

DEVELOPMENT OF PORTABLE CLOSED CANOPY CHAMBER FOR EVAPOTRANSPIRATION MEASUREMENT

By

DESAI DHARMIK RAMESHCHANDRA

(Registration No - 2050217007)

B. Tech. (Agril. Engg.)



**DEPARTMENT OF SOIL AND WATER CONSERVATION
ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH - 362001**

SEPTEMBER-2019

DEVELOPMENT OF PORTABLE CLOSED CANOPY CHAMBER FOR EVAPOTRANSPIRATION MEASUREMENT

**A THESIS SUBMITTED TO
JUNAGADH AGRICULTURAL UNIVERSITY
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF**

**MASTER OF TECHNOLOGY
(Agricultural Engineering)**

IN

SOIL AND WATER ENGINEERING

BY

DESAI DHARMIK RAMESHCHANDRA

(Registration No - 2050217007)

B. Tech. (Agril. Engg.)



**DEPARTMENT OF SOIL AND WATER CONSERVATION
ENGINEERING
COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH - 362001**

SEPTEMBER-2019

DEDICATED
TO
My BELOVED
PARENTS, TEACHERS
And
FRIENDS

- Dharmik

Department of Soil and Water Conservation Engineering

Name of Student

Desai Dharmik Rameshchandra

Major Guide

Dr. H. D. Rank

DEVELOPMENT OF PORTABLE CLOSED CANOPY CHAMBER FOR EVAPOTRANSPIRATION MEASUREMENT

ABSTRACT

Key words: *Evapotranspiration, closed canopy chamber, micro-lysimeter, crop coefficient*

The attempt was to develop a portable closed canopy chamber for the measurement of crop evapotranspiration, using transparent acrylic sheet of 4 mm thickness. The length, width and height of the chamber are 0.85 m, 0.85 m and 1.10 m respectively. Two small fans were mounted on the inner side of the chamber for proper mixing of air and water vapour inside the canopy chamber. Between the fans, a temperature and humidity sensor was suspended above the plant canopy for the measurement of instantaneous temperature and RH of vapour-air mixture. The calibration and validation of the developed closed canopy chamber were made using micro lysimeters having a size of 0.2 m × 0.2 m × 0.2 m by growing shallow rooted spinach crop in it. The irrigation applications to the spinach was made as per the crop water consumption. The sensor sensed and recorded the instantaneous temperature and relative humidity at 1 second interval during the 2 min closing time of each cycle of first 15 minutes of 12 period of 2h duration during a day. Between the measurements, the chamber over the micro-lysimeters was removed for a minimum of 2 min to obtain a micro-climate similar to the open atmosphere. Two sample t-tests were applied to compare the data pairs of crop evapotranspiration obtained by the micro-lysimeters inside the canopy chamber with that of outside the canopy chamber to ascertain whether there is any effects of the change in micro climate for a short period of 2 min on the crop growth physiological processes. Also, the data pair of crop evapotranspiration measured by the micro lysimeter and canopy chamber using the sensor data of temperature-humidity were compared and statistically analyzed through t-test. The calibration factor of the closed canopy chamber was found to be 1.3532.

The results revealed that there was no significant difference in the crop evapotranspiration measured by the micro-lysimeters inside and outside the canopy chamber, indicating that there are no effects of the change in micro climate for a short period of 2 minutes in the chamber, on the plant physiological processes. The crop evapotranspiration measured by the canopy chamber and micro-lysimeter were compared separately for the winter and summer seasons. The ET_c rate increases as sun rises and reaches the peak at 14:00 hrs and then continuously decreases with the time. The ET_c rates were found to be very low and constant during the night time, indicating the major contribution is from the soil evaporation component. There were no significant difference between the crop evapotranspiration measured by the canopy chamber and the micro-lysimeter at 95 percent confidence level.

The average crop coefficients for the initial stage, mid stage and harvest stage were found as 0.968, 1.187 and 1.07 respectively during the winter season. The developed canopy chamber is portable as well as more comfortable and cost effective compared to the lysimeter for the measurement of the actual crop evapotranspiration and the crop coefficient.

**COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY
JUNAGADH AGRICULTURAL UNIVERSITY
JUNAGADH**

C E R T I F I C A T E – I

This is to certify that the thesis/project work report entitled “**DEVELOPMENT OF PORTABLE CLOSED CANOPY CHAMBER FOR EVAPOTRANSPIRATION MEASUREMENT**” submitted by **DESAI DHARMIK RAMESHCHANDRA** in partial fulfilment of the requirements for the award of the degree of **Master of Technology (Agricultural Engineering)** in the subject of **SOIL AND WATER ENGINEERING** to the Junagadh Agricultural University is a record of bonafide research work carried out by him under my guidance and supervision and the thesis has not previously formed the basis for the award of any degree, diploma or other similar title. The candidate had fulfilled all prescribe requirements. The assistance and help received during the course of investigation have been fully acknowledged. He has successfully completed the comprehensive/preliminary examination held on **April 8, 2019** as required under the regulation for post-graduate studies. He has submitted kachcha bound thesis on **July 15, 2019**.

Place: Junagadh
Date: 19/07/2018

(Dr. H. D. Rank)
Major Guide
Professor and Head
Department of Soil and Water
Conservation Engineering
Junagadh Agricultural University
Junagadh

ACKNOWLEDGEMENT

From the depth of my heart I express my deep sincere gratitude to my parents, for the Blessings they had bestowed upon me to do this work.

*With great reverence, I express my warmest feelings with deepest sense of gratitude to my Major Guide, **Dr. H. D. Rank**, Professor and Head, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, JAU, Junagadh. I have no words to express my heartfelt thanks for his illuminating guidance, unfailing encouragement, scholarly suggestions and constructive criticism during the course of my research and preparation of this thesis. I deem it as my privilege to work under his able guidance. I ever remain grateful to him.*

*I express my warmest feelings with deepest gratitude to **Dr. A. R. Pathak**, Hon'ble Vice-chancellor, JAU, Junagadh, **Dr. V. P. Chovatia**, Director of Research and Dean PG Studies, JAU, Junagadh, **Dr. N. K. Gontia**, Principal and Dean, CAET, JAU, Junagadh for giving me opportunity for completing research work and providing necessary academic facilities.*

*May I make this opportunity to thank all the members of my advisory committee, Minor Guide **Dr. P. M. Chauhan**, Professor and Head, Department of Renewable Energy Engineering, College of Agricultural Engineering and Technology, JAU, Junagadh, **Dr. D. V. Patel**, Associate Professor, College of Agriculture, JAU, Khapat, **Prof. H. H. Mashru**, Assistant Professor, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, JAU, Junagadh, **Prof. P. B. Vekariya**, Assistant Professor, Department of Soil and Water Conservation Engineering, College of Agricultural Engineering and Technology, JAU, Junagadh, **Dr. L. C. Vekaria**, Assistant Professor, Department of Agricultural Chemistry and Soil Science, College of Agriculture, JAU, Junagadh for their constant attention, formulation of curriculum and offering valuable suggestions throughout the period of investigation.*

*My heartfelt thanks to **Dr. H. V. Parmar**, Associate Professor, Department of Soil and Water Conservation Engineering, CAET, JAU, Junagadh, **Dr. R. J. Patel**, Assistant Professor, Department of Soil and Water Conservation Engineering, CAET,*

JAU, Junagadh for rendering their constant help, impartial support and kind cooperation during my study.

*I would like to thank **Dr. J. M. Modhvadiya**, Assistant Professor, **Er. P. J. Bagada**, Senior Research Assistant, **Mr. Yunus Hala**, **Mr. Mansukh Patoliya**, **Mr. Shahnawaz**, **Mr. Govind Majethiya** and all other staff members of the Department of Soil and Water Conservation Engineering, JAU, Junagadh for their support during the period of my study.*

*I am fortunate to have good seniors and friends **Er. Harshad**, **Er. Vimal**, **Er. Parth**, **Er. Yagnesh** and **Er. Dax** for their great support, timely help and kind cooperation during the course of my study and experiment work.*

*I would also like to thank my junior friends **Er. Siddharth**, **Er. Gaurav** and **Er. Sagar** for their great support during my experiment work.*

*It is difficult to find words to express how much gratitude and heartfelt respect I have for my beloved Family, specially my Father **Mr. Rameshbhai Desai** and Mother **Mrs. Pannaben Desai** for their continued encouragement and inspiration throughout the study.*

Place: Junagadh

Date: 05/09/2019

(Dharmik R. Desai)

LIST OF FIGURES

FIGURE No.	TITLE	PAGE No.
3.1	HOBO external Temp/RH data logger (UX100-023) components and operation	24
3.2	Temperature accuracy and resolution of HOBO external Temp/RH data logger (UX100-023)	25
3.3	Time accuracy of HOBO external Temp/RH data logger (UX100-023)	25
3.4	Conceptual design of closed canopy chamber	26
3.5	Graphical illustration of the data collection in a day	29
4.1	Daily maximum and minimum temperatures during December 2018 to May 2019	39
4.2	Daily maximum and minimum relative humidity during December 2018 to May 2019	39
4.3	Daily wind speed during December 2018 to May 2019	40
4.4	Daily bright sunshine hours during December 2018 to May 2019	40
4.5	Comparison of ET _c by micro-lysimeter inside the canopy chamber and open atmosphere	42
4.6	Calibration of closed canopy chamber	44
4.7	(a) Comparison of Spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during winter season	47
	(b) Comparison of Spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during summer season	47
	(c) Comparison of Spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during winter season	48
	(d) Comparison of Spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during summer season	48
4.8	(a) Diurnal variation of spinach ET _c rate on 8 th March	49

	(b) Diurnal variation of spinach ETc rate on 23 rd March	49
	(c) Diurnal variation of spinach ETc rate on 20 th April	50
4.9	(a) The seasonal variation of spinach crop coefficient obtained by micro-lysimeter during winter season	50
	(b) Developed Kc-curve for spinach crop during winter period	51
	(c) The seasonal variation of spinach crop coefficient obtained by micro-lysimeter during winter season	51
	(d) Developed Kc-curve for spinach crop during summer season	52
4.10	(a) Decrease in temperature at 4:00 am on 14 th April 2019	54
	(b) Observed rare event - decrease in water vapour density during night at 4:00 am on 14 th April 2019	55
	(c) Water vapour density time series graph assuming constant temperature	55

LIST OF PLATES

PLATE No.	TITLE	PAGE No.
3.1	Location map of study area	20
3.2	Filling of soil in micro-lysimeter	28
3.3	Sowing of leafy vegetable in micro-lysimeter	28
3.4	Measurement of evapotranspiration in closed canopy chamber	29
3.5	Calibration of closed canopy chamber	32
3.6	ETc measurements by micro-lysimeters	33
3.7	Committee visit	36

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
3.1	Physiochemical properties of the soil of experimental field	21
3.2	Quality analysis of irrigation water	22
3.3	Specifications of HOBO External Temp/RH Data Logger (UX100-023) Temperature Sensor	23
4.1	Comparison of ET _c by micro-lysimeter inside the canopy chamber and open atmosphere (For the spinach crop sown on 10/12/2018)	41
4.2	t-test result of statistical comparison of ET _c by micro-lysimeter inside the canopy chamber and open atmosphere	43
4.3	Calibration of canopy chamber	44
4.4	Spinach crop evapotranspiration during winter season measured by Micro-lysimeter (For the spinach crop sown on 10/12/2018)	45
4.5	Spinach crop evapotranspiration during summer season measured by Micro-lysimeter (For the spinach crop sown on 06/03/2019)	45
4.6	Comparison of Spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during winter season (For the spinach crop sown on 10/12/2018)	46
4.7	Comparison of Spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during summer season (For the spinach crop sown on 06/03/2019)	46
4.8	The t-test analysis of spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter	53
4.9	Estimated cost of closed canopy chamber	53

CONTENTS

CHAPTERS	TITLE	PAGE NO.
I	INTRODUCTION	1-7
	1.1 Land and water resources of India	1
	1.2 Land and water resources of Gujarat	2
	1.3 Evapotranspiration	2
	1.4 Lysimeter	4
	1.5 Canopy chamber	4
	1.6 Practical utility of the research problem	5
	1.7 Objectives	7
II	REVIEW OF LITERATURE	8-18
	2.1 Reference evapotranspiration (e_{t0})	8
	2.2 Crop coefficient (K_c)	9
	2.3 Crop evapotranspiration (ET_c)	10
	2.3.1 Lysimeter	10
	2.3.2 Water Balance	12
	2.4 Canopy chamber	12
III	MATERIALS AND METHODS	19-37
	3.1 Study Area	19
	3.1.1 Location	19
	3.1.2 Climate	19
	3.1.3 Physiochemical properties of the soil	20
	3.1.4 Water quality analysis	21
	3.2 Experimental materials	22
	3.3 Methodology	26
	3.3.1 Fabrication of portable closed canopy chamber	26
	3.3.2 Fabrication of micro-lysimeters	27

	3.3.3	Calibration / validation of closed canopy chamber	28
	3.3.4	Performance evaluation of closed canopy chamber	32
	3.4	Crop coefficient	33
	3.4.1	Calculation of reference evapotranspiration	34
	3.5	Sensor data retrieval	35
	3.6	Observations	35
	3.7	Statistical Analysis	36
IV		RESULTS AND DISCUSSION	38-55
	4.1	Climate	38
	4.2	Fabricated Micro-lysimeter	40
	4.2.1	Statistical analysis of ETc by micro-lysimeter inside the canopy chamber and open atmosphere	42
	4.3	Developed canopy chamber	43
	4.4	Evaluation of closed canopy chamber	43
	4.4.1	Calibration of closed canopy chamber	43
	4.4.2	Performance evaluation of closed canopy chamber	44
	4.4.3	Diurnal variation of crop evapotranspiration	49
	4.4.4	Crop coefficient	50
	4.5	Statistical analysis	52
	4.6	Cost estimation of closed canopy chamber	53
	4.7	Complexity in closed canopy chamber	54
V		SUMMARY AND CONCLUSIONS	56-60
		BIBLIOGRAPHY	61-66
		APPENDICES	67-70

LIST OF ABBREVIATIONS

Agril.	: Agricultural
Agril. Engg.	: Agricultural Engineering
BCM	: Billion Cubic Meter
B. Tech	: Bachelor of Technology
CAET	: College of Agricultural Engineering and Technology
CO ₂	: Carbon Dioxide
CER	: Carbon Exchange Rate
cm	: Centimeter
DAS	: Days after sowing
dS/m	: deci Siemens per meter
E	: East
EC	: Electric conductivity
Engg.	: Engineering
ET	: Evapotranspiration
<i>et. al.</i>	: And others
ET ₀	: Reference evapotranspiration
ET _C	: Crop evapotranspiration
etc.	: Et cetera
FAO	: Food and Agricultural Organization
Fig.	: Figure
Ft	: Feet
g	: Gram
g/cm ³	: Gram per cubic centimeter
ha	: Hectare
hr	: Hour
IPCC	: Intergovernmental Panel on Climate Change
i.e.	: That is
JAU	: Junagadh Agricultural University
K	: Potash
KB	: Kilobytes
K _C	: Crop coefficient

Kp	: Pan Coefficient
kg	: kilogram
km	: Kilometer
km/hr	: Kilometer per hour
LCD	: Liquid Crystal Display
LVDT	: Linear Variable Differential Transformer
l	: Litre
m	: Meter
min	: Minutes
m ²	: Meter square
m ³	: Cubic meter
meq/L	: Milli equivalents per litter
M. Tech.	: Master of Technology
Max.	: Maximum
MCM	: Million Cubic Meter
meq/l	: Milliequivalent per liter
Mha	: Million hectare
Min.	: Minimum
mm	: Millimeter
mph	: Miles per hour
mm/day	: Millimeter per day
N	: North
no.	: Number
NS	: Not Significant
oz	: Ounces
PET	: Potential Evapotranspiration
pH	: potential of hydrogen
P	: Phosphorus
pp.	: Pages
RH	: Relative Humidity
SAR	: Sodium Absorption Ratio
Sr. No.	: Serial number
s	: Seconds
Tech.	: Technology

UNESCO	: United Nations Educational, Scientific and Cultural Organization
Uni.	: University
V	: Volts
viz.	: Namely
WAS	: Weeks After Sowing
WS	: Wind Speed
WWAP	: World Water Assessment Programme
&	: And
@	: At the rate of
°C	: Degree Centigrade
°F	: Degree Fahrenheit
<	: Less than
≤	: Less than or equal to
%	: Per cent
+	: Plus
±	: Plus or Minus
₹	: Rupees

CHAPTER I

INTRODUCTION

Water is the most valuable and renewable resource of nature. Demand of water has been increasing continuously, while its supply is decreasing. India has about 16% of the world's population as compared to only 4 % of its water resources. The globally growing demand for water has shown the need for its efficient and judicious utilization, and particularly in agriculture being single largest consumer of water (World Bank, 2005). Agriculture is by far the biggest user of water accounting more than 70% of water utilization worldwide and 90% of water utilization in the developing countries (UNESCO-WWAP, 2012). As compared to the surface water, greater proportion of additional irrigation water comes from the ground water and this source is increasingly being exploited in an unscientific manner. Major irrigation projects accompanied by unscientific water management are running into serious environmental and social problems. In addition, the problem has been further aggravated by deterioration of the water quality, thereby making utilizable water a diminishing resource and with competitive demand from other user's viz. industry, power, domestic and municipal sectors etc. Land and water are the basic inputs of agricultural and economic development of any country. The demand of these resources is continuously increasing. Therefore, it becomes necessary to utilize these resources judiciously. India ranks second having an area about 94 million hectares under irrigation, out of the total 137 Mha cultivated area.

1.1 LAND AND WATER RESOURCES OF INDIA

India accounts for the 16% of the world's human population and nearly 20% of the cattle with only 2.4% of the land and 4% of the water resource. Water resources of a country constitute one of its vital assets. India occupies only 329 Mha area. Thus, India feeds about 1/6th human population and 1/5th cattle population of the world from only 1/50th and 1/25th of world's land and water resource respectively.

The annual utilizable surface water and groundwater resources of India are estimated as 690 BCM (Billion Cubic Meter) and 396 BCM per year, respectively. In India per capita surface water availability in the years 1991 and 2001 were 2309 and

1902 m³ and these are projected to reduce to 1401 and 1191 m³ by the years 2025 and 2050 respectively. Hence, there is a need for proper planning, development and management of the greatest assets of the country, viz. water and land resources for raising the standards of living of the millions of people, particularly in the rural areas (Kumar *et al.*, 2005).

1.2 LAND AND WATER RESOURCES OF GUJARAT

Gujarat is the extreme western state (21°1'- 47°7'N latitude and 64°4'-74°4'E longitude) of India. The state has an area of 19.6 Mha, representing 6% area of the country. Gujarat state has 33% irrigated area, out of 10.7 m ha of cultivable land. The western peninsular regions of Gujarat are known as Saurashtra and Kutch (20°30'-24°N latitude and 69°-72°E longitude). Junagadh is part of Saurashtra region located at 21.5°N latitude and 70.1°E longitude with an altitude of 82 m above mean sea level.

