc of Okra were lower inside the polyhouse than that of open field conditions even though, applied irrigation water and crop duration period were similar for both conditions. Approximately, 9.5% reduction in ET_0 was experienced inside poly house during the study period which implies a consequent reduction in water requirement compared to open field. The variations in micro climate inside poly houses with reduced solar radiation and wind velocity combined with higher humidity and temperature may have contributed to lesser ET. Earlier studies have also reported similar results for poly house cultivation in other regions. The results of this study can be used as a guideline in the computation of water requirement of poly house crops instead of depending on open field accepted values for Tavanur region.

If the poly house irrigation is scheduled in such a way as to apply the right quantity of water enough to meet the evapotranspiration requirements of crops, water saving can be achieved without compromising yield. Studies have reported increased yield inside poly houses under controlled climatic conditions and the saving of even a small quantity of water for one crop season reflects considerable saving of water in year round cultivation. The quality of produce is high, duration of crop season is longer and year round cultivation is possible inside poly houses which implies significant saving in water without compromising yield and product quality.

Table.4.22 Consolidated data - polyhouse vs. open field

Measured data	**Polyhouse**			**Open field**		
Seasonal average daily ET_0(mm)	3.90			4.31		
Seasonal average daily ET_c(mm)	4.74			5.02		
K_C value	0.58	0.94	0.67	0.61	0.98	0.72

Table 4.23 ETo estimated by indirect methods

Estimated Data	**Average daily ET_0(mm)- Polyhouse**	**Average daily ET_0(mm)- Open field**
Reduced pan	2.48	2.92
FAO-56 Penman-Monteith	4.02	4.54
FAO Blaney-Criddle	7.18	9.03
Thornthwaite	6.45	7.25

From the study, it could also be concluded that the FAO -56 Penman-Monteith method provides quite good agreement with evapotranspiration obtained by direct measurements with lysimetric data. In the absence of direct measured data, this method could be used for estimation of evapotranspiration parameters of crops for all growth conditions. The crop coefficient values of Okra obtained from the study for both Poly house and Open field conditions 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.

Suggestions for future research

- Long term data is important for comparing crop evapotranspiration parameters between polyhouse and open field conditions.
- Detailed studies with daily data collected for a year is needed for establishing the statistical correlations between direct measured and model estimated ET data.

Summary and Conclusion

CHAPTER 5

SUMMARY AND CONCLUSION

Field experiment on the comparative evaluation of evapotranspiration parameters in a naturally ventilated polyhouse and open field was conducted in the research plot of the Department of Irrigation and Drainage Engineering, in KCAET campus, Tavanur, Kerala during February 18th - April 23rd 2017. In the study, Non-Weighing Mini-Lysimeters were used for direct determination of evapotranspiration parameters, ET_0 and ET_c and to develop crop-coefficient curves for Okra. Comparison with indirect methods was also done in order to assess the dependability of climatic data on evapotranspiration estimates. The study also compares the data for open field and poly house conditions in order to quantify the effect of micro climatic variations on evapotranspiration.

The poly house was oriented east–west with an overall area of 213 m^2 (26 m length and 8 m width). The open field trial was conducted in the nearby area in front of the naturally ventilated polyhouse. Land preparation was done inside the naturally ventilated polyhouse and in the open field. Polyhouse was divided into two parts for cultivating Okra crop (*Varsha Upahar*) and Grass reference crop (*Kango signal*). Four raised beds of 10 m length, 1.0 m width and 0.25 m height were made and plastic troughs and grow bags were placed on the beds for cultivating Okra. A reduced pan was installed in the middle of the polyhouse leaving an area of 48 m^2 without crop. The beds of the same dimensions were continued in the other half for planting grass. Six mini Non weighing lysimeters were used inside the poly house and open field respectively, of which, three were planted with Okra and three with grass. Lysimeters were placed randomly on the raised beds in the naturally ventilated polyhouse. Each lysimeter was filled with sandy soil collected from the field. Three Okra plants were planted in each lysimeter. Other three identical lysimeters were planted with Grass. Lysimeters were surrounded by the same crop in grow bags (40×24 cm) in the same density in order to avoid the border effect. The trials were replicated outside the polyhouse in the selected area with an identical setup.

The value of bulk density and dry density were observed as 1.63 g/cc and 1.52 g/cc respectively. Soil texture was analyzed by sieve analysis and it was found that 99.4 per cent of the soil was sandy and the remaining 0.6 per cent comprised of fines. It could be concluded that the soil was predominantly sandy. The values of field capacity, permanent wilting point and available moisture range for the soil were measured using pressure plate apparatus as 34.84, 26.09 and 8.7 per cent volumetric basis.

The amount of irrigation water applied, drainage from Non weighing mini lysimeters, effective rainfall and change in soil moisture storage were observed to measure the ETo and ETc in poly house and open field conditions using soil water balance approach.

Inside the polyhouse, the average daily ETo values of the reference crop varied from 4.30 to 5.10 mm/day with a seasonal average of 4.74 mm/day. For open field conditions, the daily ETo values of the reference crop varied from 4.58 to 5.16 mm/day with a seasonal average of 5.02 mm/day. In both conditions ET_0 was lesser in the initial stages and increased towards the late season stages when the crop height exceeded the reference height.

Inside the polyhouse, average daily ETc values of the Okra crop were 2.56, 4.5 and 3.47 mm/day during the initial stage, mid season stage and late season stage respectively. For open field conditions the average daily ETc values of the Okra crop were 2.78, 4.99 and 3.87 mm/day during the initial stage, mid season stage and late season stage respectively. This implied that lowest seasonal ETc was observed in the initial stage and highest ETc was observed in mid season stage in both conditions. ETc increased from initial stage to mid season stage and then decreased in late season stage.

Crop coefficient values of Okra were calculated as the ratio of ETc and ETo. Weekly values of ET_c and ET_o were estimated by the soil water balance approach using lysimeters for polyhouse and open field conditions. Inside the polyhouse, Kc was around 0.58 during the crop establishment stage or initial stage and then Kc increased gradually, reaching a maximum value of 0.94 in the mid season stage and finally, Kc declined to 0.67 in the late season stage. In the open field, values were 0.61, 0.98 and 0.72 during initial, mid and late season stages respectively. During initial stage, Kc values were lower compared to mid season stage in both conditions. Kc values were higher until early harvesting time and slightly declined towards the end of the crop growth period and it was observed that Kc for polyhouse conditions was lesser than that for open field conditions.

ETo estimated from five methods namely reduced pan, FAO -56 Penman-Monteith, FAO Blaney- Criddle and Thornthwaite were compared with measured lysimetric data using simple error analysis and linear regression. For each method, coefficient of determination (R^2) Root Mean square error (RMSE), Relative root mean square error (Rel RMSE) and Mean absolute error (MAE) were calculated for inside poly house and open field conditions. From the statistical analysis, FAO-56 Penman-Monteith method obtained higher R^2 value and least RMSE, Rel RMSE and MAE. Least R^2 value, higher RMSE, Rel RMSE and MAE were obtained for Blaney- Criddle and Thornthwaite methods inside polyhouse and open field conditions. It could be concluded that the FAO -56 Penman-Monteith model provides quite good agreement with evapotranspiration values obtained by direct measured lysimetric data.

During crop growth period, microclimate inside the polyhouse was recorded. From the data it was seen that higher temperature was recorded inside the polyhouse than open field conditions. The relative humidity inside the polyhouse was higher than that of open field conditions almost throughout the crop period.

ETo and ETc measured from Non weighing mini- lysimeters inside polyhouse and open field were compared. Seasonal ETo for polyhouse and open field was 4.74 and 5.02 mm/day. Seasonal ETc values of Okra for polyhouse and open field conditions were 3.90 and 4.31mm/day. ETo and ETc values were low inside the polyhouse than that of open field conditions. Crop growth and yield parameters were observed during crop growth period at each stage. Inside the polyhouse, plant height was 163.3 cm, which was found higher than the open field conditions (129.3 cm). The number of branches inside the polyhouse and open field were11.0 and 11.0 respectively and there was no much variation in crop vegetative growth between poly house and open field. Inside the polyhouse, number of leaves was 42, which was found higher than the open field conditions (38). The total crop yield per plant was recorded as 0.54 and 0.55 kg respectively and there was no much variation between polyhouse and open field conditions.

The consumptive use requirements of agricultural crops is an important component in irrigation planning and water resources management. FAO has published Kc values and length of the crop development stages for various crops. These values are widely used for open field cultivation and are as such adopted for polyhouses. These proposed Kc values are affected by various factors such as difference in plant spacing, crop height and aerodynamic properties. Moreover, the measure of diffuse radiation in polyhouse is differing from outdoors. The results obtained from this study reveal that polyhouse Kc values were lower than the open field values and hence these values can be used in Tavanur region for polyhouse cultivation instead of Kc values proposed by researchers for other regions.

Measured ETo using lysimeter was compared with indirect methods. Out of all methods FAO-56 Penman-Monteith provides quite good agreement with evapotranspiration obtained by lysimetric data. In the absence of direct measured data, this method could be used for estimation of evapotranspiration parameters of crops for all growth conditions. It was observed that evapotranspiration was lower inside the polyhouse than open field conditions. Approximately, 9.5% reduction in ET_0 was experienced inside poly house during the study period which implies a consequent reduction in water requirement compared to open field. The variations in micro climate inside poly houses with reduced solar radiation and wind velocity combined with higher humidity and temperature may have contributed to lesser

ET. The results of this study can be used as a guideline in the computation of water requirement of poly house crops instead of depending on open field accepted values for Tavanur region. More research with daily measured data for extended time periods is required to establish the results.

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Appendices

APPENDIX I

Physical properties of soil by Core cutter method

Calculations

Weight of core soil (W) : 1472.5 g

Volume of core soil (V) : 900.20 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

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

$= 1472.5/900.20$

$= 1.63$ g/cc

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

$= 1.63/(1+7.48)$

$= 0.19$ 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
	<75 µ	256.0	264.5	8.5	0.6	100.0	0.0
				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

Applied irrigation water and drainage collected from lysimeters - polyhouse reference crop.

Crop period in weeks	Applied irrigation in mm	Drainage in mm		
		Lysimeter-1	Lysimeter-2	Lysimeter-3
1	75.81	37.55	37.69	37.91
2	75.81	38.84	38.63	37.55
3	75.81	37.40	37.26	36.03
4	75.81	36.10	35.88	35.45
5	75.81	36.53	36.10	36.32
6	75.81	37.18	36.75	36.61
7	75.81	37.04	36.97	36.68
8	75.81	36.82	36.10	36.10
9	75.81	34.08	33.50	33.94
10	75.81	33.14	33.14	33.36
11	75.81	32.27	31.91	31.41
12	75.81	30.76	30.18	30.11
13	75.81	30.69	29.53	29.53

Applied irrigation water and drainage collected from lysimeters – open field reference crop.