Gujarat's total water resource potential is 55,000 MCM (Million Cubic Meter) of which the surface water is about 38,000 MCM (69 %) and groundwater is about 17,000 MCM (31%). North, South and Central Gujarat regions have 17 river basins, having 89 % share in the total surface water. Kutch region has the highest number of river basins (97 river basins), having only 2% share in the total surface water. Saurashtra region has 71 river basins, having 9% share in the total surface water. The total utilizable groundwater recharge in the state is 15080 MCM per annum, out of the gross annual recharge of 15874 MCM. The groundwater recharge rate per unit area is the highest for South and Central Gujarat (0.235 MCM km⁻²), followed by Saurashtra and North Gujarat (0.188 MCM km⁻²) and lowest for Kutch (0.015 MCM km⁻²).

1.3 EVAPOTRANSPIRATION

Evaporation (E) is the process of liquid water being converted to water vapour, which moves away from the evaporating surface. Transpiration (T) consists of the vaporization of liquid water contained in plant tissues and the vapour moves to the atmosphere, particularly through the leaf stomata. In short, evapotranspiration (ET) is the sum of evaporation and transpiration. Solar radiation, air temperature, air humidity and wind speed are the main climate parameters that influence ET. Soil water content,

which relates to soil water movement, vapour transfer and soil root relationships, is another vital factor for ET (Allen *et al.*, 1998; Campbell and Norman, 1998).

Transpiration occurs simultaneously with the photosynthetic gas exchange. Therefore, ET is widely considered in plant physiological studies (Grau, 1995). Some physiological studies focus on single leaf or small shoot scale, such as the behavior of stomata and the change of photosynthesis rate and photosynthetic gas exchange flux for various ambient conditions, i.e. temperature, humidity, photosynthetically active radiation (Wagner and Reicosky, 1992). At the field scale, ET is a valuable tool for evaluating plant water use and water stresses connected with management practices. ET can also serve as an indicator of plant water use efficiency and provide necessary information for conservation and use of field water resources (Wagner and Reicosky, 1992; Reicosky and Peters, 1977).

ET is a key component of the field water balance in the soil-vegetation-atmosphere continuum (Yang *et al.*, 2006), and it is a major sink of precipitation and irrigation, particularly in semiarid and arid farmland. Thus, ET becomes an indicator of plant water stress (Wagner and Reicosky, 1992; Reicosky and Peters, 1977). Because of the large latent heat of vaporization of water, ET is also an important term in the soil surface energy balance (Gowda *et al.*, 2013). With the change of climate and atmospheric conditions, obtaining soil-vegetation-atmosphere interactions especially the ET from the plant canopy layer becomes more important (IPCC, 2001; Burkart *et al.*, 2007). Therefore, it is meaningful to measure the ET flux for different plant canopies.

The crop evapotranspiration under standard conditions, denoted as ET_c , is the evapotranspiration from disease-free, well-fertilized crops, grown in large fields, under optimum soil water conditions, and achieving full production under the given climatic conditions. Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard reference crop to determine its evapotranspiration rate, i.e., ET_0 . Experimentally determined ratios of ET_c/ET_0 , called crop coefficients (K_c), are used to relate ET_c to ET_0 or $ET_c = K_c ET_0$.

1.4 LYSIMETER

Evaporation of water from soil is an important component of the soil water balance, especially in fallow fields and in cropped fields before full cover is achieved. Techniques for estimating evaporation of water from cropped or uncropped soil include micro-meteorological and water balance approaches and lysimetric methods (van Bavel, 1961; Black *et al.*, 1968).

A lysimeter is a measuring device, which can be used to measure the amount of actual evapotranspiration which is released by plants (usually crops or trees). By recording the amount of precipitation that an area receives and the amount lost through the soil, the amount of water lost to evapotranspiration can be calculated. Lysimeters are of two types: weighing and non-weighing.

Weighing lysimeters permit the mass or volumetric soil-water content change to be determined by weighing the lysimeter and determining its mass change over time. Weighing lysimeters, thus, can determine the ‘net’ infiltration from rainfall or irrigation and the amount of evaporation between wetting events. If properly designed, weighing lysimeters can coincidentally measure the drainage rate as well as the evaporation rate.

1.5 CANOPY CHAMBER

Indirect and direct methods have been used to quantify ET fluxes. Indirect methods include the use of micrometeorological techniques such as eddy covariance (EC) (Baldocchi *et al.*, 1996; Rana and Katerji, 2000; Burkart *et al.*, 2007), surface energy balance and field water balance approaches (Bowen, 1926, Gowda *et al.*, 2013). The indirect methods do not disturb the plant canopy; however, they require large homogeneous fields to obtain stable, valid results. In many agricultural studies, the size of research plots is often too small to enable the use of micrometeorological methods (Stewart, 1984). A direct method may include equipment to obtain and isolate gas samples from plant canopies, and analyze the changes of water vapour concentration to determine ET. A common strategy is to use a canopy chamber to sample the air. There are many categories of chamber design, such as leaf chambers for plant physiology studies and canopy chambers for field crop studies. Although a

chamber was first used approximately 80 years ago by Thomas and Hill (1937), ongoing development of gas analyzers enables even more accurate and rapid measurements with canopy chambers of varying shapes and dimensions.

Canopy chambers can be classified as open or closed systems. For an open system, the gas is continuously pumped into and out of the chamber through openings (or channels). The differences of water vapour concentration between the chamber inlet and outlet are measured and used to determine the ET flux. The measurements can be obtained continuously over time periods from several days to whole growing seasons; however, complex systems are required to maintain the climate within the chambers to be similar to the ambient conditions (Burkart *et al.*, 2007). Thus, the portability of open chambers is usually limited. A closed chamber is usually designed as a portable system, i.e., it can be transported among several sampling locations in the field. A closed chamber system measures the changes of water vapour concentration inside the chamber to evaluate the instantaneous ET. Rapid measurements for brief periods (2 min or so) are used to avoid chamber-induced canopy microclimate changes (Garrity *et al.*, 1984, Wagner and Reicosky, 1992, Reicosky and Peters, 1977).

The closed canopy chambers can be cross-validated with local micrometeorological or field water balance measurements to provide a small scale complement to the large scale measurements (Angell and Svejcar, 1999). Due to the usefulness of the chamber techniques, multiple designs have been reported. Steduto *et al.* (2002) reported a chamber design with comprehensive tests of climate changes within the chamber during measurements. However, actual field measurements are still necessary to evaluate how well canopy chambers measure crop ET under a range of time scales and weather conditions.

1.6 PRACTICAL UTILITY OF THE RESEARCH PROBLEM

The crop evapotranspiration ET_c estimation for irrigation planning on a regional scale, the crop coefficient (K_c) is needed. K_c value represents crop-specific water use and is required for accurate estimation of irrigation requirements of different crops in the command area. Crop coefficient values for a number of crops grown under different climatic conditions have been suggested by Doorenbos and Pruitt (1977). These values are commonly placed in places where local data are not available. However, they had

emphasized the strong need for local calibration of crop coefficients under given climatic conditions. Crop coefficients have not been developed for important crops under semi-arid climatic conditions in India and other Asian countries. The information generated on the Kc values for particular crop, using daily climatic and crop ET data would be useful for irrigation planning at farm and regional level.

Moreover, irrigation scheduling is the most important factor responsible for improving crop productivity. The fundamental requirement of irrigation scheduling is the determination of crop evapotranspiration (ETc). ETc differs with crops mainly due to variation in crop canopy and climatic conditions. Accurate estimation of crop ET is an important practical consideration for efficient water management. Crop coefficient (Kc) is an important parameter for irrigation scheduling and water allocation. Crop coefficient values taken from literature may provide a practical guideline for scheduling irrigation, but considerable error in estimating crop water requirement can occur due to their empirical nature (Jagtap and Jones, 1989).

Compared with indirect methods, canopy chamber measurements do not require large uniform fields. The closed chamber system is designed as a portable system, i.e., it can be transported among several sampling locations in the field, and rapid measurements are used to avoid chamber induced climate changes (Garrity *et al.*, 1984; Wagner and Reicosky, 1992; Reicosky and Peters, 1977). Changes in water vapour concentration inside the chamber are measured to evaluate the ET flux. Chamber measurements are used to represent instantaneous values of ET.

Lysimeters are used for accurate measurement for crop evapotranspiration ETc. However, there are some limitations for using lysimeters on field scale due to its higher initial cost, regular maintenance requirement, complex and difficult construction and usage limitation to a single crop at a time. Lysimeters cannot be transported from one place to another place due to its immovable installation. So these problems can be avoided by the use of a canopy chamber due to its simple construction and portability. With the help of canopy chambers, we can estimate the crop evapotranspiration without crop coefficient and for more than one crop, through diurnal planning of ETc measurement.

1.7 OBJECTIVES

Keeping in view the above issues and importance of ET, the present study was carried out with the following objectives:

1. To develop a portable closed canopy chamber for the measurement of crop evapotranspiration (ET_c).
2. To evaluate the performance and the cost effectiveness of the closed canopy chamber for measuring the crop evapotranspiration (ET_c).

CHAPTER II

REVIEW OF LITERATURE

The irrigation planning and management either at field, water course, sub canal or main canal level requires the information of crop evapotranspirations. The estimation of the crop water requirement or crop evapotranspirations requires the information of reference evapotranspiration (ET_0) or crop coefficient (K_c). The sizable research has been done on reference evapotranspiration (ET_0) or crop coefficient (K_c) determination by lysimeter. However, a few attempts has been done in the world on the ET_c or K_c measurement using the canopy chamber. However, an attempt was done to collect the part works relevant to ET_0 , ET_c , lysimeter and K_c , which are reviewed in the subsequent heads.

2.1 REFERENCE EVAPOTRANSPIRATION (ET_0)

Conceicao (2002) Estimated reference evapotranspiration (ET_0) based on Class A pan evaporation (ECA) in irrigated areas. For this purpose he multiplied the ECA value by a pan coefficient (K_p) to obtain ET_0 . In the present work estimated values of ET_0 based on Class A pan evaporation, using K_p values determined by different methods, were compared to Penman-Monteith-FAO (ET_0 PM) values for the northwest region of the Sao Paulo State, Brazil. The annual average K_p , determined dividing ET_0 PM by ECA, was 0.74. For the rainy months (December to March) the average K_p value was 0.80 and for the dry months (April to November) 0.70. The reference evapotranspiration estimated using K_p determined by the Snyder equation presented the best regression coefficients when compared to ET_0 PM.

Arunadevi *et al.* (2017) compared the values of reference evapotranspiration ET_0 by FAO Penman-Montieth equation, CROPWAT 8.0 software, and Pan Evaporimeter data for the period of June 2015 to May 2016. The calculation of ET_0 with FAO Penmann Monteith method was done in Excel and the values of ET_0 varied from 4.5 mm/day to 6.21 mm/day. The ET_0 value was 3.93 mm/day to 6.16 mm/day when calculated through CROPWAT 8.0 software. The ET_0 value for using the Pan Evaporimeter data varied from 2.2 mm/day to 6.7 mm/day. They suggested that the reference evapotranspiration was not dependent on crop types, development and

management practices. They considered the Penman-Monteith method was the most physical and reliable method and was often used as a standard to verify other empirical methods.

Bajirao and Awari (2017) estimated the reference evapotranspiration (ET_0) using 32 year's meteorological data by CROPWAT software. They recommended the FAO-56 Penman–Monteith method as the standard method for estimating reference evapotranspiration (ET_0). They estimated the average annual reference evapotranspiration by CROPWAT software as 5.06 mm/day. The monthly average reference evapotranspiration was observed maximum in the month of May (8.4 mm/day) while minimum in the month of December (3.27 mm/day).

2.2 CROP COEFFICIENT (K_c)

Ko *et al.* (2009) determined growth-stage-specific K_c and crop water use for cotton (*Gossypium hirsutum*) and wheat (*Triticum aestivum*). Weighing lysimeters were used to measure crop water use and local weather data were used to determine the reference evapotranspiration (ET_0). Seven lysimeters, weighing about 14 Mg, consisted of undisturbed 1.5 m $\times$ 2.0 m $\times$ 2.2 m deep soil monoliths. Six lysimeters were located in the center of a 1-ha field beneath a linear-move sprinkler system equipped with low energy precision application (LEPA) and a seventh lysimeter was established to measure reference grass ET_0 . Crop water requirements, K_c determination, and comparison to existing FAO K_c values were determined 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 830 mm for cotton and from 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.

Giovanni *et al.* (2009) determined growth-stage-specific K_C and crop water use for maize (*Zea Mays*) and sorghum (*Sorghum bicolor*). Seven lysimeters, weighing about 14 Mg, consisted of undisturbed 1.5 m $\times$ 2.0 m $\times$ 2.2 m deep soil monoliths. Six lysimeters were located in the center of a 1-ha field beneath a linear-move sprinkler system equipped with low energy precision application (LEPA). A seventh lysimeter was established to measure reference grass ET_0 . Crop water requirements, K_C determination, and comparison to existing FAO K_C values were

determined over a 3-year period for both maize and sorghum. Accumulated seasonal crop water use ranged between 441 and 641 mm for maize and between 491 and 533 mm for sorghum. The K_C values determined during the growing seasons varied from 0.2 to 1.2 for maize and 0.2 to 1.0 for sorghum.

Odofin *et al.* (2011) carried out a two-year field experiment to determine crop evapotranspiration (ET_c) and crop coefficients (K_C) for irrigated bush okra (*Corchorus olitorius*) at Minna in a tropical sub-humid area of Nigeria between February and April of 2008 and 2009. The soil moisture depletion method was used to determine ET_c while potential evapotranspiration (ET_p) was calculated on a daily basis using Blaney-Morin-Nigeria (BMN) evapotranspiration model developed for Nigerian environmental conditions. K_C values were derived as dimensionless ratios of ET_c to ET_p on a weekly basis. Across varieties and cropping periods, average weekly ET_c ranged from 2.0 to 6.8 mm/day while seasonal ET_c ranged from 326 to 374 mm, with Amugbadu having significantly higher seasonal ET_c ($P \leq 0.01$) in each cropping period, presumably because of its spreading growth habit. Weekly K_C values rose from a minimum of 0.38 at the initial stage of crop growth to a peak value of 1.05 at the mid-season stage and dropped to 0.40 at the end of the late season stage.

2.3 CROP EVAPOTRANSPIRATION (ET_c)

2.3.1 Lysimeter

Tyagi *et al.* (2000) conducted lysimeter experiments on rice during rainy season (July-October) and sunflower during summer seasons (March-June) in a set of two electronic weighing type lysimeters of 2m×2m×2m size to measure the hourly evapotranspiration of these crops from 1994 to 1995 at Karnal, India. The average weekly ET of rice varied from 6.6 mm per day at milking stage. The peak ET_c was 6.61 mm per day and it occurred 11 weeks after transplanting at reproductive stage when LAI was 3.4. In case of sunflower, ET_c was <1.0 mm/day at the initial stage, achieved a peak value of 14.1 mm per day between 8 and 9 weeks after sowing (WAS) and it declined to 3 mm per day during maturity phase. The estimated values of crop coefficient for rice at the four crop growth stages (initial, crop development, reproductive and maturity) were 1.15, 1.23, 1.14 and 1.02 and corresponding K_C values

for sunflower were 0.52, 1.1, 1.32 and 0.41. The estimated Kc values of sunflower is 11.6-74.2% higher than the values suggested by FAO.

Liu *et al.* (2002) determined daily evapotranspiration of irrigated winter wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) for five seasons between 1995 and 2000 using a large-scale weighing lysimeter, and soil evaporation for each crop was measured for one season using two micro-lysimeters. The results showed that total water consumption averaged 453 and 423 mm for winter wheat and maize grown without water deficit. The average crop coefficient during the whole growth period was 0.93 for winter wheat and 1.1 for maize. Evaporation from the soil surface took up 29.7 and 30.3% of the total evapotranspiration for winter wheat and maize, respectively, equaling an annual loss of more than 250 mm water.

Benli *et al.* (2006) determined the evapotranspiration and basal crop coefficient of alfalfa with a weighing lysimeter. Penman–Monteith, Makkink (FAO-radiation (FAO-Rad)) and Penman-FAO methods performed satisfactorily for estimating the reference evapotranspiration of alfalfa in semi-arid climate conditions. Measured evapotranspiration rates were 1470, 1557 and 1161 mm in 1995, 1996 and 1997, respectively. Basal crop coefficients were computed from evapotranspiration measurements and weather data. The estimated values of the basal crop coefficients for alfalfa at the four growth stages of an individual cutting period were 0.71, 1.78 and 1.51 for initial, mid and late season, respectively.

Fisher (2012) constructed electronic weighing lysimeters, consisting of a steel outer tank and inner tank, electronic loadcell assemblies, and a PVC drain system. Daily ET data for cotton were collected from 2003 to 2006 to quantify cotton water-use and to develop crop coefficient functions. Seasonal water use ranged generally from 2 to 8 mm/day. Seasonal water-use patterns varied considerably among growing seasons due to variable environmental and crop-growth conditions, making determination of an “average” crop-coefficient function difficult.

2.3.2 Water Balance

Zeleeke and Wade (2012) demonstrated the root zone soil water balance and the crop coefficient methods for estimating crop evapotranspiration using a field crop grown in a semiarid environment of Australia. Evapotranspiration was calculated as an independent parameter in the soil water balance equation. AquaCrop was also used to estimate crop evapotranspiration using the dual coefficient approach. It was found that the dual coefficients, basal or transpiration coefficient K_{cb} and evaporation coefficient K_e , correctly depict the actual process. The effects of weather (rainfall and radiation) and crop phenology were correctly simulated in this method. However, single coefficient did not show the high evaporation component during the initial and late season stages. The evapotranspiration estimated using different approaches was as follows: soil water balance ($ET_a = 313$ mm), single crop coefficient ($ET_c = 332$ mm), dual coefficient approach ($ET_c = 366$ mm with E of 79 mm and T of 288 mm), AquaCrop ($ET_c = 382$ mm with E of 139 mm and T of 243 mm). ET estimated using rootzone water balance is lower than the ET estimated using the other methods. The single coefficient approach resulted in the lowest ET_c as it was not taking into account the evaporation spikes after rainfall during the initial and late season stages.

2.4 CANOPY CHAMBER

Reicosky and Peters (1977) constructed a chamber from aluminum conduit covered with Mylar film and mounted on a farm tractor for portability. The air within the chamber was mixed continuously with four strategically located fans. The ET rate was calculated from air and wet-bulb temperatures of a thermistor psychrometer before the chamber was lowered on the plot and 1 min later. The psychrometer's accuracy was checked by measuring the transpiration from a solution-absorption system that accurately measured the change in solution level using an LVDT float system. When micro-climatological conditions were changing slowly, transpiration was assumed to be equal to the absorption. The high correlation between measured absorption and transpiration rates indicated reasonable accuracy. They concluded that the chamber's accuracy and rapidity of measurement, portability and relatively low cost makes it a useful tool measuring ET under field condition.