Crop period in weeks	Applied irrigation in mm	Drainage in mm		
		Lysimeter-1	Lysimeter-2	Lysimeter-3
1	75.81	33.50	33.14	31.41
2	75.81	32.92	31.91	32.49
3	75.81	31.62	31.77	31.91
4	75.81	32.56	32.92	33.07
5	75.81	34.37	34.30	34.01
6	75.81	33.94	33.86	34.44
7	75.81	33.57	33.65	34.15
8	75.81	33.79	34.01	34.37
9	75.81	31.55	31.84	31.48
10	75.81	30.76	30.90	30.97
11	75.81	29.60	29.60	28.74
12	75.81	28.30	27.94	27.36
13	75.81	29.68	29.82	28.74

Applied irrigation water and drainage collected from lysimeters – polyhouse Okra crop.

Crop period in weeks	Applied irrigation in mm	Drainage in mm		
		Lysimeter-1	Lysimeter-2	Lysimeter-3
1	101.08	50.11	49.75	47.94
2	101.08	44.40	44.62	43.90
3	101.08	43.18	41.44	41.88
4	151.62	58.63	58.48	58.99
5	151.62	57.33	57.11	57.26
6	151.62	53.43	53.14	53.14
7	151.62	50.76	50.04	49.46
8	151.62	47.51	46.50	46.50
9	151.62	47.00	46.50	46.21
10	151.62	43.32	42.60	43.25
11	151.62	41.95	41.08	41.01
12	126.35	41.59	41.30	41.23
13	126.35	47.44	49.17	48.30

Applied irrigation water and drainage collected from lysimeters – open field Okra crop.

Crop period in weeks	Applied irrigation in mm	Drainage in mm		
		Lysimeter-1	Lysimeter-2	Lysimeter-3
1	101.08	42.60	41.66	42.82
2	101.08	39.71	37.40	37.04
3	101.08	38.99	37.04	36.03
4	151.62	50.47	50.11	49.82
5	151.62	46.71	46.50	44.91
6	151.62	44.55	43.47	43.97
7	151.62	43.25	43.03	43.10
8	151.62	40.07	38.19	38.48
9	151.62	38.34	38.05	38.27
10	151.62	39.35	39.13	38.99
11	151.62	37.91	37.91	37.40
12	126.35	37.91	38.05	38.12
13	126.35	45.34	45.56	44.40

APPENDIX V

Change in soil moisture storage for lysimeter-1 (polyhouse Reference crop)

Growth period in weeks	**Gravimetric soil moisture content in 1st layer (%)**	**$((M_{bi}-M_{ei})/100)*(A_i*D_i)$ (1)**	**Gravimetric soil moisture content in 2nd layer (%)**	**$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)**	**Soil moisture Storage change (Δs) Ly=(1)+(2)**
1	36.82	8.17	46.36	0.00	8.17
2	31.82	-1.02	46.36	7.71	6.68
3	32.45	15.84	41.65	-9.14	6.69
4	22.76	-7.66	47.24	14.89	7.23
5	27.44	1.63	38.13	4.67	6.29
6	26.45	4.87	35.28	-1.01	3.86
7	23.47	-2.84	35.90	8.05	5.21
8	25.21	5.08	30.97	-2.10	2.98
9	22.10	5.37	32.26	2.91	8.28
10	18.82	0.59	30.48	11.03	11.62
11	18.46	-3.37	23.73	12.10	8.73
12	20.53	6.15	16.33	3.02	9.18
13	16.76	8.72	14.48	0.80	9.52
14	11.43		13.99		

Change in soil moisture storage for lysimeter-2 (polyhouse Reference crop)

Growth period in weeks	**Gravimetric soil moisture content in 1st layer (%)**	**$((M_{bi}-M_{ei})/100)*(A_i*D_i)$ (1)**	**Gravimetric soil moisture content in 2nd layer (%)**	**$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)**	**Soil moisture Storage change (Δs) Ly=(1)+(2)**
1	42.82	5.10	47.06	5.68	10.79
2	39.70	-13.60	43.59	21.87	8.27
3	48.02	15.95	30.21	-7.77	8.18
4	38.26	5.37	34.96	3.43	8.79
5	34.98	-7.72	32.87	14.14	6.42
6	39.70	3.99	24.22	-0.29	3.70
7	37.26	-1.64	24.39	5.61	3.97
8	38.26	11.53	20.96	-5.81	5.71
9	31.21	0.76	24.52	4.39	5.16
10	30.74	14.28	21.83	-5.04	9.24
11	22.01	3.23	24.92	3.90	7.13
12	20.03	2.69	22.53	7.51	10.20
13	18.39	1.99	17.94	9.41	11.40
14	17.17		12.18		

Change in soil moisture storage for lysimeter-3 (polyhouse Reference crop)