Reicosky *et al.* (1983) measured ET with portable chamber (CET) and weighing lysimeter (LET). Intensive portable chamber measurements were made and microclimate data collected between 05:00-21:00 h. Potential evapotranspiration (PET) was calculated using modified combination equation of van Bevel. Expressed on an hourly basis, there was reasonable agreement between diurnal patterns of CET, LET, PET, although CET was as much as 0.16 mm/h lower than LET at 11:00 h and as much as 0.09 mm/h higher than LET at 18:00 h. Daytime ET values between 05:00 and 21:00 h were 7.97, 7.71 and 7.58 mm for LET, CET and PET, respectively. They concluded that the reasonable agreement between the CET and LET throughout the day and daytime ET suggests that the chamber is satisfactory for measurements of crop water use on field plots.

Wagner and Reicosky (1992) measured the effect of a portable closed chamber (8.15 m³ volume, covering 2.67 m² of soil surface area) on leaf and air temperatures and determined any subsequent effects on calculated CO₂, and water vapour exchange rates. Measurements of CO₂ Exchange Rate (CER) and ET were made on field plots of irrigated and non-irrigated maize (*Zea mays* L.) shortly after anthesis. Leaf and air temperatures were measured at 2-5 intervals inside and outside the chamber for 1 min prior, 1 min during, and 1 min after chamber closure. Leaf and air temperatures in the closed chamber increased 2 to 4 °C in 1 minute. Changes in canopy CER and ET were not strongly correlated with mean leaf temperatures. The calculated CER and ET rates underestimated the rates extrapolated to time 0 by approximately 10%, partially attributed to the increase in leaf temperature. Therefore, they concluded that chamber measurements should be made rapidly to minimize possible effects of temperature increases and other plant environment changes.

Grau (1995) used a portable chamber and closed system to investigate canopy gas exchange of forage species. The polycarbonate chamber encloses a volume of 62.5 lit from a 50× 25 cm open base inserted 3 cm into the soil. Air within the chamber was mixed by two 80-mm fans. Evapotranspiration from potted plants measured with the chamber was 25% higher than gravimetric water loss. Nevertheless, chamber values and actual gravimetric water loss were highly correlated. The chamber was tested in a pilot study comparing different forage species at a high-country site in Central Otago. Individual measurements using the canopy chamber were normally completed in less

than 2 min, a speed of operation similar to that achieved with conventional leaf chambers. The chamber system provides a simple and useful tool for rapid physiological comparison of whole canopies under field conditions.

Wagner *et al.* (1997) suggested that portable closed chambers provide a valuable tool for measuring crop photosynthesis and evapotranspiration. Typically, the rates of change of CO₂ and water vapour concentration were assumed to be constant in the short time required to make the closed-chamber measurement, and a linear regression model was used to estimate the CO₂ and H₂O fluxes. They compared the linear regression model with a quadratic regression model using field measurements from two studies. Generally, 60 to 100% of all chamber measurement data sets were significantly nonlinear, causing the quadratic model to yield fluxes 10 to 40% greater than those calculated with the linear regression model. They concluded that the frequency and degree of nonlinearity were related to the measured rate and chamber volume. Closed chamber data should be tested for nonlinearity and an appropriate model used to calculate flux. The quadratic model provides users of well-mixed closed chambers an alternative to a simple linear model for data sets with significant nonlinearity.

Steduto *et al.* (2002) developed an automated transient-state closed-system canopy-chamber for gas-exchange determinations of field-crops to allow unattended day and night, high frequency CO₂ and H₂O exchange measurements, with short measurement time (15 s) and high scanning rate (0.5 s). Environment tests on the chamber performance indicated that: atmospheric pressure variation during operation was 10–20 Pa and limited to a few seconds; leaks introduced maximum errors of 1% in the flux calculation; turbulence effect on CO₂ and H₂O fluxes was not detectable; during the measurement period, temperature build-up inside the chamber was typically within 1–2 °C range; photosynthetic photon flux density (R_p) attenuation by the chamber as a whole was in the 15–20% range; whereas, net radiation (R_n) inside the chamber was always higher than outside by 10–20%. The flux determinations of the automated canopy-chamber were compared with other methods. Daily evapotranspiration (ET) of artichoke obtained by canopy-chamber was at the most 4.2% lower than ET obtained by high-precision weighing lysimeter. Diurnal ET and carbon exchange rates (CER) of sugarbeet and marjoram crops obtained by canopy-chamber closely followed the

pattern of those obtained by the Bowen-ratio/energy-balance (BREB) method, with maximum daily underestimations of 6–8 and 5–6% for ET and CER, respectively. No differences in flux calculations came out when the rate of change in CO₂ and H₂O concentrations was derived either by linear or quadratic regressions (QR). The results of all tests and comparisons showed that the automated chamber presented is a valuable and accurate tool for monitoring day and night CO₂ and H₂O fluxes.

McLeod *et al.* (2004) constructed an enclosed portable chamber and calibrated to measure actual evapotranspiration (ET) from crop and pasture and then evaluated against established methods that are used to determine evapotranspiration. The chamber was equipped with variable speed electric fans to mix the air within the chamber during each ET measurement. Mean cumulative pasture ET for the 6-day period was 5.8 and 5.9 mm measured with the enclosed portable chamber and water balance method, respectively. Mean ET of wheat crop measured using the enclosed portable chamber was 2.4 mm/day compared with 2.3mm per day using the BR method for a 2-day period in the early growth stages of the crop. A slow fan speed that produced an air velocity of 2.7 km/h, gave the closest agreement with the Bowen ratio method (2.3 mm/day versus 2.2 mm/day) for the wheat crop.

Stannard and Wertz (2006) used a portable chamber to separate evapotranspiration (ET) from a sparse, mixed-species shrub canopy in southeastern Arizona, United States, into vegetation and soil components. Chamber measurements were made of ET from the five dominant species, and from bare soil, on 3 days during the monsoon season when the soil surface was dry. Chamber estimates of landscape ET were well correlated with, but about 26% greater than, simultaneous eddy-correlation measurements. Excessive air speed inside the chamber appears to be the primary cause of the overestimate. Overall, transpiration accounted for 84% of landscape ET, and bare soil evaporation for 16%. Partitioning of ET into components varied as a function of air temperature and shallow soil moisture. Transpiration from shorter species was more highly correlated with air temperature whereas transpiration from taller species was more highly correlated with shallow soil moisture. Application of these results to a full drying cycle between rainfalls at a similar site suggests that during the monsoon, ET at such sites may be about equally partitioned between transpiration and bare soil evaporation.

Burkat *et al.* (2007) tested the performance of the chamber system in a crop rotation of sugar beet and winter wheat and the main climatic driving forces for CO₂ and H₂O fluxes were determined. Measured fluxes were also validated using data from destructive growth analysis and calculation of reference evapotranspiration according to FAO-guidelines. Chamber walls reduced total incident radiation by 19% and increased the fraction of diffuse radiation. Maximum temperature increase inside the chamber was less than 5 °C, and rarely exceeded 2 °C after canopy closure. Canopy CO₂ exchange rates (CCER) and evapotranspiration (ET) closely tracked transitional changes of radiation and potential evaporation, respectively. ET measured with chambers was only slightly lower than calculated reference evapotranspiration.

Garcia *et al.* (2008) made portable chamber measurements of evapotranspiration (ET) at the U.S. Geological Survey's Amargosa Desert Research Site in southern Nevada to help quantify component and landscape-scale contributions to ET in an arid environment. Evapotranspiration data were collected approximately every 3 months from 2003 to 2006. Chamber measurements of ET were partitioned into bare-soil evaporation and mixed-species transpiration components. The component-scale ET fluxes from native shrubs typically surpassed those from bare soil by as much as a factor of four. Component-scale ET fluxes were extrapolated to landscape-scale ET using a one-layer, multi-component canopy model. Landscape-scale ET fluxes predominantly were controlled by bare-soil evaporation. Bare soil covered 94% of the landscape on average and contributed about 70% of the landscape-scale vapour flux. Creosote bush, an evergreen shrub, accounted for about 90% of transpiration on average due to its dominance across the landscape (80% of the 6% shrub cover) and evergreen character.

Perez-Priego *et al.* (2010) developed a transient-state chamber to measure the canopy gas exchange of single trees in the field. The chamber, with a volume of 41.6 m³, was designed to enclose a medium-size orchard tree; chamber top and windows left open, causing minimum disturbance to the tree environment. Transitory closures allow simultaneous measurement of CO₂ exchange and transpiration of the enclosed tree. The chamber was tested during a 2-year study in an olive orchard submitted to different irrigation treatments: control with no water stress (CI) and regulated deficit irrigation (RDI). Leakage had a minimal impact on flux calculations (0.8% min⁻¹); adsorption

was not detectable. Maximum increases in canopy temperature of $0.58\text{ }^{\circ}\text{C min}^{-1}$ for CI and $1.3\text{ }^{\circ}\text{C min}^{-1}$ for RDI generated very small effects on fluxes. Changes in the transpiration rate induced by the chamber's modification of the canopy environment were evaluated by continuous sap flow measurements with heat pulse gauges inserted in the trunk of two trees enclosed by chambers. Results showed a sap flow decrease of about 8% after 180 s of chamber closure. The artificial turbulence generated by fans into the chamber to facilitate air mixing did not alter the transpiration rate. The enclosure had a very small impact on the tree canopy conductance (G_c). The initial lag and mixing time was estimated as 30 s; the optimal duration of the calculation window was 70 s. Hourly carbon assimilation (A), transpiration (E), and water use efficiency (WUE) for two olive trees in the field subjected to different levels of water stress were measured.

Luo (2015) constructed a portable canopy chamber; to quantify the diurnal and seasonal trends of ET in three cropping systems; and to compare reference evaporation (Priestley-Taylor method), ET estimated from field water balance components, and portable canopy chamber measured ET. Portable canopy chambers were used to measure ET in three cropping systems, including corn and soybean in a corn-soybean rotation and reconstructed prairie during the part of growing season in 2013, and the whole growing season in 2014. Three different chamber sizes were used to match different crop growth stages. In 2013 (DOY 164 - 206 for corn and DOY 164 - 255 for prairie and soybean) the cumulative chamber measured ET values were less than half of the reference evaporation values, due to relatively dry soil conditions. In 2014 (DOY 156 - 261 for corn and DOY 156 - 277 for prairie and soybean), because of wet weather condition, cumulative chamber measured ET fluxes were 80% (corn), 70% (prairie), and 67% (soybean) of the reference evaporation, respectively. The cumulative chamber measured ET values were similar to the cumulative water balance estimated ET values for both growing seasons. However, the agreements between chamber measured ET and water balance estimated ET in both years provided strong evidence that the portable canopy chamber accurately measured field ET at the plot scale.

Pérez-Priego *et al.* (2015) presented a practical study with novel methods for analyses of flux uncertainties in an original chamber design excluding soil fluxes and allowing simultaneous measurements of whole-plant photosynthesis and transpiration.

They indicated that random errors caused by IRGA noise and the lack of criteria to optimize the time window (TW) of chamber enclosure lead to significant flux uncertainties (12 %). Although enclosure should be rapid to minimize plant disturbances, longer TWs (3 min) increase confidence in flux estimates. Stabilization times were identified via the change-point detection method, and flux uncertainties were reduced. Photosynthesis was over estimated by up to 28 % when not correcting the evolving CO₂ molar fraction for water vapour dilution. Leakage can compromise flux estimates, but was negligible (ca. 2 %) here due to the large chamber-headspace and relatively small values of both collar contact length and closure time.

Hewitt *et al.* (2018) compared field-scale ET measurements using a portable chamber ET measurement device and modeled ET using the remote sensing Regional Evapotranspiration Estimation Model (REEM). Data were collected during the growing season of 2015 in three irrigated agricultural valleys of northern New Mexico in agricultural and nonagricultural settings. No statistically significant difference was observed in agricultural datasets between means of measured ($M = 3.7$ mm/day, $SE = 0.31$ mm/day) and modeled ($M = 4.0$ mm/day, $SE = 0.01$ mm/day) daily ET. As there was no statistical difference observed between agricultural datasets, results support the use of REEM in irrigated agricultural areas of northern New Mexico. A statistically significant difference was observed in nonagricultural datasets between means of measured ($M = 1.7$ mm/day, $SE = 0.22$ mm/day) and modeled ($M = 0.0$ mm/day, $SE = 0.00$ mm/day) daily ET. With additional calibrations and air temperature sensors placed outside of agricultural areas, REEM may be suitable for use in nonagricultural areas of northern New Mexico.

CHAPTER-III

MATERIALS AND METHODS

This chapter deals with the materials used and methodology adopted for the experimentation on development, fabrication, calibration, validation and evaluation of the canopy chamber to measure the crop evapotranspiration and thereby the crop coefficient. The details of experimental site, experimental materials used, experimental set-ups, procedures followed, and techniques adopted for attaining the objectives of the investigation are presented in this chapter, in subsequent sections.

3.1 STUDY AREA

3.1.1 Location

The experiment was conducted at the Soil and Water Conservation Engineering Department, CAET, Junagadh Agricultural University, Junagadh. It is located at 21.5 °N latitude and 70.44 °E longitude with an altitude of 82.92 meter above mean sea level.

3.1.2 Climate

Climate of the study area is subtropical and semi-arid type with an average annual rainfall of 900 mm. The area is characterized by climatic conditions of fairly cold and dry winter, hot and dry summer and warm and moderately humid monsoon. Winter sets in the month of November and continues till the end of February. January is the coldest month of winter. Summer commences in the second fortnight of February and ends in the middle of June. April and May are the hottest months of summer. According to last 35 years weather data recorded at the JAU observatory located near to the experimental site, the monthly mean of daily maximum temperature, minimum temperature, relative humidity, bright sunshine hours and pan evaporation during the crop period ranged from 30.2 °C to 38.9 °C and 12.2 °C to 22.2 °C. Also the variation in the monthly mean of relative humidity, wind speed, bright sun shine hours and pan evaporation were from 62.2 % to 74.4 %, 3.5 km/hr to 6.6 km/hr, 8.1 to 9.5 hours and 4.6 to 9.6 mm, respectively.

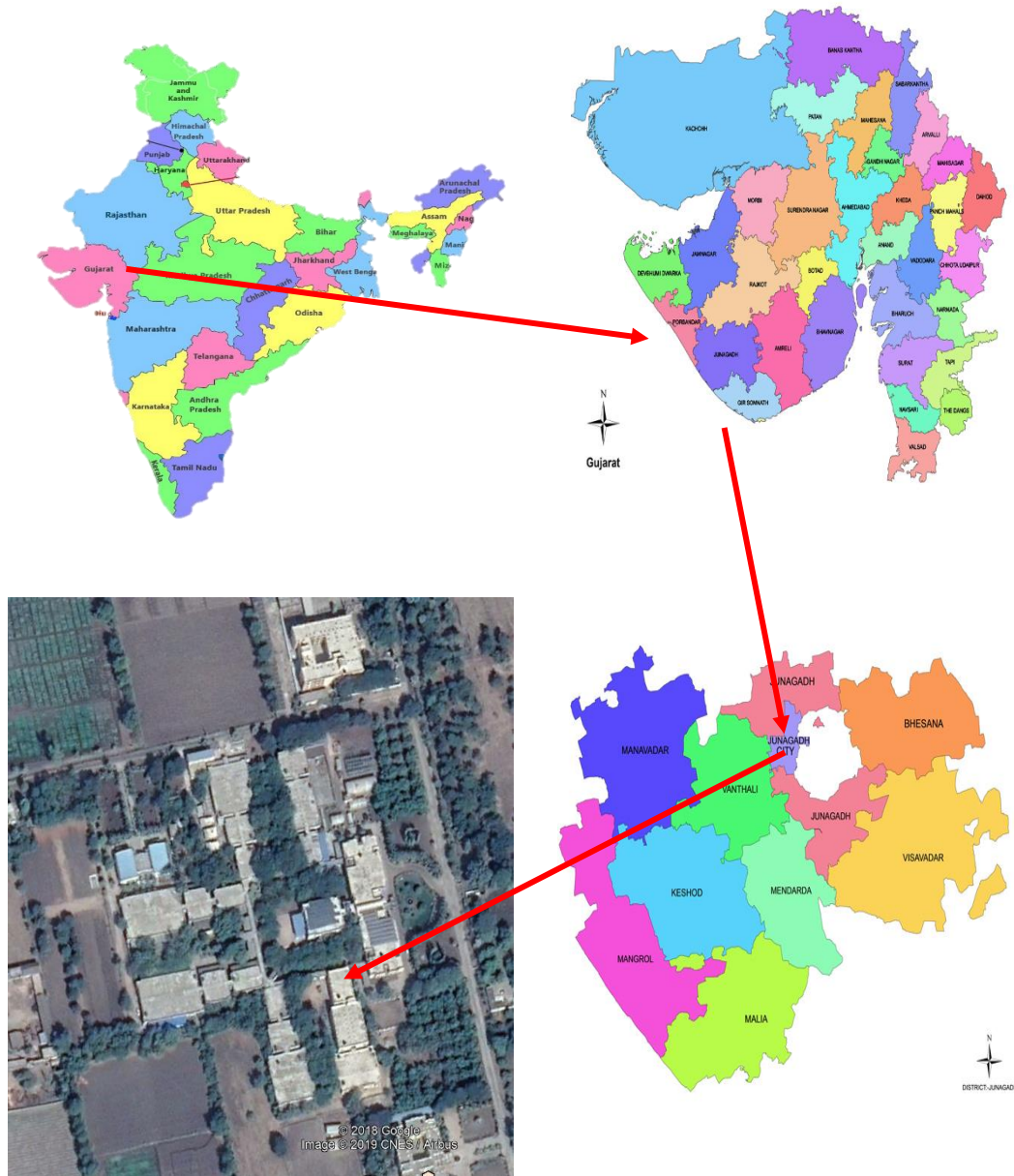


Plate 3.1 Location map of study area

3.1.3 Physiochemical Properties of the Soil

Physiochemical properties including fertility status of soil in the experimental soil are presented in Table 3.1. The texture of the soil was clay loam.

Table 3.1 Physiochemical properties of the soil of experimental field

Sr. No.	Particular	Values	Unit
A	Physical properties		
1	Sand	31.88	%
2	Silt	26.92	%
3	Clay	41.19	%
4	Field capacity	23.77	%
5	Bulk density	1.43	g/cc
6	Infiltration rate	1.00	cm/hr
7	Porosity	42.00	%
8	Specific gravity	2.50	g/cc
B	Chemical Properties		
1	pH (1:2.5)	7.49	
2	EC(1:2.5)	0.66	dS/m
3	Nitrogen (kg/ha)	268.00	kg/ha
4	Phosphate (P ₂ O ₅)	49.52	kg/ha
5	Potash (K ₂ O)	311.81	kg/ha
6	Sulphur	20.08	Ppm
7	Copper	3.82	Ppm
8	Iron	2.08	Ppm
9	Manganese	10.97	Ppm
10	Zinc	1.95	Ppm
11	Boron	0.32	Ppm

3.1.4 Water Quality Analysis

Ground water was used to irrigate the spinach crop. The analysed quality of the irrigation water was depicted in Table 3.2 and quality of water was found good for irrigation.

Table 3.2: Quality analysis of irrigation water

Sr. No	Constituents	Values
1	Carbonate(CO ₃) (ppm)	-
2	Bicarbonate(HCO ₃) (ppm)	590.00
3	Calcium(Ca) (ppm)	96.00
4	Chlorine(Cl)(ppm)	236.50
5	Sodium(Na) (ppm)	221.00
6	EC (dS/m)	1.06
7	pH	6.94
8	Magnesium(ppm)	68.00
9	Sodium absorption ratio (SAR)	3.51
10	Total Dissolve Salts (ppm)	711.20

3.2 EXPERIMENTAL MATERIALS

The resources and materials used during the experiment are described in the subsequent heads.

Transparent Acrylic Sheet:

Acrylic sheet having 4 mm thickness and 90% transparency was used for fabrication of chamber.

Framing Material:

The supporting frame was made using 0.75” GI square pipe to support the acrylic sheet and the mounting of components like sensors and fans.

Temperature / Relative Humidity Sensors with Data Logger:

HOBO External Temp/RH Data Logger (UX100-023) was used for sensing and recording the temperature and relative humidity inside the closed canopy chamber. The logger can also calculate minimum, maximum, average, and standard deviation statistics. This compact data logger has a built-in LCD screen to monitor the current

temperature, relative humidity, logging status, battery use, and the memory consumption in between readouts.

The sensor having the following required specification was decided, procured and used for the experimentation.

Table 3.3: Specifications of HOBO external Temp/RH data logger (UX100-023)

Temperature Sensor	
Range	: -20° to 70°C (-4° to 158°F)
Accuracy	: $\pm 0.21^{\circ}\text{C}$ from 0° to 50°C ($\pm 0.38^{\circ}\text{F}$ from 32° to 122°F), see Plot A
Resolution	: 0.024°C at 25°C (0.04°F at 77°F), see Plot A
Response Time	: 6 minutes in air moving 1 m/s (2.2 mph)
Drift	: $<0.1^{\circ}\text{C}$ (0.18°F) per year
RH Sensor	
Range	: 1% to 100% RH at -40° to 75°C (-40° to 167°F), non-condensing; exposure to conditions below -20°C (-4°F) or above 95% RH may temporarily increase the maximum RH sensor error by an additional 1%
Accuracy	: $\pm 2.5\%$ from 10% to 90% RH typical to a maximum of $\pm 3.5\%$ including hysteresis at 25°C (77°F); below 10% and above 90% $\pm 5\%$ typical
Resolution	: 0.05%
Response Time	: 5 minutes to 90% in airflow of 1 m/s (2.2 mph)
Drift	: $<1\%$ per year typical
Cable Length	: 1.83 m (6 ft)
Logger	
Logger Operating Range	: Logging: -20° to 70°C (-4° to 158°F); 0 to 95% RH (non-condensing) Launch/Readout: 0° to 50°C (32° to 122°F) per USB specification
Logging Rate	: 1 second to 18 hours, 12 minutes, 15 seconds
Logging Modes	: Fixed interval (normal), burst, or statistics
Memory Modes	: Wrap when full or stop when full
Start Modes	: Immediate, push button, date & time, or next interval

Stop Modes	: When memory full, push button, or date & time
Restart Mode	: Push button
Time Accuracy	: ± 1 minute per month at 25°C (77°F), see Plot B
Power Source	: One 3V CR2032 lithium battery and USB cable
Battery Life	: 1 year, typical with logging rate of 1 minute and sampling interval of 15 seconds or greater
Memory	: 128 KB (84,650 measurements, maximum)
Download Type	: USB 2.0 interface
Full Memory	: 20 seconds
Download Time	
LCD	: LCD is visible from 0° to 50°C (32° to 122°F); the LCD may react slowly or go blank in temperatures outside this range
Size	: 3.66 x 8.48 x 1.52 cm (1.44 x 3.34 x 0.6 in.)
Weight	: 30 g (1.06 oz)
Environmental	: IP50
Rating	

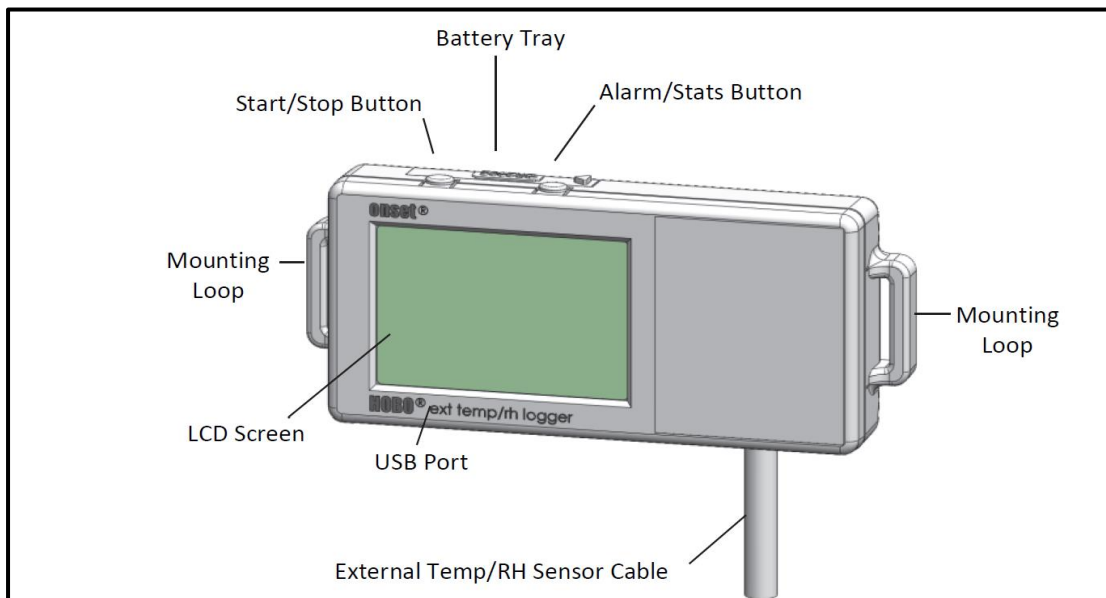


Fig. 3.1 HOBO external Temp/RH data logger (UX100-023) components and operation

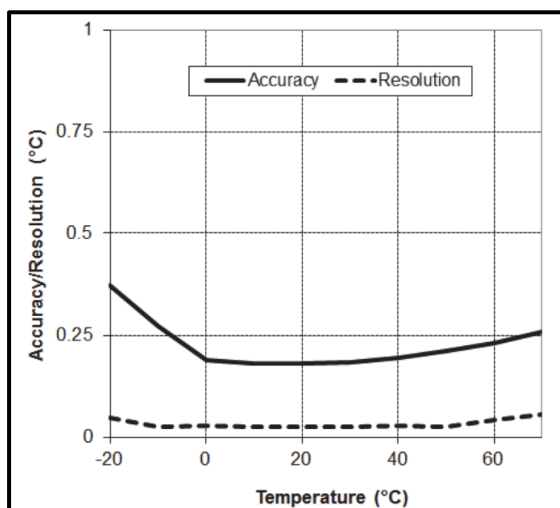


Fig. 3.2 Temperature accuracy and resolution of HOBO external Temp/RH data logger (UX100-023)

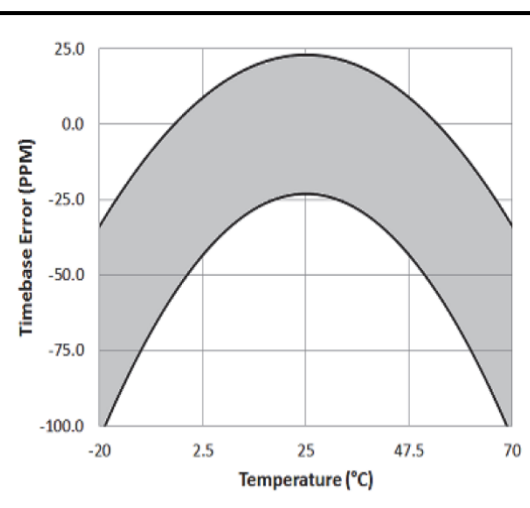


Fig. 3.3 Time accuracy of HOBO external Temp/RH data logger (UX100-023)

Small Fans:

Two small fans having 75mm diameter were used as per requirement for proper air and water vapour mixing inside the chamber.

Power Source:

Two dry batteries of 9 V and 400 mAh capacity was connected in series and power was supplied to each fan. So total 4 such batteries were used for 2 fans.

Weight Balance:

The electronic balance was used for weighting the micro-lysimeters having capacity of 20 kg and least count of 0.1 g.

Micro-Lysimeters:

Thirty two weighing type micro-lysimeters of size $0.20 \times 0.20 \times 0.20$ m were fabricated from aluminium sheet of 1 mm thickness. It was used for growing crops by filling soil inside.

Square Aluminium Tray:

A square aluminium tray was used for filling the water and measuring the evaporation by the closed canopy chamber as well as the pan evaporation method.

3.3 METHODOLOGY**3.3.1 Fabrication of the Portable Closed Canopy Chamber**

The portable closed canopy chamber was fabricated from transparent acrylic sheet having thickness of 4 mm. Square GI pipe was used for framing of the closed canopy chamber. The length, width and height of chamber were 0.85 m, 0.85 m and 1.10 m respectively. The chamber volume was 0.794 m^3 with a base area of 0.7225 m^2 .

Two small fans were mounted on the inner side of the chamber opposite to each other, for the proper mixing of air and water vapour inside the canopy chamber, so that a homogeneous air-water vapour mixture can be obtained inside the chamber.

Between the fans, a temperature and humidity sensor was suspended above the plant canopy for the measurement of temperature and RH of the chamber air.

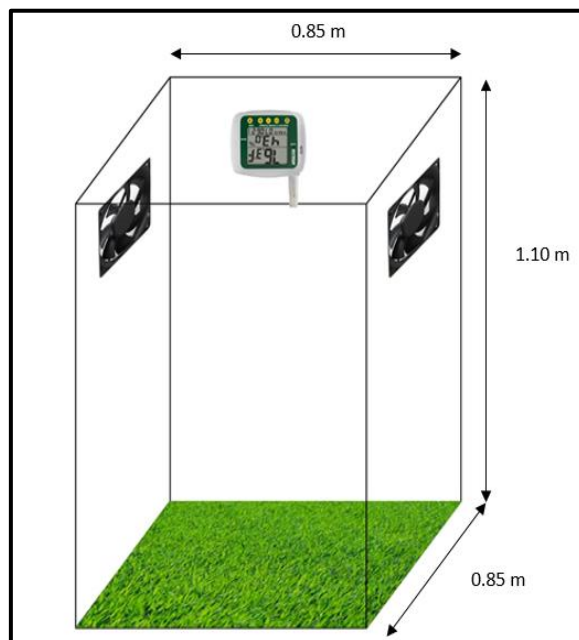


Fig. 3.4 Conceptual design of closed canopy chamber

3.3.1.1 Checking of transparency of acrylic sheet

Generally, the transparency of 4 mm acrylic sheet is 90%. The transparency of the acrylic sheet with and without overlapping was checked using lux meter at different time intervals.

3.3.2 Fabrication of Micro-Lysimeters

Micro-lysimeters were fabricated from light aluminium sheets of 1 mm thickness. The size of each micro-lysimeter was 20 cm × 20 cm × 20 cm. Soil was filled in it in such a way that the properties of the soil inside the micro-lysimeters are just similar to in-situ conditions. A shallow rooted spinach was grown in the micro-lysimeters. The spinach has a root zone depth of 20 cm and the tap root grows up to 12 to 15 cm. So the depth of micro lysimeters was selected to be 20 cm. The average weight of the empty micro lysimeter was 0.55 kg.

3.3.2.1 Filling of soil in micro-lysimeters

All the 32 micro lysimeters were filled with soil of RTTC farm in such a way that the bulk density of the soil was maintained at the field value. The average weight of the soil in the micro lysimeters was 11.4 kg and the volume of the soil in each of the micro lysimeter was 7600 cm³. The bulk density of soil in the micro-lysimeter was 1.5 g/cm³ which was same as the field value. The faces of adjacent micro lysimeters were kept just touching each other.

3.3.2.2 Sowing of leafy vegetable in micro-lysimeter

Spinach was sown manually in the micro-lysimeters on 10/12/2018 for the winter season and on 06/03/2019 for the summer season. The seed to seed distance was maintained at 2-3 cm and the depth of sowing was maintained at 1 cm. The average germination percentage of the seeds was 65%.

3.3.2.3 Irrigation application

Irrigation was applied to the spinach manually with a measuring flask as per the crop water requirement calculation. The crop water requirement was obtained from the lysimeter and the irrigation water depth was calculated. Application of irrigation water in the micro-lysimeter was in such a way that there was no drainage due to the deep percolation.



Plate 3.2 Filling of soil in micro-lysimeter



Plate 3.3 Sowing of leafy vegetable in the micro-lysimeter

3.3.3 Calibration / Validation of the Closed Canopy Chamber

The entire day of 24 hours was divided into 12 periods, each of 2 hours. The 12 periods of 2 hours were divided into 8 periods of 15 minutes. During the first 15 minutes period, the 2 min closing and 2 min opening of 4 min cycle was repeated 3 times. The sensor sensed and recorded the instantaneous temperature and relative humidity at 1 second intervals during the 2 min closing time of each cycle of first 15 minutes of each 2 hour periods.

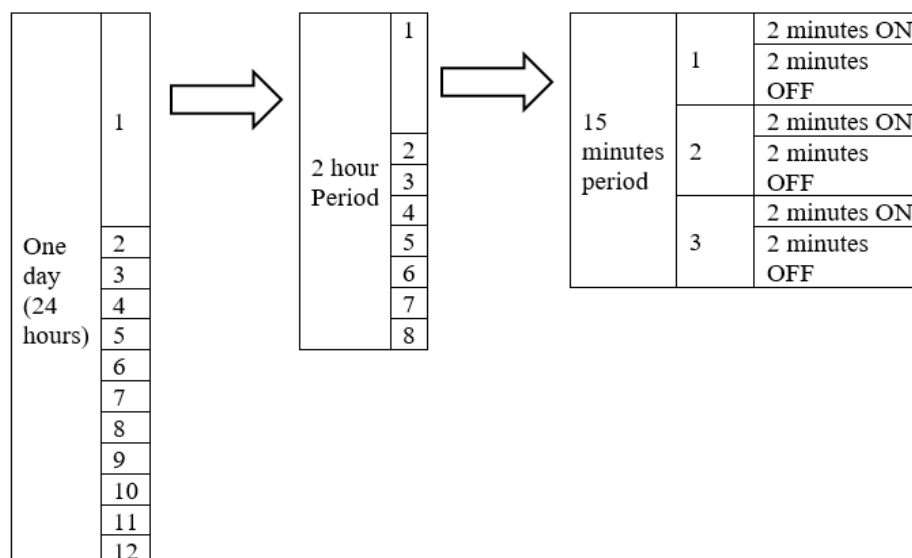


Fig. 3.5 Graphical illustration of the data collection in a day

3.3.3.1 Measurement of evapotranspiration in closed canopy chamber

The crop evapotranspiration data were collected over a period of approximately 15 min duration throughout the day at 2 hours interval. The closed canopy chamber was positioned over the crop grown in the micro-lysimeters while a data logger measured the temperature and RH at every 1 seconds of the 2-min interval. Between measurements, the chamber was taken away from the micro-lysimeters for a minimum of 2 min to obtain micro-climate similar to open atmosphere.

Efforts were made not to block solar radiation during measurements. Datasets were collected within 15 min and datasets were repeated at 2 hr interval.



Plate 3.4 Measurement of evapotranspiration in the closed canopy chamber

3.3.3.2 Estimation of water vapour density from temperature and RH data

Saturation water vapour pressure

Temperature and relative humidity measurements were converted into saturation vapour pressure (E_s), actual vapour pressure (E_a), and vapour density (ρ_v) as per McLeod *et al.* (2004):

$$E_s = 6.11 f(p) e^{\frac{17.5 T}{241.2 + T}} \quad \dots(3.1)$$

Where;

E_s = saturation vapour pressure (Pa)

T = temperature of air ($^{\circ}\text{C}$)

$f(p)$ = assumed to be a constant value as 100.47 related to atmospheric pressure

Actual vapour pressure (E_a)

It was calculated using relative humidity as:

$$E_a = E_s \times \frac{RH}{100} \quad \dots(3.2)$$

Where;

E_a = Actual vapour pressure (Pa)

RH = Relative humidity (%)

Density of water vapour

The density of water vapour inside the closed canopy chamber was estimated as:

$$\rho_v = \frac{0.622 E_a}{R_d T} \times 1000 \quad \dots(3.3)$$

Where;

ρ_v = Water vapour density (g/m^3)

R_d = Universal gas constant (287.04 J/kg/K)

T = Temperature (K)

3.3.3.3 Calculation of ET rate from the water vapour density (Stannard, 1988)

$$ET = 86.4 \frac{MVC}{A} \quad \dots(3.4)$$

Where;

ET = Evapotranspiration rate (mm/day)

M = maximum slope of water vapour density time series ($\text{g/m}^3 \text{ s}$)

V = volume of chamber, (m^3)

C = calibration factor of the chamber (unitless)

A = land surface area covered by the chamber (m^2)

86.4 is a factor that converts $\text{g/m}^3 \text{ s}$ to mm/day using the density of water.

3.3.3.4 Area Factor for the closed canopy chamber

The soil surface area in micro-lysimetes was 0.64 m^2 and the base area of closed canopy chamber was 0.7225 m^2 . There was no evapotranspiration from the remaining area and that much less water vapour was generated. So the area factor for calculation of ET_c under closed canopy chamber was taken as $0.7225/0.64=1.13$. It is multiplied by the chamber ET_c for correction of chamber ET_c .

The area factor of closed canopy chamber was calculated by following equation.

$$F_{ac} = \frac{A_b}{A_{ss}} \quad \dots(3.5)$$

Where;

F_{ac} = area correction factor

A_b = base area of canopy chamber, m^2

A_{ss} = total soil surface area of all micro lysimeters, m^2

3.3.3.5 Calibration of closed canopy chamber

The chamber calibration factor, which account for the slight hydrophilicity of the chamber material, was determined using methods described by Stannard (1988). The procedure involved evaporating a known mass of water and then placing the chamber over the water to determine the chamber-measured rate. The water lost from the tray was measured volumetrically and converted into depth term.