Growth period in weeks	Gravimetric soil moisture content in 1st layer (%)	$((M_{bi}-M_{ei})/100)*(A_i*D_i)$ (1)	Gravimetric soil moisture content in 2nd layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)	Soil moisture Storage change (Δs) Ly=(1)+(2)
1	43.62	8.03	46.11	-2.93	5.09
2	38.71	2.70	47.90	2.58	5.29
3	37.06	0.70	46.32	5.84	6.53
4	36.63	9.20	42.75	0.15	9.35
5	31.01	-5.79	42.66	19.21	13.42
6	34.55	18.13	30.91	-4.99	13.14
7	23.46	16.35	33.96	-11.23	5.12
8	13.46	-18.30	40.83	22.68	4.38
9	24.65	4.70	26.96	4.00	8.70
10	21.78	-1.43	24.51	9.74	8.31
11	22.65	10.21	18.55	-0.78	9.43
12	16.41	7.89	19.03	0.33	8.22
13	11.59	-2.66	18.83	12.24	9.58
14	13.21		11.34		

Change in soil moisture storage for lysimeter-1 (open field Reference crop)

Growth period in weeks	Gravimetric soil moisture content in 1st layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (1)	Gravimetric soil moisture content in 2nd layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)	Soil moisture Storage (Δs) Ly=(1)+(2)
1	48.86	-1.31	57.03	11.83	10.52
2	49.66	8.42	49.80	2.73	11.16
3	44.51	10.09	48.12	2.18	12.27
4	38.34	0.00	46.79	8.31	8.31
5	38.34	-3.67	41.70	14.07	10.40
6	40.59	17.06	33.09	-8.20	8.85
7	30.16	0.00	38.11	7.18	7.18
8	30.16	3.30	33.72	2.31	5.61
9	28.14	-0.71	32.31	9.14	8.43
10	28.57	0.32	26.72	6.35	6.67
11	28.37	10.08	22.83	-2.20	7.89
12	22.21	6.11	24.18	1.48	7.59
13	18.47	3.34	23.27	9.57	12.91
14	16.43		17.42		

Change in soil moisture storage for lysimeter-2 (open field Reference crop)

Growth period in weeks	Gravimetric soil moisture content in 1st layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (1)	Gravimetric soil moisture content in 2nd layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)	Soil moisture Storage (Δs) Ly=(1)+(2)
1	48.76	1.76	55.03	8.83	10.59
2	47.68	10.24	49.63	1.38	11.62
3	41.42	7.32	48.78	5.11	12.43
4	36.95	5.82	45.66	4.58	10.39
5	33.39	-9.73	42.86	17.61	7.88
6	39.34	8.55	32.09	-6.08	2.47
7	34.11	-4.12	35.81	11.05	6.93
8	36.63	5.24	29.05	0.34	5.58
9	33.43	2.32	28.84	2.82	5.14
10	32.01	5.76	27.11	2.13	7.90
11	28.49	5.88	25.81	5.76	11.63
12	24.89	9.72	22.29	-0.61	9.12
13	18.95	2.41	22.66	9.84	12.25
14	17.47		16.64		

Change in soil moisture storage for lysimeter-3 open field (Reference)

Growth period in weeks	Gravimetric soil moisture content in 1st layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (1)	Gravimetric soil moisture content in 2nd layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)	Soil moisture Storage (Δs) Ly=(1)+(2)
1	48.76	1.96	53.03	8.11	10.07
2	47.56	6.12	48.07	4.33	10.44
3	43.82	15.78	45.43	-3.09	12.69
4	34.17	7.16	47.31	2.48	9.64
5	29.79	10.55	45.80	-3.71	6.84
6	23.34	-4.56	48.07	9.41	4.86
7	26.12	5.48	42.31	0.02	5.49
8	22.77	-3.47	42.30	8.26	4.79
9	24.90	-8.12	37.25	13.89	5.77
10	29.86	12.77	28.76	-2.15	10.62
11	22.05	-1.49	30.07	12.57	11.07
12	22.96	13.38	22.38	-2.93	10.45
13	14.78	-1.96	24.17	16.11	14.15
14	15.98		14.32		

Change in soil moisture storage for lysimeter-1 (polyhouse Okra crop)

Growth period in weeks	Gravimetric soil moisture content in 1st layer (%)	$((M_{bi}-M_{ei})/100)*(A_i*D_i)$ (1)	Gravimetric soil moisture content in 2nd layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)	Soil moisture Storage change (Δs) Ly=(1)+(2)
1	36.25	2.68	47.43	2.49	5.17
2	34.61	5.30	45.91	1.72	7.02
3	31.37	3.23	44.86	-13.08	-9.85
4	29.39	10.63	52.86	1.51	12.14
5	22.90	-5.96	51.93	3.16	-2.80
6	26.54	-3.22	50.00	-0.45	-3.67
7	28.51	-8.92	50.27	12.34	3.42
8	33.96	6.26	42.73	6.91	13.17
9	30.14	0.15	38.50	6.84	6.99
10	30.05	8.42	34.32	2.15	10.57
11	24.90	-0.96	33.00	21.26	20.29
12	25.49	2.97	20.00	1.08	4.05
13	23.67	11.07	19.34	2.84	13.91
14	16.90		17.60		

Change in soil moisture storage for lysimeter-2 (polyhouse Okra crop)