A square aluminum tray having sides of 84 cm was used for the calibration of closed canopy chamber by measuring the water evaporation throughout the day. Known weight of water was filled in the tray and its evaporation was measured by the closed canopy chamber and compared with water volume lost from the tray.

This procedure was repeated several times at each of the several known evaporation rates. The chamber and known evaporation rates were plotted against one another and the slope of the best-fit line was taken as the calibration factor.



Plate 3.5 Calibration of closed canopy chamber

3.3.4 Performance Evaluation of Closed Canopy Chamber

3.3.4.1 ET_c measurement by the closed canopy chamber

The fabricated and calibrated closed canopy chamber was put on a tray having 16 micro-lysimeters. The ET values were estimated using data of water vapour flux measured and recorded by the Temperature-RH sensor using the equations (3.1) to (3.4) stated in sections 3.3.3.2 and 3.3.3.3 were compared with the ET values measured through micro-lysimeters and the performance was analysed.

3.3.4.2 ET_c measurements by the micro-lysimeters

The weight of each of the 32 micro-lysimeters were taken at 3 day intervals. Irrigation water as per requirement was applied to micro-lysimeters during the experimentation. Drainage from the micro-lysimeters was also measured if occurred.

The crop evapotranspiration was calculated as below.

$$ET_c = I + R - \frac{d_w}{A} + \frac{(W_1 - W_2)}{A} \quad \dots(3.6)$$

Where;

ET_c = Crop evapotranspiration (mm)

I = Irrigation input to micro-lysimeters (mm)

R = Rainfall input to micro-lysimeters (mm)

dw = Amount of water drained (lit)

W₁ & W₂ = Initial and final weight of micro-lysimeters at given intervals (kg)

A = Cross sectional area of micro-lysimeters (m²)

The ET_c measured by closed canopy chamber was compared with that obtained by the water balance in micro-lysimeters.



Plate 3.6 ET_c measurements by micro-lysimeters

3.4 CROP COEFFICIENT

Fundamentally, the crop coefficient is defined as the ratio of crop ET (ET_c) to some reference ET (ET₀) as defined by weather data. In FAO-56, values listed for K_C represent ET under growing conditions having a high level of management and with little or no water or other ET reading stress and thus represent what are referred to as potential levels for crop ET.

K_C curve comprises of four straight line segments representing the initial period, the development period, the midseason period, and the late season period. These segments are defined by three primary K_C values; K_C during the initial period K_{C ini}, K_C during midseason (full cover) period K_{C mid}, and K_C at harvest (or at the end of late

season) $K_{C\text{ end}}$. The $K_{C\text{ ini}}$ defines the horizontal portion of the K_C curve during the initial period until approximately 10 % of the ground is covered by vegetation. The $K_{C\text{ mid}}$ defines the value for K_C during the peak period for the crop, which is normally when the crop is at “effective full cover”. This period is described by a horizontal line extending through $K_{C\text{ mid}}$. The development period is defined by a sloping line that connects the initial and midseason period. The late season has a sloping line that connects the end of the midseason period with the harvest (end) date.

The crop coefficient can be calculated by the following equation.

$$K_c = \frac{ET_c}{ET_0} \quad \dots\dots(3.7)$$

Where;

K_c = Crop coefficient

ET_c = Crop evapotranspiration (mm)

ET_0 = Reference Evapotranspiration (mm)

3.4.1 Calculation of the Reference Crop Evapotranspiration

Allen *et al.* (1998) defined and published the FAO paper no. 56 the Penman-Monteith ET_0 , as the rate from a hypothetical reference crop with an assumed crop height (12 cm), a fixed surface resistance (70 s/m) and albedo (0.23), closely resembling the ET from an extensive surface of the green grass cover with adequate water. Using daily or monthly data it can be simplified as follows.

$$ET_0 = \frac{0.408 \Delta (R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 u_2)} \quad \dots\dots(3.8)$$

Where, ET_0 = Reference evapotranspiration (mm/day)

R_n = Net radiation at the crop surface (MJ/m² day)

G = Soil heat flux density (MJ/m² day)

T = Mean daily air temperature at 2 m height (°C)

u_2 = Wind speed at 2 m height (m/s)

e_s = Saturation vapour pressure (kPa)

e_a = Actual vapour pressure (kPa)

$e_s - e_a$ = Saturation vapour pressure deficit (kPa)

Δ = Slope vapour pressure curve (kPa/°C)

γ = Psychrometric constant (kPa/°C)

3.5 SENSOR DATA RETRIEVAL

The following steps were followed for the retrieval of sensor data as shown below.

- 1) The Hoboware 3.7.16 software for working with the HOBO External Temp/RH Data Logger (UX100-023) was downloaded from the following website. <https://www.onsetcomp.com/hoboware-free-download>
- 2) First of all, the logger was launched to start the logging.
- 3) The Device menu from menu bar was opened and selected Launch option. Here, the logging interval was selected, which data to be logged, which mode to start/stop logging, alarm.
- 4) After launching, to start and stop the logging, the left push button above the logger display was pressed and held for 3 seconds.
- 5) The display showed the memory and battery capacity of the logger. There were 2 options for automatically stopping the logging. First when memory full and 2nd never stop. If it was chosen the never stop option, when memory would be full then logger rewrite the oldest data with new data. So at regular interval, the logged data were downloaded from the logger to computer.
- 6) To download the data from logger, Device menu and select Utilities → Force Offload USB Logger path was opened.
- 7) All the data could be downloaded to the computer as .hobo file. To analyze these data it was converted into the excel file by exporting it.
- 8) To clear the old data, the logger was launched again.

3.6 OBSERVATIONS

- 1) Temperature and relative humidity data inside the closed canopy chamber for calculation of the ET_c and pan evaporation by the closed canopy chamber method.
- 2) Weight of micro lysimeters for calculation of ET_c by micro lysimeters
- 3) Irrigation water depth
- 4) Drainage water depth
- 5) Rainfall (if any)
- 6) Initial and final weight of water in the tray for calculation of pan evaporation.



Plate 3.7 Advisory committee visit

3.7 STATISTICAL ANALYSIS

A two sample t-test was used to compare the 2 sets of data to check whether they are significantly different or not. It is rigorous test of the hypothesis that the two samples are drawn from a population having the same variance. t - Test is generally used only with small samples. If $\bar{m}$ is the mean of a sample of size n and s is the standard deviation as estimated from the sample and if we are testing the deviation of $\bar{m}$ from a hypothetical value μ then the t - Test used to test whether the means are different or not that can be calculated as follows (Panse and Sukhatme, 1967).

$$t = \frac{\bar{m}_1 - \bar{m}_2}{S_p \sqrt{\frac{1}{n_1} + \frac{1}{n_2}}} \quad \dots(3.7)$$

$$S_p = \sqrt{\frac{(n_1 - 1)S_{x_1}^2 + (n_2 - 1)S_{x_2}^2}{n_1 + n_2 - 2}} \quad \dots(3.8)$$

Where,

m_1 and m_2 = mean of sample 1 and 2,

n_1 and n_2 = size of sample 1 and 2 and

S_{x1} and S_{x2} = standard deviation of sample 1 and 2.

In these formula, $n_i - 1$ is the number of degrees of freedom for each group, and the total sample size minus two (that is, $n_1 + n_2 - 2$) is the total number of degrees of freedom, which is used in significance testing.

CHAPTER - IV

RESULTS AND DISCUSSION

The results on the investigation entitled, “Development of portable closed canopy chamber for evapotranspiration measurement” conducted at the Soil and Water Conservation Engineering Department, College of Agricultural Engineering and Technology, Junagadh Agricultural University, Junagadh during December 2018 to May 2019 are described and discussed in this chapter along with the statistical inferences in the subsequence heads.

4.1 Climate

4.2 Fabricated micro-lysimeters

4.3 Developed Canopy Chamber

4.4 Evaluation of the closed canopy chamber

4.5 Statistical analysis of ET_c of canopy chamber and micro-lysimeter

4.6 Cost economics of canopy chamber

4.1 CLIMATE

The evapotranspiration during the plant growth period depends mainly on weather factors such as temperature, relative humidity, wind speed and daily bright sunshine hours prevailing during the respective season. Weather parameters also affect the plant growth, development, and yield. Also attack of pests, insects and diseases depends on weather conditions. Weather factors show spatial variations in an area at a given time, temporal variations at a given place and year to year variations for a given place and time. For cropping purposes, weather over short periods and year to year fluctuations at a particular place over the selected time interval have to be considered.

The meteorological observations with regard to the temperature, relative humidity, wind speed, daily bright sunshine hours and evaporation experienced during the experimental period (December 2018 to May 2019) are given in Appendix-A.

Daily maximum and minimum temperature observed during December to May 2018-19 is shown in Fig. 4.1. The maximum and minimum temperature during the crop period ranged between 25.6 °C to 44.7 °C and 6.5 °C to 27.6 °C respectively.

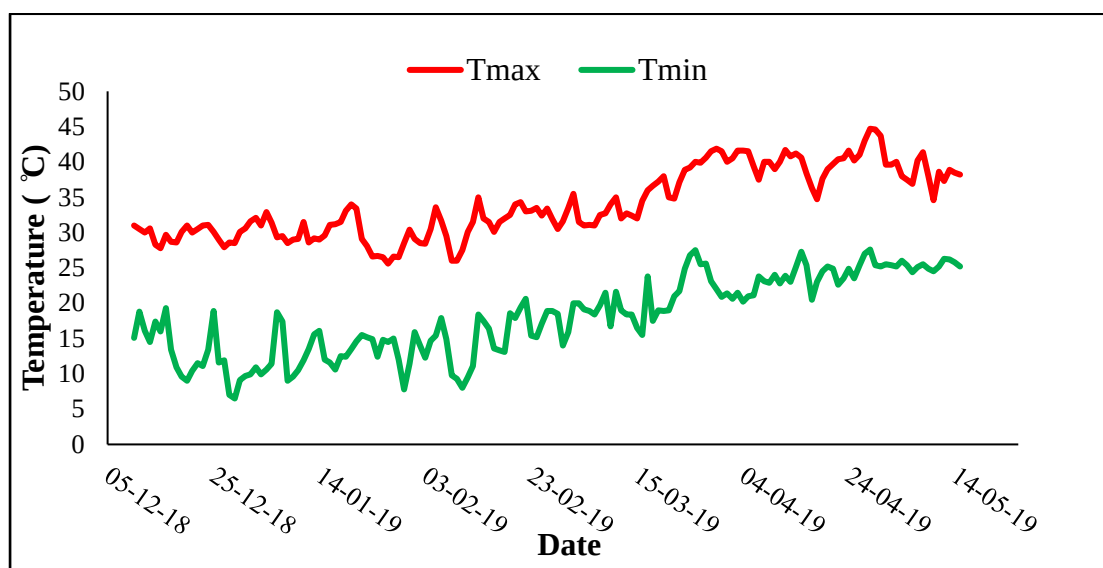


Fig 4.1 Daily maximum and minimum temperatures during December 2018 to May 2019

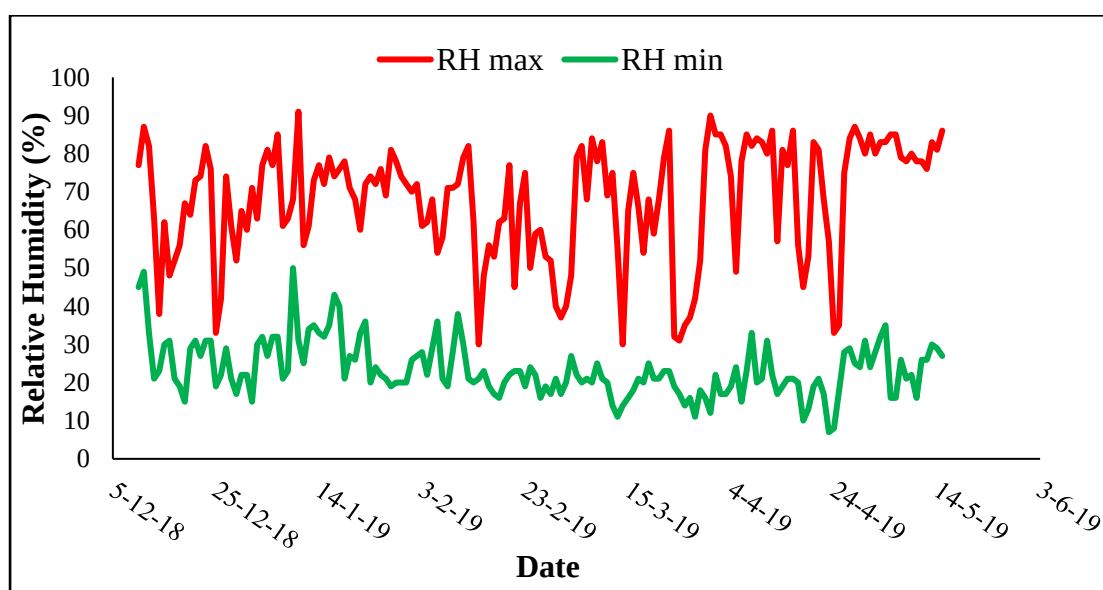


Fig. 4.2 Daily maximum and minimum relative humidity during December 2018 to May 2019

Daily maximum and minimum relative humidity during the season is shown in Fig. 4.2. The average relative humidity varied from 23 % to 68 % during the season. The highest relative humidity was observed on 10th January 2019 and lowest relative humidity on 23rd April 2019 respectively.

The wind speed during the growing season varied from 1.9 km/hr to 10.2 km/hr. Maximum wind speed was observed on 2nd February 2019 as shown in the Fig. 4.3.

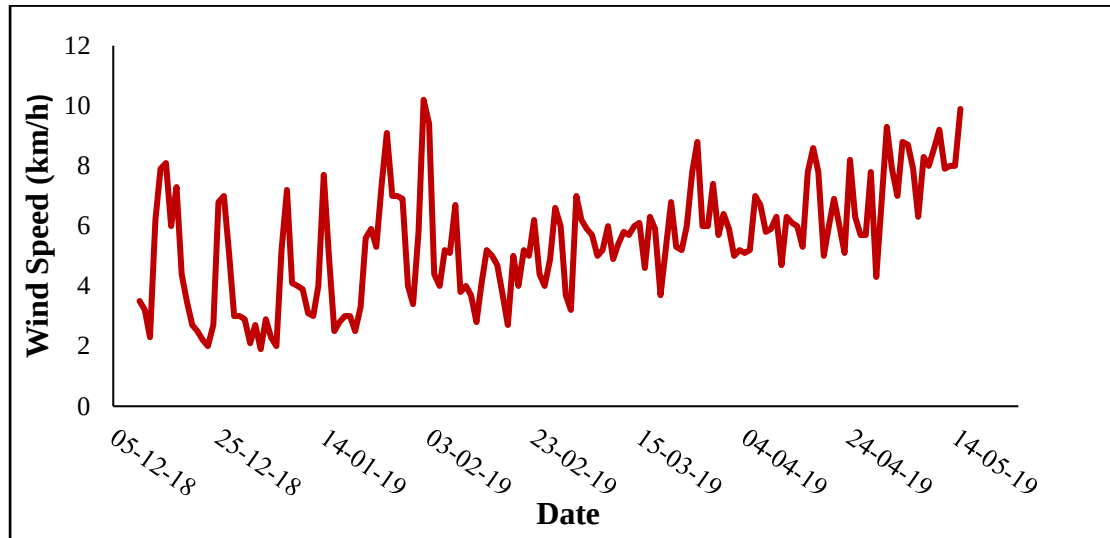


Fig 4.3 Daily wind speed during December 2018 to May 2019

The maximum bright sunshine hours was observed as 11.4 hrs on 9th May 2019 while minimum bright sunshine hour was observed as 0.1 hr on 17th December 2018 as shown in the Fig. 4.4.

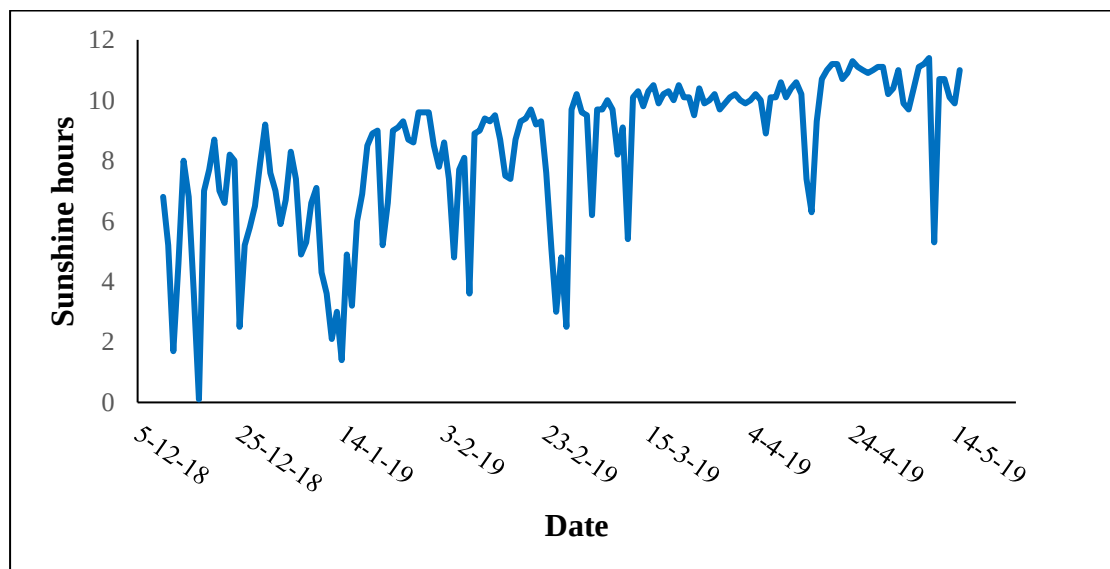


Fig 4.4 Daily bright sunshine hours during December 2018 to May 2019

4.2 FABRICATED MICRO-LYSIMETER

The average weight of the micro-lysimeters empty and that filled with soil were 0.55 kg and 11.4 kg respectively. The size of micro-lyasimeter was 0.2 m × 0.2 m × 0.2 m. The fabricated micro-lysimeters were water leak proof.

The weight of micro-lysimeters were measured at the required intervals. Two sets of 16 micro-lysimeters were used. One set of 16 micro-lysimeter was used for estimating the crop evapotranspiration of spinach crop inside the canopy chamber and another set was kept outside the canopy chamber having condition of continuous open atmosphere. The inputs of the irrigation was kept similar in both the sets. Using the water balance of the each micro-lysimeter, the ET_c was measured for both set as depleted in Table 4.1.

Table 4.1 Comparison of the ET_c from micro-lysimeter inside the canopy chamber and open atmosphere (For the spinach crop sown on 10/12/2018).

Period	ET _c from micro-lysimeter	
	Inside the canopy chamber (mm/day)	In open atmosphere (mm/day)
10-13 Dec	2.2	2.27
13-15 Dec	4.5	4.32
15-17 Dec	3.91	3.87
17-20 Dec	2.91	2.54
20-24 Dec	2.69	2.97
24-27 Dec	3.27	3.51
27-31 Dec	2.59	2.56
31 Dec to 2 Jan	3.04	3.14
2-5 Jan	2.99	2.75
5-8 Jan	3.71	3.43
8-10 Jan	3.12	3.34
10-15 Jan	2.4	2.16
15-18 Jan	3.8	3.65
18-21 Jan	4.23	4.36
21-24 Jan	4.29	4.56
24-28 Jan	5.38	5.11
28-31 Jan	5.07	5.32
31 Jan to 4 Feb	5.08	5.07

Period	ET _c from micro-lysimeter	
	Inside the canopy chamber (mm/day)	In open atmosphere (mm/day)
4-6 Feb	4.5	4.67
6-9 Feb	5.65	5.29
9-11 Feb	5.35	5.47
11-14 Feb	4.59	4.57
14-18 Feb	5.23	5.27
18-21 Feb	5.22	5.48
21-25 Feb	5.21	5.33
25-28 Feb	4.85	4.87
28 Feb to 2 March	5.54	5.23
2-5 March	5.69	5.78
5-8 March	5.7	5.63
8-11 March	6.09	6.19
11-14 March	5.55	5.64
14-18 March	6.14	6.31
18-20 March	7.13	7.47
20-22 March	5.8	5.41
22-25 March	6.75	6.82
25-28 March	7.35	7.48

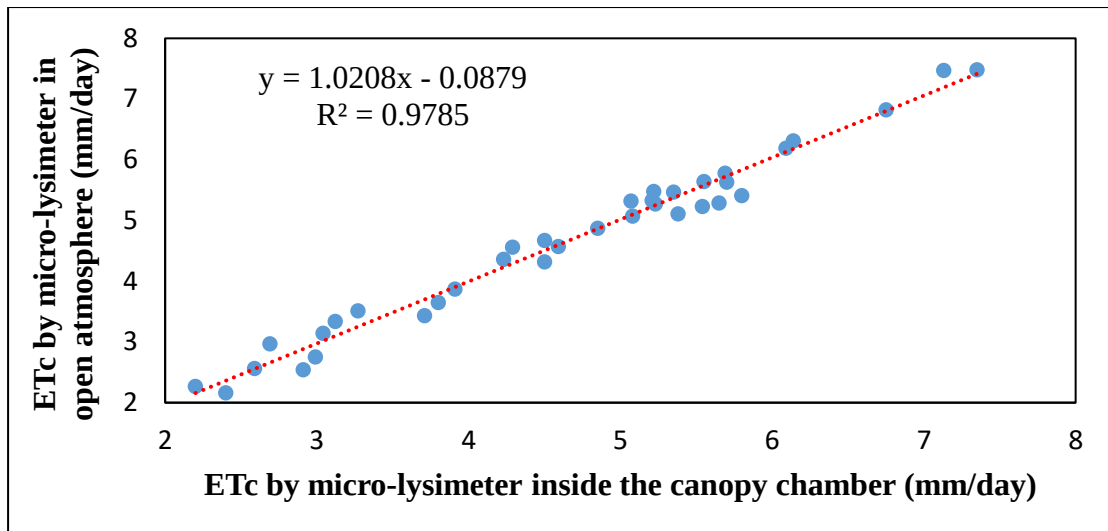


Fig. 4.5 Comparison of ETc by micro-lysimeter inside the canopy chamber and open atmosphere

ETc by micro-lysimeter inside the canopy chamber and open atmosphere are compared in Table 4.1 and graphically in Fig. 4.5. It is revealed that there was no effects of change in micro climate for short period in chamber on plant physiology.

4.2.1 Statistical Analysis of ETc by Micro-Lysimeter Inside the canopy chamber and Open Atmosphere

The ETc by micro-lysimeter inside the canopy chamber and open atmosphere were recorded for statistical comparison. Statistical analysis of ETc by micro-lysimeter inside the canopy chamber and open atmosphere was carried out to check whether these two values are statistically similar or not. The ETc by micro-lysimeter inside the canopy chamber and open atmosphere values were considered as one group and two sample t-test was conducted assuming equal variances at 95 percent confidence level of each group.

The statistical comparison by t-test of ETc by micro-lysimeter inside the canopy chamber and open atmosphere for spinach crop are presented in Table 4.5. The values of number of samples, degree of freedom, t_{table} and t_{cal} were 36, 70 and 1.99 and 0.02, respectively. The value of t_{cal} lower than t_{table} revealed that there are non-significant difference between ETc by micro-lysimeter inside the canopy chamber and open atmosphere at 95 percent confidence level (Table 4.2). Hence, the data of ETc by micro-lysimeter inside the canopy chamber and open atmosphere are matching with each other without any significant statistical differences. It indicated that the change in micro

climate inside the canopy chamber did not affect on plant growth physiological processes.

Table 4.2 t-test result of statistical comparison of ET_c by micro-lysimeter inside the canopy chamber and open atmosphere

	ET _c by micro-lysimeter inside the canopy chamber	ET _c by micro-lysimeter in open atmosphere
Mean	4.6533	4.6622
Variance	1.8551	1.9755
Observations	36	36
Pooled Variance	1.9153	
Hypothesized Mean Difference	0	
Df	70	
T _{Calculated}	0.0272	
T _{Table}	1.9944	
Result	NS	

4.3 DEVELOPED CANOPY CHAMBER

The developed closed canopy chamber is as per the dimension shown in the chapter 3.3.1. The transparency of the 4 mm acrylic sheet was 89.5%. The chamber in place alters the internal micro environment including inside temperature, vapour pressure, and net radiation, which includes incoming and outgoing shortwave and longwave radiation inside the chamber. Though the effect of the chamber in place on internal conditions remains a large source of uncertainty with the chamber method, past research with similarly designed chambers has shown that the altered conditions inside the chamber during measurements do not have a significant effect on plant transpiration in the first 120 s (Wagner and Reicosky 1992; Grau 1995).

4.4 EVALUATION OF CLOSED CANOPY CHAMBER

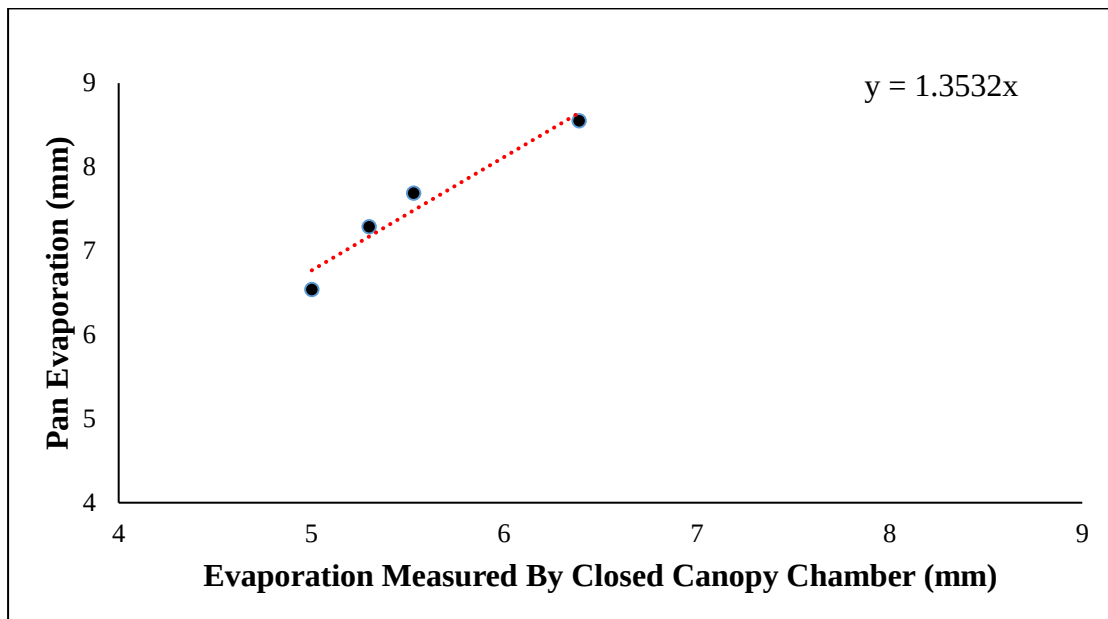
4.4.1 Calibration of Closed Canopy Chamber

The calibration of closed canopy chamber was done by evaporating a known mass of water and then placing the chamber over the water to determine evaporation rate based on temperature and relative humidity measurement. The evaporation of water estimated by measuring the volume of evaporated water from tray and closed canopy chamber are shown in table 4.3.

Table 4.3 Calibration of canopy chamber

Date	Evaporation measured by Pan Evaporation	Evaporation measured by closed canopy chamber
23 rd March	6.54	5.00
30 th March	8.55	6.39
13 th April	7.69	5.53
20 th April	7.29	5.30

The chamber and known evaporation rates was plotted against one another and the slope of the best-fit line was taken as the calibration factor. Accordingly, the calibration factor of the closed canopy chamber was found as 1.3532. McJannet et al. (1996) adopted a similar technique and employed a coefficient of 1.296

**Fig. 4.6 Calibration of closed canopy chamber**

4.4.2 Performance Evaluation of Closed Canopy chamber

4.4.2.1 Micro-lysimeter evapotranspiration

The present investigation was carried out during two seasons; winter (10th December, 2018 to 25th March, 2019) and summer (6th March, 2019 to 15th May, 2019). The spinach crop was sown during both the seasons in micro-lysimeters. Water balance method was adopted to measure the crop evapotranspiration.

Table 4.4 Spinach crop evapotranspiration during winter season measured by Micro-lysimeter (For the spinach crop sown on 10/12/2018).

Period	ETc measured by Micro-lysimeters (mm/day)	Period	ETc measured by Micro-lysimeters (mm/day)
10-13 Dec	2.2	4-6 Feb	4.5
13-15 Dec	4.5	6-9 Feb	5.65
15-17 Dec	3.91	9-11 Feb	5.35
17-20 Dec	2.91	11-14 Feb	4.59
20-24 Dec	2.69	14-18 Feb	5.23
24-27 Dec	3.27	18-21 Feb	5.22
27-31 Dec	2.59	21-25 Feb	5.21
31 Dec to 2 Jan	3.04	25-28 Feb	4.85
2-5 Jan	2.99	28 Feb to 2 March	5.54
5-8 Jan	3.71	2-5 March	5.69
8-10 Jan	3.12	5-8 March	5.7
10-15 Jan	2.4	8-11 March	6.09
15-18 Jan	3.8	11-14 March	5.55
18-21 Jan	4.23	14-18 March	6.14
21-24 Jan	4.29	18-20 March	7.13
24-28 Jan	5.38	20-22 March	5.8
28-31 Jan	5.07	22-25 March	6.75
31 Jan to 4 Feb	5.08	25-28 March	7.35

Table 4.5 Spinach crop evapotranspiration during summer season measured by Micro-lysimeter (For the spinach crop sown on 06/03/2019).

Period	ETc measured by Micro-lysimeters (mm/day)	Period	ETc measured by Micro-lysimeters (mm/day)
6-8 March	3.61	9-12 April	5.78
8-11 March	4.02	12-15 April	7.462
11-14 March	3.89	15-18 April	8.32
14-16 March	4.05	18-20 April	10.1
16-19 March	5.16	20-23 April	8.89
19-22 March	4.53	23-26 April	9.25
22-25 March	5.46	26-29 April	8.8
25-28 March	6.41	29 April to 1 May	8.84
28-30 March	7.14	1-3 May	8.95
30 March to 2 April	6.96	3-6 May	8.72
2-4 April	7.1	6-8 May	9.8
4-6 April	7.34	8-10 May	10.48
6-9 April	6.27	10-13 May	9.34

4.4.2.2 Canopy chamber measured ETc

The crop evapotranspiration (ETc) measured by closed canopy chamber at weekly interval and its comparison with relevant micro-lysimeter measured ETc is shown in tables 4.6 and 4.7 respectively.

Table 4.6 Comparison of Spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during winter season (For the spinach crop sown on 10/12/2018).

Date	ETc by canopy chamber (mm/day)	ETc by Micro-lysimeters (mm/day)
12th February	5.52	4.59
13th February	5.19	4.59
18th February	5.74	5.23
20th February	5.76	5.22
22nd February	6.12	5.21
2nd March	6.14	5.54
8th March	5.86	5.7
15th march	6.47	6.14
23rd March	6.35	6.75

Table 4.7 Comparison of Spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during summer season (For the spinach crop sown on 06/03/2019).

Date	ETc by canopy chamber (mm/day)	ETc by Micro-lysimeters (mm/day)
15th March	4.21	4.05
23rd March	4.43	5.46
30th March	6.59	7.14
6 April	7.82	7.34
13th April	7.83	7.46
20th April	8.06	10.1
27th April	8.43	8.8
6th May	7.05	8.72
11th May	8.08	9.34

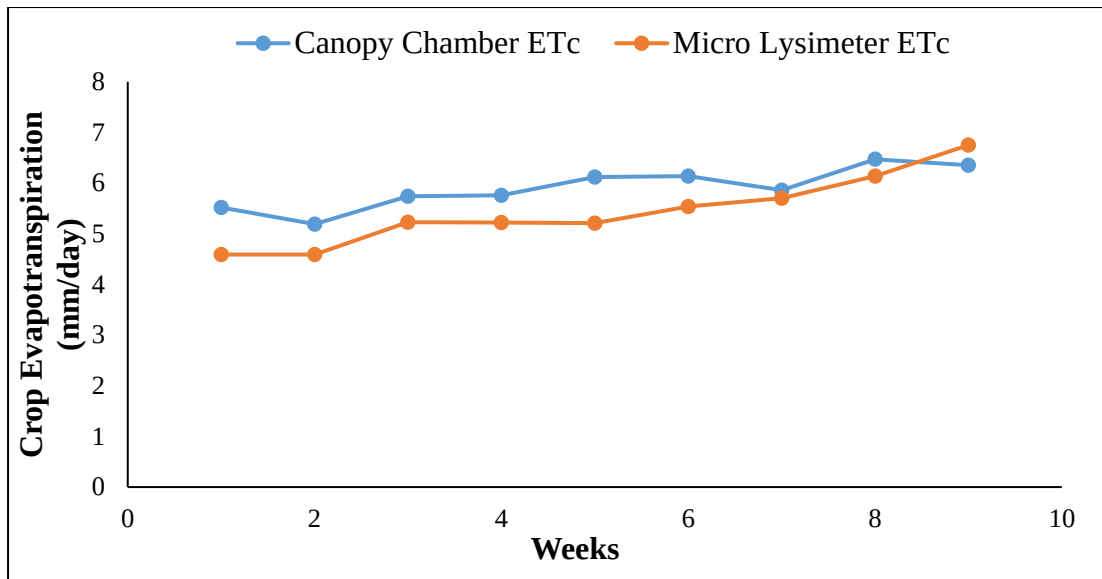


Fig. 4.7(a) Comparison of spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during winter season

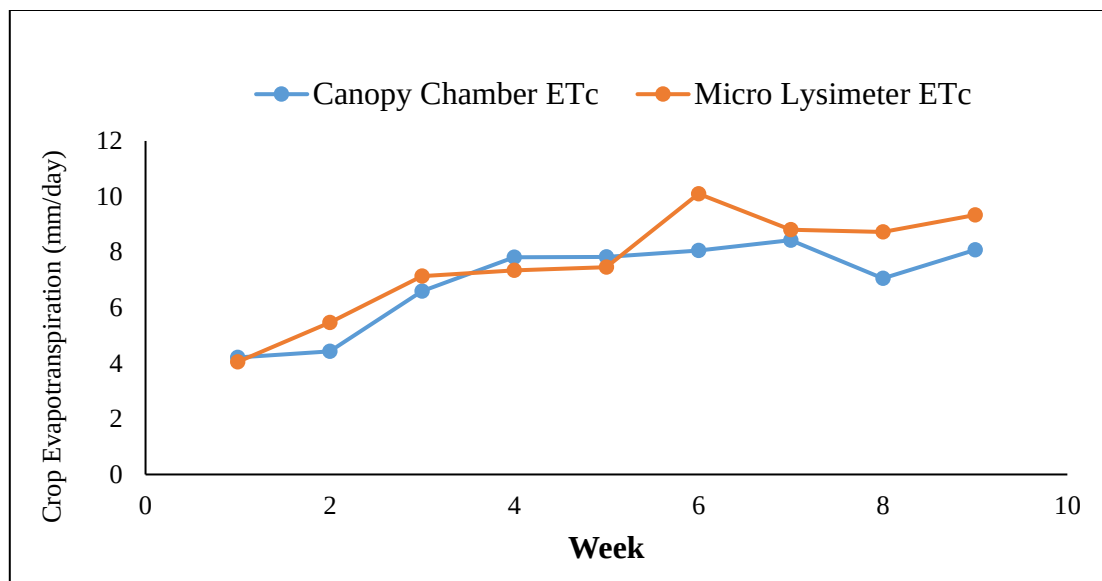


Fig 4.7(b) Comparison of spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during summer season

The crop evapotranspiration measured by canopy chamber and micro-lysimeter are plotted as shown in Fig. 4.8(a) and 4.8(b) for winter and summer season respectively.