Growth period in weeks	Gravimetric soil moisture content in 1st layer (%)	$((M_{bi}-M_{ei})/100)*(A_i*D_i)$ (1)	Gravimetric soil moisture content in 2nd layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)	Soil moisture Storage change (Δs) Ly=(1)+(2)
1	35.05	-0.61	44.13	6.03	5.42
2	35.42	1.07	40.44	0.52	1.59
3	34.77	-0.48	40.12	0.63	0.15
4	35.07	7.88	39.74	-3.79	4.09
5	30.25	-2.83	42.05	5.46	2.64
6	31.98	-8.62	38.71	9.14	0.52
7	37.25	4.05	33.12	1.11	5.16
8	34.77	8.00	32.44	3.55	11.55
9	29.88	-0.10	30.27	5.68	5.58
10	29.93	5.00	26.79	2.25	7.25
11	26.88	11.14	25.42	1.49	12.63
12	20.06	0.89	24.51	10.73	11.62
13	19.52	5.59	17.94	4.30	9.89
14	16.10		15.31		

Change in soil moisture storage for lysimeter-3 (polyhouse Okra crop)

Growth period in weeks	Gravimetric soil moisture content in 1st layer (%)	$((M_{bi} - M_{ei})/100)*(A_i*D_i)$ (1)	Gravimetric soil moisture content in 2nd layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)	Soil moisture Storage change (Δs) Ly=(1)+(2)
1	38.74	0.65	48.23	3.84	4.49
2	38.34	-1.38	45.88	6.27	4.90
3	39.19	-2.86	42.05	2.09	-0.77
4	40.94	9.84	40.76	1.02	10.86
5	34.92	0.70	40.14	6.31	7.01
6	34.49	2.01	36.28	6.53	8.55
7	33.26	3.68	32.29	-0.08	3.60
8	31.01	9.87	32.34	0.69	10.56
9	24.97	4.57	31.92	-1.58	3.00
10	22.17	3.31	32.88	3.96	7.27
11	20.15	5.34	30.46	12.97	18.32
12	16.88	-0.79	22.52	5.87	5.08
13	17.36	5.12	18.93	1.93	7.05
14	14.23		17.75		

Change in soil moisture storage for lysimeter-1 (open field Okra crop)

Growth period in weeks	Gravimetric soil moisture content in 1st layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (1)	Gravimetric soil moisture content in 2nd layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)	Soil moisture Storage (Δs) Ly=(1)+(2)
1	28.19	0.38	36.62	4.91	5.29
2	27.95	3.51	33.62	2.57	6.07
3	25.81	-8.76	32.05	0.99	-7.77
4	31.17	0.58	31.45	1.99	2.58
5	30.81	-9.81	30.23	10.54	0.73
6	36.81	17.57	23.78	-22.25	-4.68
7	26.06	-3.02	37.39	2.19	-0.82
8	27.91	0.95	36.05	2.77	3.72
9	27.33	7.96	34.35	9.69	17.65
10	22.46	0.82	28.43	1.61	2.42
11	21.96	5.59	27.44	-1.01	4.57
12	18.54	7.46	28.06	1.07	8.53
13	13.98	-4.30	27.41	11.41	7.11
14	16.61		20.43		

Change in soil moisture storage for lysimeter-2 (open field Okra crop)

Growth period in weeks	Gravimetric soil moisture content in 1st layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (1)	Gravimetric soil moisture content in 2nd layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)	Soil moisture Storage (Δs) Ly=(1)+(2)
1	37.19	6.20	46.62	-1.97	4.23
2	33.40	4.76	47.82	2.12	6.88
3	30.49	-0.88	46.53	4.72	3.85
4	31.02	0.72	43.64	9.04	9.77
5	30.58	-0.41	38.11	13.14	12.73
6	30.83	8.57	30.07	-6.88	1.70
7	25.59	0.08	34.28	6.24	6.32
8	25.54	2.78	30.46	1.64	4.41
9	23.84	3.01	29.46	0.19	3.20
10	22.00	2.30	29.34	2.03	4.33
11	20.59	4.13	28.11	3.35	7.48
12	18.06	-5.11	26.06	12.61	7.50
13	21.18	0.01	18.35	2.38	2.39
14	21.18		16.89		

Change in soil moisture storage for lysimeter-3 (open field Okra crop)

Growth period in weeks	Gravimetric soil moisture content in 1st layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (1)	Gravimetric soil moisture content in 2nd layer (%)	$((M_{bi}+M_{ei})/100)*(A_i*D_i)$ (2)	Soil moisture Storage (Δs) Ly=(1)+(2)
1	38.89	6.04	42.12	-1.00	5.04
2	35.19	1.38	42.74	10.13	11.51
3	34.35	-6.14	36.54	2.95	-3.18
4	38.10	19.71	34.74	-3.10	16.61
5	26.04	-7.78	36.63	12.79	5.01
6	30.80	1.49	28.81	1.62	3.11
7	29.89	8.05	27.82	-7.87	0.18
8	24.97	4.42	32.63	4.47	8.89
9	22.27	-0.40	29.90	5.34	4.94
10	22.51	6.54	26.63	-3.09	3.45
11	18.51	5.79	28.52	3.29	9.08
12	14.97	-2.03	26.51	3.59	1.56
13	16.21	-6.03	24.32	9.95	3.92
14	19.90		18.23		

APPENDIX VI

Water balance computation for lysimeter 2- polyhouse (reference crop)

Growing period	**Applied water (I) in mm**	**Drainage (D) in mm**	**Soil moisture Storage change (Δs)**	**ET=I-D±Δs**
1st week	75.81	37.69	10.79	27.33
2nd week	75.81	38.63	8.27	28.91
3rd week	75.81	37.26	8.18	30.37
4th week	75.81	35.88	8.79	31.13
5th week	75.81	36.10	6.42	33.28
6th week	75.81	36.75	3.70	35.36
7th week	75.81	36.97	3.97	34.87
8th week	75.81	36.10	5.71	33.99
9th week	75.81	33.50	5.16	37.15
10th week	75.81	33.14	9.24	33.43
11th week	75.81	31.91	7.13	36.77
12th week	75.81	30.18	10.20	35.42
13th week	75.81	29.53	11.40	34.88