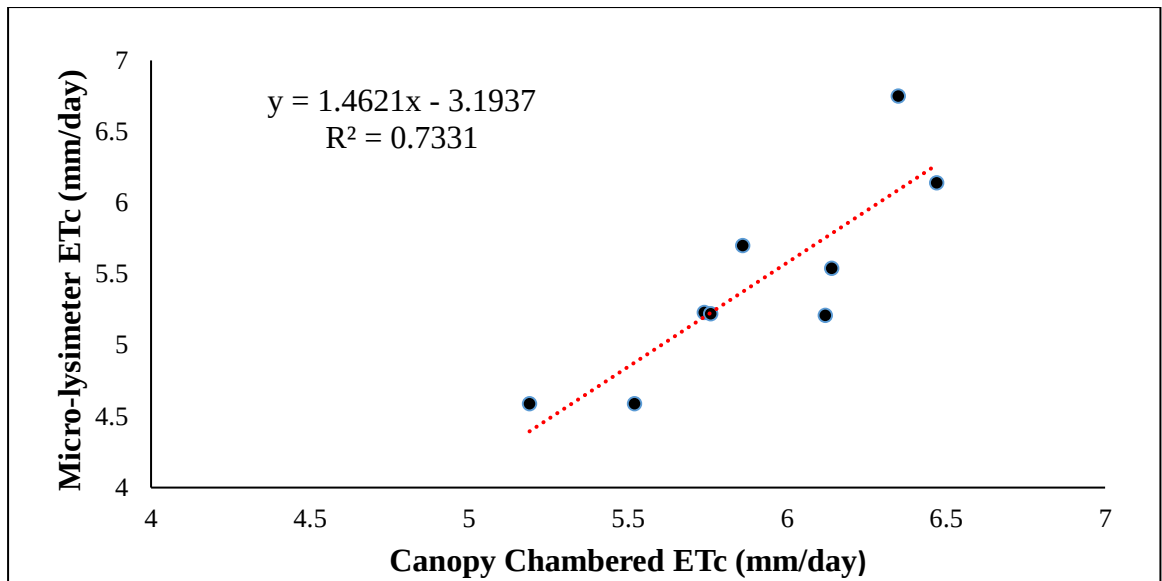


Fig. 4.7(c) Comparison of spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during winter season

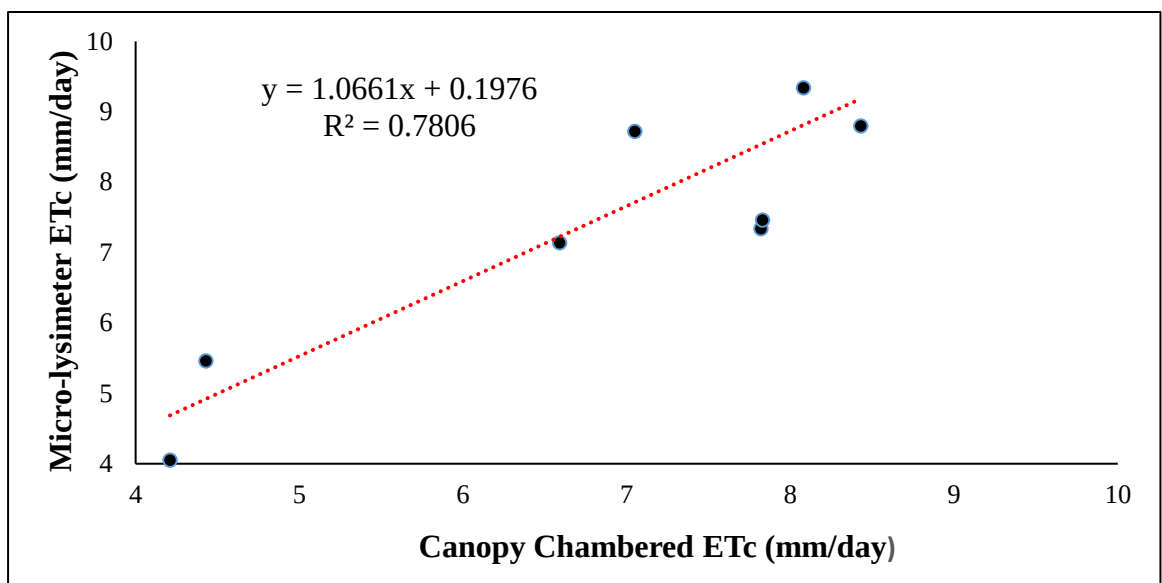


Fig 4.7(d) Comparison of spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter during summer season

It can be seen in fig 4.8(c) and 4.8(d) that the crop evapotranspiration measured by canopy chamber and micro-lysimeter are reasonably agreed with each other during winter and summer season.

4.4.3 Diurnal Variation of Crop Evapotranspiration

The crop evapotranspiration rate (mm/day) were measured throughout the day at 2 hr interval for 24 hr. The ET_c rate is increasing as sun rises and reaches to the peak at 14:00 and then continuously decreasing with time. The ET_c rate were found constant at the night time which indicated the major contribution of soil evaporation component.

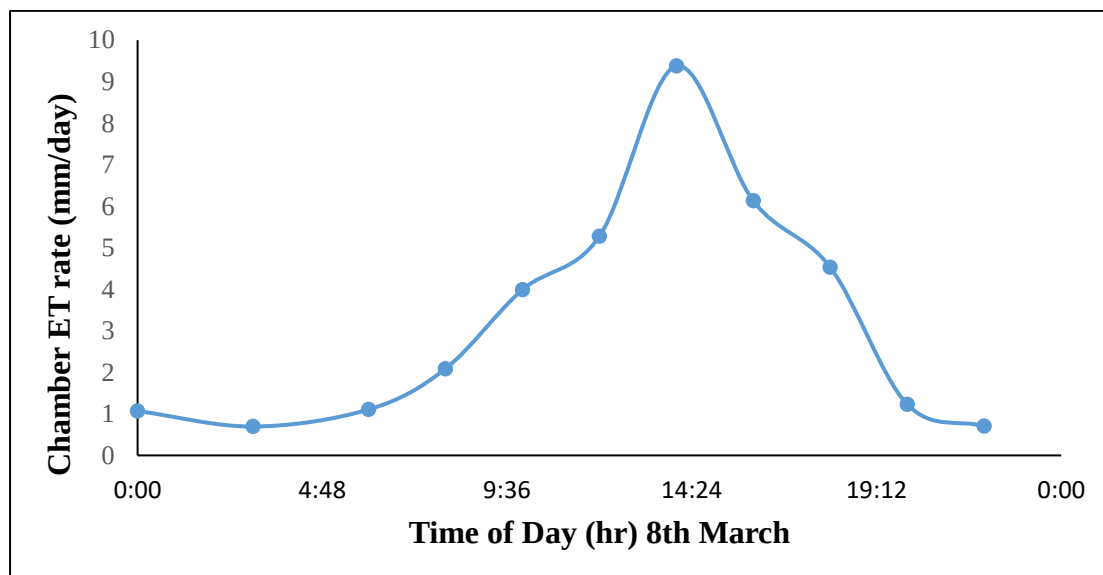


Fig. 4.8(a) Diurnal variation of spinach ET_c rate on 8th March

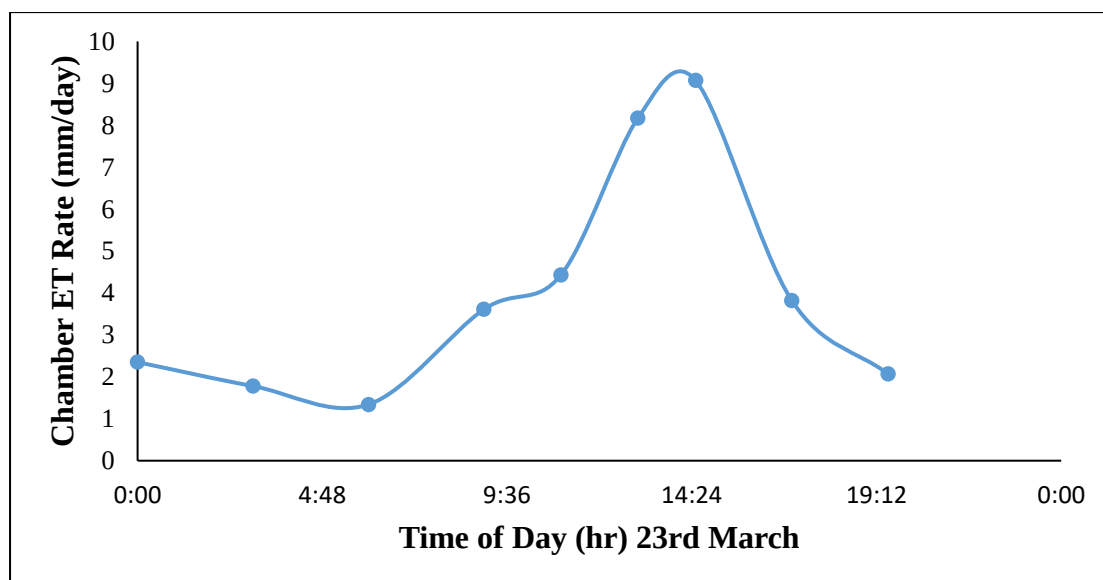


Fig. 4.8(b) Diurnal variation of spinach ET_c rate on 23rd March

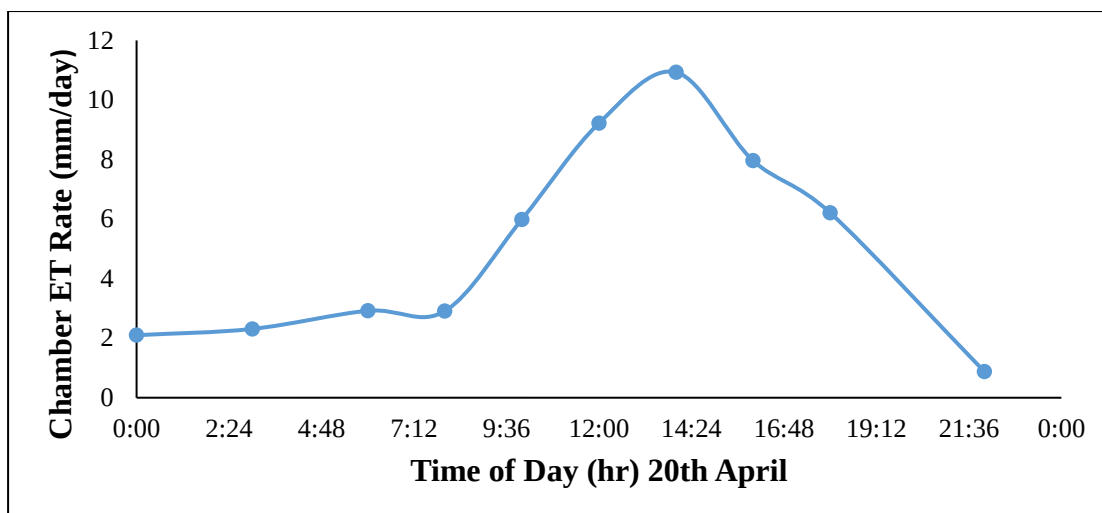


Fig 4.8(c) Diurnal variation of spinach ETc rate on 20th April

The canopy chamber ETc data were measured throughout the day of 24 hours at 2 hr interval and found as shown in Fig. 4.9(a), 4.9(b) and 4.9(c). It can be seen in Fig. 4.9 that at the night time evapotranspiration was very less as compared to the day time evapotranspiration.

4.4.4 Crop Coefficient

The crop coefficient (K_c) was taken as the ratio of the actual evapotranspiration to reference evapotranspiration. The actual evapotranspiration was measured by micro-lysimeter (ETc) and reference evapotranspiration (ET_0) was estimated using pan evaporation method.

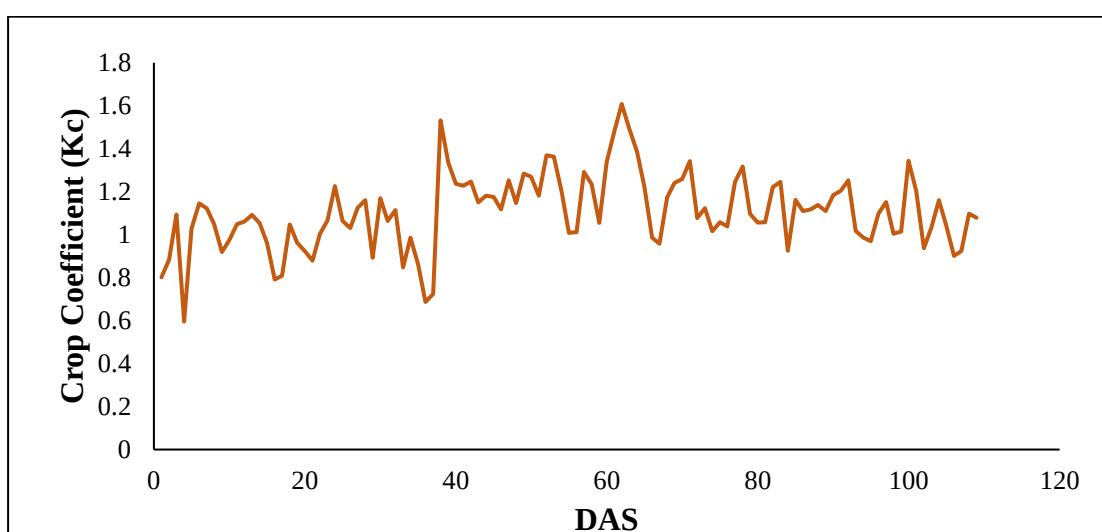


Fig. 4.9(a) The seasonal variation of spinach crop coefficient obtained by micro-lysimeter during winter season

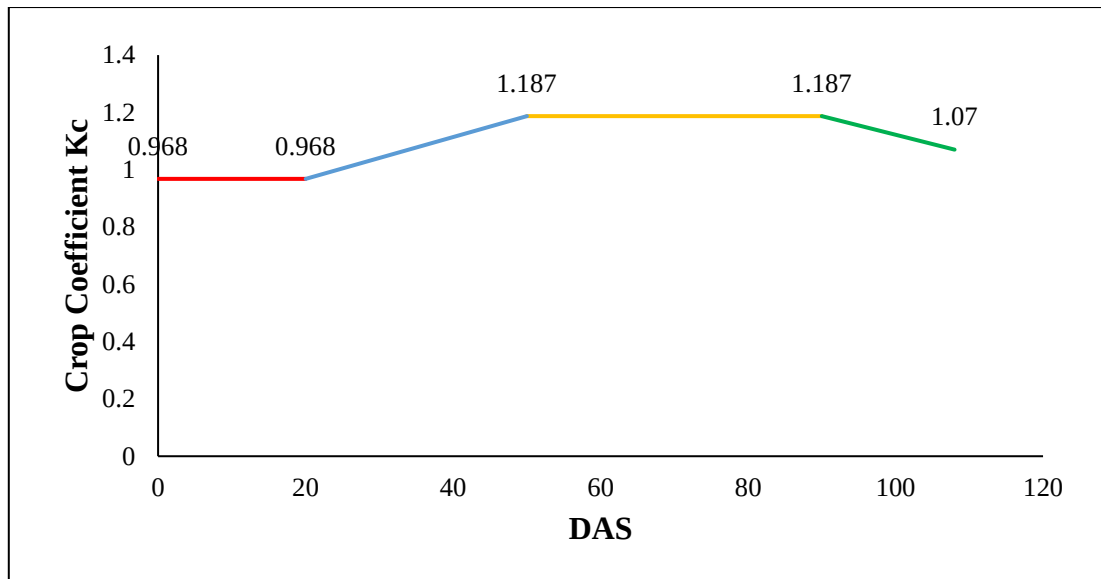


Fig. 4.9(b) Developed Kc-curve for spinach crop during winter summer

According to FAO 56, the growing period is divided in 4 sections as initial (0 to 20 DAS), development (20 to 50 DAS), mid (50 to 90 DAS) and late (90 and onwards) period. The average crop coefficient for the initial stage, mid stage and harvest stage are 0.968, 1.187 and 1.07 respectively.

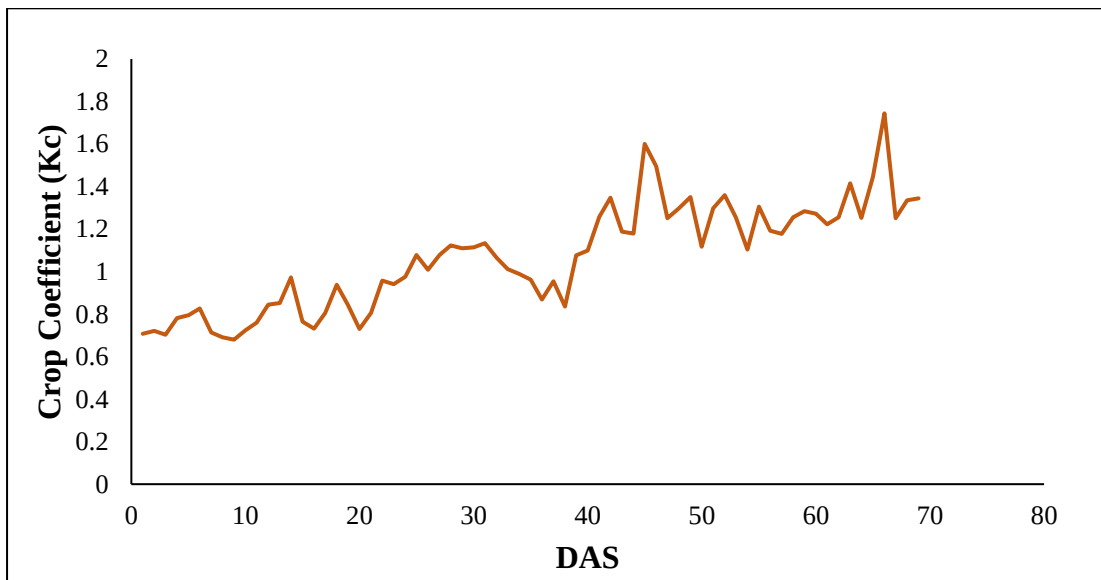


Fig. 4.9(c) The seasonal variation of spinach crop coefficient obtained by micro-lysimeter during summer season

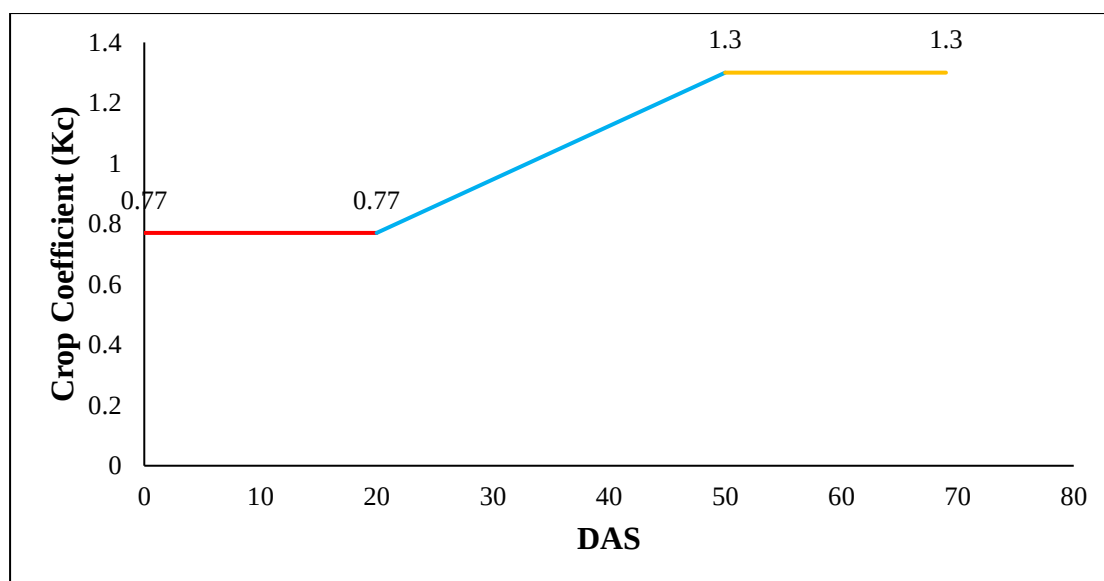


Fig. 4.9(d) Developed Kc-curve for spinach crop during summer season

The average crop coefficient for the initial stage and mid stage are 0.77, 1.30 respectively.