Water balance computation for lysimeter 3- polyhouse (reference crop)

Growing period	**Applied water (I) in mm**	**Drainage (D) in mm**	**Soil moisture Storage change (Δs)**	**ET=I-D±Δs**
1st week	75.81	37.91	5.09	32.80
2nd week	75.81	37.55	5.29	32.98
3rd week	75.81	36.03	6.53	33.25
4th week	75.81	35.45	9.35	31.01
5th week	75.81	36.32	13.42	26.07
6th week	75.81	36.61	13.14	26.06
7th week	75.81	36.68	5.12	34.01
8th week	75.81	36.10	4.38	35.33
9th week	75.81	33.94	8.70	33.18
10th week	75.81	33.36	8.31	34.14
11th week	75.81	31.41	9.43	34.97
12th week	75.81	30.11	8.22	37.48
13th week	75.81	29.53	9.58	36.70

APPENDIX VII

Water balance computation for lysimeter 2- open field (reference crop)

Growing period	Applied water (I) in mm	Rainfall (R) in mm	Drainage (D) in mm	Soil moisture Storage change (Δs)	ET=I+R-D±Δs
1st week	75.81	0.00	33.14	10.59	32.07
2nd week	75.81	0.00	31.91	11.62	32.28
3rd week	75.81	0.00	31.77	12.43	31.62
4th week	75.81	0.00	32.92	10.39	32.49
5th week	75.81	0.00	34.30	7.88	33.64
6th week	75.81	0.00	33.86	2.47	39.48
7th week	75.81	0.00	33.65	6.93	35.23
8th week	75.81	0.00	34.01	5.58	36.22
9th week	75.81	0.00	31.84	5.14	38.83
10th week	75.81	0.00	30.90	7.90	37.01
11th week	75.81	0.00	29.60	11.63	34.57
12th week	75.81	0.00	27.94	9.12	38.75
13th week	75.81	2.80	29.82	12.25	36.53

Water balance computation for lysimeter 3- open field (reference crop)

Growing period	Applied water (I) in mm	Rainfall (R) in mm	Drainage (D) in mm	Soil moisture Storage change (Δs)	ET=I+R-D±Δs
1st week	75.81	0.00	33.41	10.07	32.33
2nd week	75.81	0.00	32.49	10.44	32.88
3rd week	75.81	0.00	31.91	12.69	31.20
4th week	75.81	0.00	33.07	9.64	33.10
5th week	75.81	0.00	34.01	6.84	34.96
6th week	75.81	0.00	34.44	4.86	36.51
7th week	75.81	0.00	34.15	5.49	36.17
8th week	75.81	0.00	34.37	4.79	36.65
9th week	75.81	0.00	31.48	5.77	38.56
10th week	75.81	0.00	30.97	10.62	34.21
11th week	75.81	0.00	28.74	11.07	36.00
12th week	75.81	0.00	27.36	10.45	38.00
13th week	75.81	2.80	28.64	14.15	35.82

APPENDIX VIII

Water balance computation for lysimeter 2- polyhouse (Okra crop)

Growing period	**Applied water (I) in mm**	**Drainage (D) in mm**	**Soil moisture Storage change (∆s)**	**ET=I-D±∆s**
1st week	101.08	49.75	5.42	45.91
2nd week	101.08	44.62	1.59	54.87
3rd week	101.08	41.44	0.15	59.49
4th week	151.62	58.48	4.09	89.05
5th week	151.62	57.11	2.64	91.88
6th week	151.62	53.14	0.52	97.96
7th week	151.62	50.04	5.16	96.42
8th week	151.62	46.50	11.55	93.57
9th week	151.62	46.50	5.58	99.54
10th week	151.62	42.60	7.25	101.78
11th week	151.62	41.08	12.63	97.91
12th week	126.35	41.30	11.62	73.43
13th week	126.35	49.17	9.89	67.29

Water balance computation for lysimeter 3- polyhouse (Okra crop)

Growing period	**Applied water (I) in mm**	**Drainage (D) in mm**	**Soil moisture Storage change (∆s)**	**ET=I-D±∆s**
1st week	101.08	47.94	4.49	48.65
2nd week	101.08	43.90	4.90	52.29
3rd week	101.08	41.88	-0.77	59.98
4th week	151.62	58.99	10.86	81.77
5th week	151.62	57.26	7.01	87.36
6th week	151.62	53.14	8.55	89.94
7th week	151.62	49.46	3.60	98.56
8th week	151.62	46.50	10.56	94.57
9th week	151.62	46.21	3.00	102.42
10th week	151.62	43.25	7.27	101.11
11th week	151.62	41.01	18.32	92.29
12th week	126.35	41.23	5.08	80.04
13th week	126.35	48.30	7.05	71.00

APPENDIX IX

Water balance computation for lysimeter 2- open field (Okra crop)

Growing period	Applied water (I) in mm	Rainfall (R) in mm	Drainage (D) in mm	Soil moisture Storage change (Δs)	ET=I+R-D±Δs
1st week	101.08	0.00	41.66	4.23	55.19
2nd week	101.08	0.00	37.40	6.88	56.80
3rd week	101.08	0.00	37.04	3.85	60.20
4th week	151.62	0.00	50.11	9.77	91.75
5th week	151.62	0.00	46.50	12.73	92.40
6th week	151.62	0.00	43.47	1.70	106.46
7th week	151.62	0.00	43.03	6.32	102.27
8th week	151.62	0.00	38.19	4.41	109.02
9th week	151.62	0.00	38.05	3.20	110.37
10th week	151.62	0.00	39.13	4.33	108.16
11th week	151.62	0.00	37.91	7.48	106.24
12th week	126.35	0.00	38.05	7.50	80.80
13th week	126.35	2.80	45.56	2.39	81.20

Water balance computation for lysimeter 3- open field (Okra crop)

Growing period	Applied water (I) in mm	Rainfall (R) in mm	Drainage (D) in mm	Soil moisture Storage change (Δs)	ET=I+R-D±Δs
1st week	101.08	0.00	42.82	5.04	53.22
2nd week	101.08	0.00	37.04	11.51	52.53
3rd week	101.08	0.00	36.03	-3.18	68.24
4th week	151.62	0.00	35.96	16.61	99.05
5th week	151.62	0.00	44.91	5.01	101.71
6th week	151.62	0.00	43.97	3.11	104.54
7th week	151.62	0.00	43.10	0.18	108.34
8th week	151.62	0.00	38.48	8.89	104.25
9th week	151.62	0.00	38.27	4.94	108.41
10th week	151.62	0.00	38.99	3.45	109.19
11th week	151.62	0.00	37.40	9.08	105.14
12th week	126.35	0.00	38.12	1.56	86.67
13th week	126.35	3.80	44.40	3.92	81.84

APPENDIX X

ETo from FAO-56 Penman-Monteith by CROPWAT- polyhouse

Period in week	Max temp ºC	Min temp º C	Humidity %	Wind km/h	Sun hours	Rad MJ/mm/day	ETo mm/day
1	34.79	26.11	69.57	6.43	5.81	16.40	3.23
2	35.81	23.00	66.43	5.00	8.97	21.20	3.88
3	36.17	22.97	71.29	4.86	9.19	21.89	4.33
4	35.81	23.89	59.57	7.71	7.64	19.97	3.83
5	36.96	24.47	68.57	3.29	7.84	20.60	4.13
6	36.46	24.54	59.71	4.14	8.97	22.59	4.12
7	35.76	25.21	68.86	3.14	9.19	23.20	4.49
8	35.23	25.93	60.14	3.00	7.64	21.03	3.90
9	37.51	26.21	68.00	2.86	7.84	21.50	4.25
10	36.89	24.90	65.29	3.29	8.47	22.59	4.48
11	36.40	24.63	65.86	2.86	7.04	20.40	4.12
12	35.59	24.94	66.29	3.00	5.53	18.07	3.78
13	34.11	24.53	63.00	2.86	5.54	18.04	3.73

ETo from FAO-56 Penman-Monteith by CROPWAT- Openfield

Period in week	Max temp ºC	Min temp º C	Humidity %	Wind km/h	Sun hours	Rad MJ/mm/day	ETo mm/day
1	34.47	21.67	76.71	6.86	5.81	16.37	3.52
2	34.36	18.66	86.86	5.43	8.97	21.20	4.56
3	35.43	22.79	84.71	5.29	9.19	21.89	4.71
4	34.66	23.01	81.71	8.57	7.64	19.97	4.33
5	35.07	24.07	86.00	3.43	7.84	20.60	4.62
6	33.03	20.39	77.57	4.43	8.97	22.50	4.85
7	34.09	21.79	82.29	3.14	9.19	23.20	5.10
8	33.60	21.51	87.29	3.14	7.64	21.03	4.74
9	34.33	22.26	83.14	2.86	7.84	21.50	4.95
10	34.40	23.79	81.71	3.29	8.47	22.59	5.06
11	24.97	33.53	82.14	3.29	7.04	20.40	4.58
12	34.01	26.10	83.71	3.14	5.53	18.07	4.07
13	33.83	26.16	84.14	3.14	5.54	18.04	3.99

ETo from Blaney- Criddle- Polyhouse

Crop period	Mean temp °C	Humidity %	Wind km/day	Sun hours	ETo mm/day
1st week	30.45	69.57	6.43	5.81	6.52
2nd week	29.41	66.43	5.00	8.97	7.61
3rd week	29.57	71.29	4.86	9.19	8.82
4th week	29.85	59.57	7.71	7.64	7.55
5th week	30.71	68.57	3.29	7.84	7.61
6 th week	30.50	59.71	4.14	8.97	7.14
7 th week	30.49	68.86	3.14	9.19	7.99
8th week	30.58	60.14	3.00	7.64	6.41
9 th week	31.86	68.00	2.86	7.84	7.14
10 th week	30.89	65.29	3.29	8.47	7.70
12th week	30.51	66.29	3.00	5.53	6.03
13th week	30.26	63.00	2.86	5.54	5.84
Average	30.42	65.56	4.13	7.72	7.20

ETo from Blaney- Criddle method –Open field

Crop period	Mean temp °C	Humidity %	Wind km/day	Sun hours	ETo mm/day
1st week	28.07	71.71	6.86	5.79	7.79
2nd week	26.51	81.86	5.43	8.97	10.18
3rd week	29.11	79.71	5.29	9.19	10.22
4th week	28.84	76.71	8.57	7.64	9.68
5th week	29.57	81.00	3.43	7.84	9.28
6 th week	26.71	72.57	4.43	8.97	9.73
7 th week	27.94	77.29	3.14	9.19	9.92
8th week	27.56	82.29	3.14	7.64	9.11
9 th week	28.29	78.14	2.86	7.84	9.33
10 th week	29.09	76.71	3.29	8.47	9.51
12th week	29.25	77.14	3.29	7.04	8.38
13th week	30.06	78.71	3.14	5.53	7.25
Average	28.42	77.82	3.14	5.54	7.04

ETo from Thornthwaite method –polyhouse

Crop period	Mean temp °C	Max temp °C	Sun hours	ETo mm/day
1st week	30.45	34.8	5.8	4.09
2nd week	29.41	35.8	9.0	7.45
3rd week	29.57	36.2	9.2	8.53
4th week	29.85	35.8	7.6	6.52
5th week	30.71	37.0	7.8	6.97
6 th week	30.50	36.5	9.0	7.53
7 th week	30.49	35.8	9.2	8.16
8th week	30.58	35.2	7.6	6.19
9 th week	31.86	37.5	7.8	6.62
10 th week	30.89	36.9	8.5	7.63
12th week	30.51	36.4	5.5	4.12
13th week	30.26	35.6	5.5	4.13
Average	30.42	36.11	7.72	6.50

ETo from Thornthwaite method –Open field

Crop period	Mean temp °C	Max temp °C	Sun hours	ETo mm/day
1st week	28.07	34.47	7.52	4.68
2nd week	26.51	34.36	8.09	8.69
3rd week	29.11	35.43	7.48	9.03
4th week	28.84	34.66	7.42	7.08
5th week	29.57	35.07	6.37	7.61
6th week	26.71	33.03	2.92	9.06
7th week	27.94	34.09	3.77	9.32
8th week	27.56	33.60	5.90	7.27
9th week	28.29	34.33	6.17	7.95
10th week	29.09	34.40	5.61	8.51
11th week	29.25	24.97	5.84	6.47
12th week	30.06	34.01	7.06	4.37
13 th week	29.99	33.83	6.2	4.20
Average	28.54	33.56	6.18	7.25

Abstract

COMPARATIVE EVALUATION OF EVAPOTRANSPIRATION PARAMETERS IN A NATURALLY VENTILATED POLYHOUSE AND OPEN FILED

By

MADHAVI TULLURU

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ABSTRACT

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(Soil and Water Engineering)

**Faculty of Agricultural Engineering & Technology
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ABSTRACT

Studies on the water requirement of horticultural crops in polyhouses are scarce and despite the water scarcity, irrigation is mainly scheduled according to farmer’s experience. Canopy development and management of some polyhouse horticultural crops is quite different from that outdoors. Differences in plant spacing, crop height and aerodynamic properties may affect the crop coefficient values. Moreover, the proportion of diffuse radiation in polyhouse is different from that outdoors. Thus it is questionable whether the standard crop coefficient values, determined experimentally outside polyhouse can be used directly to determine the evapotranspiration of the greenhouse crops. Complete data on meteorological parameters inside poly houses is very rarely obtained and it causes lot of limitations in applying indirect estimation methods of ET_0 based on climatological data.

Field experiment on the comparative evaluation of evapotranspiration parameters in a naturally ventilated polyhouse and open field was conducted in a naturally ventilated polyhouse and open field in the research plot of the Department of Irrigation and Drainage Engineering, in KCAET campus, Tavanur. In the study, Non-Weighing Mini-Lysimeters were used to determine evapotranspiration parameters and to develop crop-coefficient curves for Okra. Comparison with indirect methods was also done in order to assess the dependability of climatic data for evapotranspiration estimates. The study compares the data for open field and poly house conditions in order to quantify the effect of micro climatic variations.

ETo estimated using climatological methods *viz* reduced pan, FAO -56 Penman-Monteith, FAO Blaney- Criddle and Thornthwaite were compared with measured lysimetric data using simple error analysis and linear regression. Out of all methods FAO-56 Penman-Monteith provides quite good agreement with evapotranspiration obtained by lysimetric data with a high correlation coefficient of 0.88 and 0.87 for polyhouse and open field conditions respectively. Studies on

crop morphological parameters indicated that plant growth and yield parameters were not significantly different for polyhouse and open field conditions.

Seasonal average ETo for polyhouse and open field were 4.74 and 5.02 mm/day. Seasonal average ETc values of Okra for polyhouse and open field conditions were 3.90 and 4.31mm/day. The calculated values of Kc for the initial, mid and late season stages were 0.58, 0.94 and 0.67 in polyhouse. Open field values were 0.61, 0.98 and 0.72 for different stages respectively. It was observed that polyhouse Kc values were lower than the open field. The variations in micro climate inside poly houses with reduced solar radiation and wind velocity combined with higher humidity and temperature may have contributed to lesser ET. The results implied that water requirement is lower inside the polyhouse compared to open field conditions.

The results of this study can be used as a guideline in the computation of water requirement of poly house crops instead of depending on open field accepted values for Tavanur region. If the poly house irrigation is scheduled in such a way as to apply the right quantity of water enough to meet the evapotranspiration requirements of crops, considerable water saving can be achieved. The quality of produce is high, duration of crop season is longer and year round cultivation is possible inside poly houses which implies significant saving in water without compromising yield and product quality.