4.5 STATISTICAL ANALYSIS

The spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter were statistically analysed. Statistical analysis of spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter was carried out to check whether these two values are statistically similar or not. The spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter values were considered as one group and two sample t-test assuming equal variances at 95 percent confidence level to each group.

The statistical comparison by t-test of spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter are presented in Table 4.5. The values of number of sample, degree of freedom, t_{table} and t_{cal} were 18, 34 and 2.03 and 0.20, respectively. The value of t_{cal} lower than t_{table} reveals that there are non-significant difference between spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter at 95 percent confidence level (Table 4.7). Hence, the data of spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter are matching with each other without any significant statistical differences.

Table 4.8 The t-test analysis of spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter

	ETc by canopy chamber	ETc by micro-lysimeter
Mean	6.3894	6.4894
Variance	1.5953	2.7165
Observations	18	18
Pooled Variance	2.1559	
Hypothesized Mean Difference	0	
Df	34	
T _{Calculated}	0.2043	
T _{Table}	2.0322	
Result	NS	

4.6 COST ESTIMATION OF CLOSED CANOPY CHAMBER

The total cost of the canopy chamber and the cost of items required for its evaluation are tabulated in Table 4.9. The total cost of the canopy chamber including materials used and labour charges for its fabrication was found as Rs. 42020/- only which is very lower than the Rs. 35,00,000/- cost of fixed weighing type lysimeter. In addition to cost, the developed canopy chamber is portable and be used for different crops in a single season.

Table 4.9 Estimated cost of closed canopy chamber

Item	Quantity	Rate	Amount (₹)
For canopy chamber Fabrication			
Transparent 4mm acrylic sheet	4.46 m ²	2400.00	10704.00
0.75" GI Square Pipe	18 m	92.00	1656.00
HOBO External Temp/RH Data Logger (UX100-023)	1	27000.00	27000.00
Small fans	2	10.00	20.00
9 V DC battery	4	15.00	60.00
9 V DC motor	2	40.00	80.00
Fabrication of canopy chamber	1	2500.00	2500.00
Total cost of canopy chamber fabrication (₹)			42020.00

For canopy chamber Evaluation			
1 mm aluminium sheet	7.3 m ²	718.00	5247.00
Weight Balance	1	7500.00	7500.00
Fabrication of micro-lysimeter	32	80.00	2560.00
Fabrication of square aluminium tray	1	200.00	200.00
Total cost of canopy chamber evaluation (₹)			15507.00
Total Cost (₹)			53027.00

4.7 COMPLEXITY IN CLOSED CANOPY CHAMBER

Generally, the temperature during day time inside the canopy chamber were higher than outside. The temperature inside the closed canopy chamber increased upto 2-3 °C depending upon the solar radiation intensity. However, during night, decrease in temperature inside the canopy chamber was found as rare case. According to psychrometric properties of the air and correlation between temperature and RH and thereby with the water vapour density, the increase of water vapour density could not be found. It gave negative slope of water vapour density time series graph and thus ET_c rate was found negative.

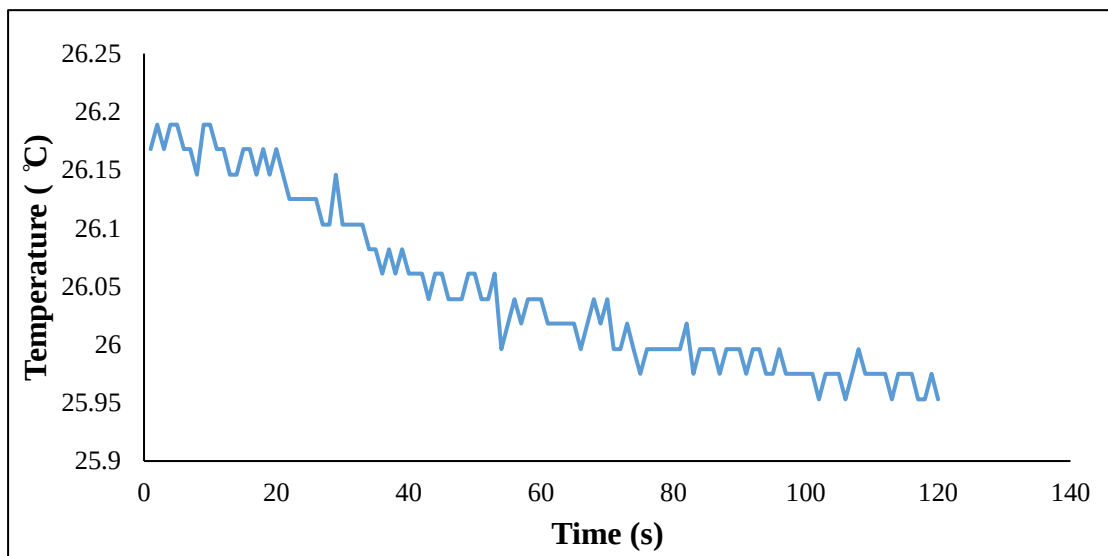


Fig. 4.10(a) Decrease in temperature at 4:00 am on 14th April 2019

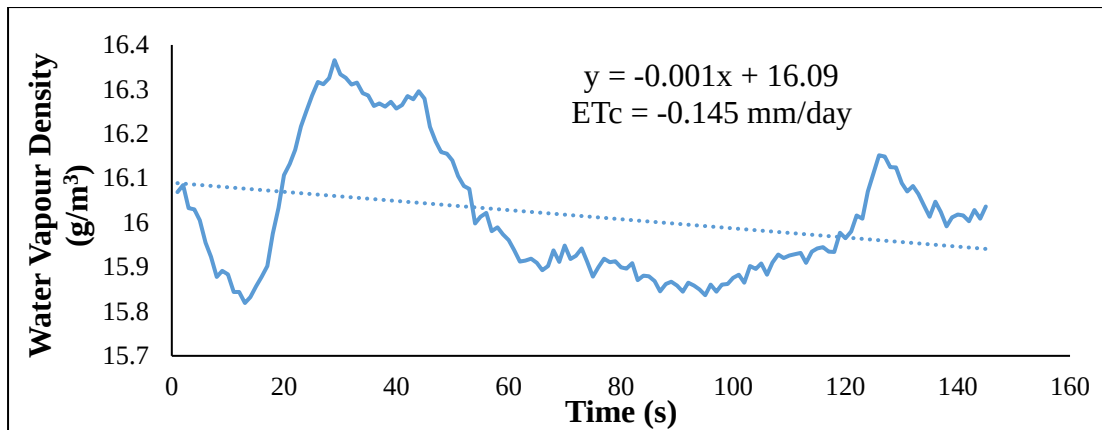


Fig. 4.10(b) Observed rare event of decrease in water vapour density during night at 4:00 am on 14th April 2019

Even though the drop in the temperature inside the canopy chamber, the relative humidity cannot found increased as rare case. It gives the negative slope of the water vapour density versus time, which indicates the negative ET_c rate.

Fig. 4.10(a) shows the decrease in the temperature from 26.19 °C to 25.97 °C at the night time at 4:00 am on 14th April 2019. In this condition the slope of the water vapour density time series graph is -0.001 and instantaneous crop evapotranspiration was observed as -0.145 mm/day.

In such rare case of complexity, constant temperature throughout the 2 min interval during measurement were considered. Fig. 4.10(c) shows the water vapour density versus time assuming the constant temperature throughout the 2 min measurement interval and instantaneous ET_c rate was observed as 0.057 mm/day.

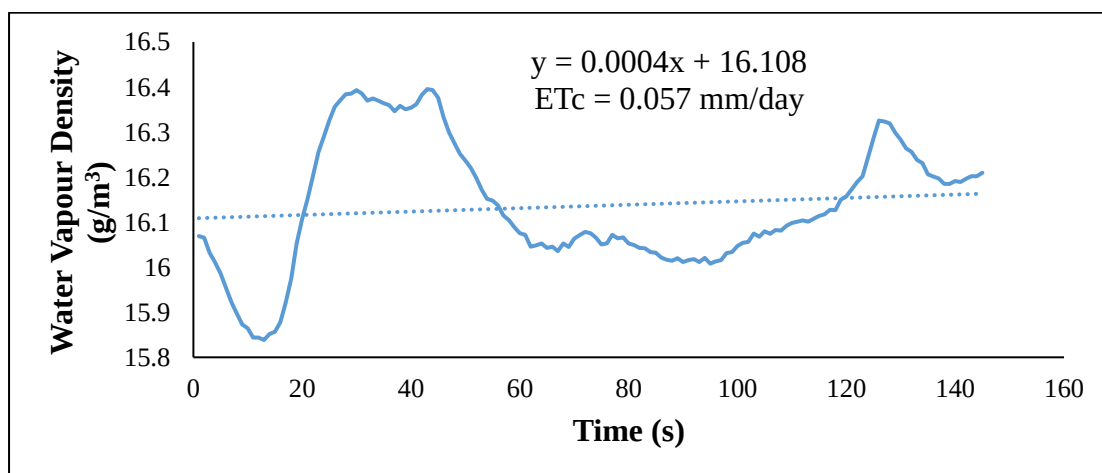


Fig 4.10(c) Water vapour density time series graph assuming constant temperature

CHAPTER V

SUMMARY AND CONCLUSIONS

The demand of water has been increasing continuously, while its supply decreasing. India has about 16% of the world's population as compared to only 4 % of its water resources. The globally growing demand for water has shown the need for its efficient and judicious utilization, and particularly in agriculture being the single largest consumer of water. Land and water are the basic inputs of agricultural and economic development of any country. The demand of these resources is continuously increasing. Therefore, it becomes necessary to utilize these resources judiciously. India ranks second having an area about 94 million hectares under irrigation, out of total 137 Mha cultivated area. The annual utilizable surface water and groundwater resources of India are estimated as 690 BCM (Billion Cubic Meter) and 396 BCM per year, respectively. In India per capita surface water availability in the years 1991 and 2001 were 2309 and 1902 m³ and these are projected to reduce to 1401 and 1191 m³ by the years 2025 and 2050 respectively. Gujarat state has an area of 19.6 Mha, representing 6% area of the country. Gujarat state has 33% irrigated area, out of 10.7 m ha of cultivable land. Gujarat's total water resource potential is 55,000 MCM (Million Cubic Meter) of which the surface water is about 38,000 MCM (69 %) and groundwater is about 17,000 MCM (31%). North, South and Central Gujarat regions have 17 river basins, having 89 % share in the total surface water. Kutch region has the highest number of river basins (97 river basins), having only 2% share in the total surface water. Saurashtra region has 71 river basins, having 9% share in the total surface water.

The evapotranspiration (ET) is the sum of evaporation and transpiration. Solar radiation, air temperature, air humidity and wind speed are the main climate parameters that influence ET. ET is a key component of the field water balance in the soil-vegetation-atmosphere continuum and it is a major sink of precipitation and irrigation, particularly in semiarid and arid farmland. Because of the large latent heat of vaporization of water, ET is also an important term in the soil surface energy balance.

The weighing lysimeters permit the mass or volumetric soil-water content change to be determined by weighing the lysimeter and determining its mass change over time. Lysimeters are used for accurate measurement for crop evapotranspiration

ETc. However, there are some limitations for using lysimeters on field scale higher initial cost, need for regular maintenance, complex and difficult construction and usage limitation to a single crop at a time. Lysimeters cannot be transported from one place to another place due to its immovable establishment.

Indirect and direct methods have been used to quantify ET fluxes. Indirect methods include the use of micrometeorological techniques such as eddy covariance (EC), surface energy balance and field water balance approaches. The indirect methods do not disturb the plant canopy; however, they require large homogeneous fields to obtain stable, valid results. A direct method may include equipment to obtain and isolate gas samples from plant canopies, and analyze the changes of water vapour concentration to determine ET. A common strategy is to use a canopy chamber to sample the air. Canopy chambers can be classified as open or closed systems. For an open system, the gas is continuously pumped into and out of the chamber through openings (or channels). The differences of water vapour concentration between the chamber inlet and outlet are measured and used to determine the ET flux. A closed chamber is usually designed as a portable system, i.e., it can be transported among several sampling locations in the field. A closed chamber system measures the changes of water vapour concentration inside the chamber to evaluate the instantaneous ET. Rapid measurements for brief periods (2 min or so) are used to avoid chamber-induced canopy microclimate changes.

The direct measurements of crop evapotranspiration and thus crop coefficient can be obtained easily and accurately by canopy chamber due to its simple construction and portability. With the help of canopy chambers, one can estimate the crop evapotranspiration and crop coefficient for many crops through diurnal planning of ETc measurement. However, such studies have not been conducted yet in India. Therefore, keeping in view the above issues and importance of ET, the present study was carried out with the following objectives:

1. To develop a portable closed canopy chamber for the measurement of crop evapotranspiration (ETc).
2. To evaluate the performance and the cost effectiveness of the closed canopy chamber for measuring the crop evapotranspiration (ETc).

The portable closed canopy chamber was fabricated from transparent acrylic sheet having a thickness of 4 mm. Square GI pipe was used for framing of the closed canopy chamber. The length, width and height of chamber were 0.85 m, 0.85 m and 1.10 m respectively. The chamber volume was 0.794 m^3 and having base area of 0.7225 m^2 . Two small fans were mounted on inner side of chamber opposite to each other for the proper mixing of air and water vapour inside the canopy chamber, so that homogeneous air vapour mixture can be obtained. Between the fans, a temperature and humidity sensor was suspended above the plant canopy for the measurement of temperature and RH of the chamber air.

The calibration and validation of the developed closed canopy chamber was made using the micro lysimeters. Micro-lysimeters were fabricated from light metal aluminium sheet of 1 mm thickness. The size of each micro-lysimeter was $0.2 \text{ m} \times 0.2 \text{ m} \times 0.2 \text{ m}$. The soil was filled in it in such a way that properties of soil inside the micro-lysimeters are just similar to that of in situ conditions. Shallow rooted spinach was grown in the micro-lysimeters. Total 32 micro lysimeters were filled with soil to such an extent to obtain the in-situ bulk density. The irrigation applications to the spinach was made as per the weight loss in the lysimeter from last irrigation. The crop water requirement was calculated by change in the lysimeter weight and the irrigation water depth was calculated. Application of irrigation water in micro-lysimeter was such a way that there was no drainage.

The entire day of 24 hours was divided into 12 periods, each of 2 hours. The each of those 2 hour periods were divided into 8 sub periods of 15 minute each. During the first 15 minutes period, 4 min cycle of 2 min closing and 2 min opening was repeated for 3 times. The sensor sensed and recorded the instantaneous temperature and relative humidity at 1 second intervals during the 2 min closing time of each cycle of first 15 minutes of 2 hr duration of all 12 periods of the day. Between measurements, the chamber was taken away from the micro-lysimeters for a minimum of 2 min to obtain micro-climate similar to open atmosphere. Two sample t-test was applied to compare the data pairs of crop evapotranspiration obtained by lysimeters inside the canopy chamber with that of lysimeters outside the canopy chamber as well as crop evapotranspiration obtained by lysimeters inside the canopy chamber and that obtained by canopy chamber using the sensor data of temperature and humidity. The crop

evapotranspiration obtained by lysimeters inside the canopy chamber were compared with that of lysimeters outside the canopy chamber to ascertain the effects of change in micro climate over the short period of 2 minutes inside the closed chamber on evapotranspiration. The calibration factor of the closed canopy chamber was found as 1.3532, through the known evaporation rates from the pan filled with water kept inside the chamber.

The differences in the crop evapotranspiration measured by micro-lysimeter inside the canopy chamber and open atmosphere were found non-significant. It revealed that there was no effects of change in micro climate for short periods of 2 minutes in chamber on plant physiological processes. The t-test results showed t_{table} and t_{cal} as 1.99 and 0.02 respectively.

During night, generally, decrease in temperature inside the canopy chamber was found, which should increase the water vapour density. However, the increase in the vapour density could not be found as a rare case during the experimentation, indicating the negative ET_c flux. This complexity of negative ET_c flux inside the canopy chamber was found as a rare case during night time. In such rare cases of complexity, constant temperature throughout the 2 min interval during measurement had to be considered.

The crop evapotranspiration measured by canopy chamber and micro-lysimeter were compared separately for winter and summer season. The crop evapotranspiration measured by canopy chamber and micro-lysimeter were reasonably comparable to each other during both winter and summer season. The ET_c rate increases as sun rises and reaches the peak at 14:00 hrs and then continuously decrease with time. The ET_c rates were found constant during the night time which indicated the major contribution of soil evaporation component. It was found that during night time, evapotranspiration was very less as compared to the day time evapotranspiration.

There were non-significant difference between spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter at 95 percent confidence level. Hence, the data of spinach crop evapotranspiration measured by canopy chamber and micro-lysimeter are matching with each other without any significant statistical differences.

The average crop coefficient for the initial stage, mid stage and harvest stage were found as 0.968, 1.187 and 1.07 respectively during the winter season.

The results of the present investigation led to the following conclusions:

- (1) The crop evapotranspiration measured by lysimeters inside and outside the canopy chamber were found reasonably comparable to each other indicating that there are no effects of changes in micro climate inside the chamber on plant growth processes.
- (2) The crop evapotranspiration measured by the micro-lysimeters kept inside the canopy chamber and that calculated by sensed temperature and relative humidity inside the chamber were found reasonably comparable to each other.
- (3) The developed canopy chamber is portable as well as more convenient, cost effective and reasonably accurate as compared to the lysimeter to measure the actual crop evapotranspiration and crop coefficient.
- (4) The following models are proposed to estimate the crop evapotranspiration by closed canopy chamber

$$ET_c = 1.4621 ET_{Cc} - 3.1937 \text{ for winter season}$$

$$ET_c = 1.066 ET_{Cc} + 0.1976 \text{ for summer season}$$

Where;

ET_c = Crop evapotranspiration (mm/day)

ET_{Cc} = Crop evapotranspiration measured by closed canopy chamber (mm/day)

BIBLIOGRAPHY

- Allen, R., Pereira, L., Raes, D. and Smith, M. 1998. Crop evapotranspiration: guidelines for computing crop water requirements. *FAO Irrigation and Drainage Paper No. 56*.
- Angell, R. and Svejcar, T. 1999. A Chamber Design for Measuring Net CO₂ Exchange on Rangeland. *Journal of Range Management*. **52**.
- Arunadevi, K., Ramachandran, J., Vignesh, S., Visuvanathakumar, S. and Anupriyanka, S. 2017. Comparison of reference evapotranspiration in semi-arid region. *International Journal of Agriculture Sciences*. **9(52)**: 4886-4888.
- Bajirao, T. and Awari, H. 2017. Estimation of reference evapotranspiration for Parbhani district. *International Journal of Agricultural Engineering*. **10(1)**: 51-54.
- Benli, B., Kodal, S., Ilbeyi, A. and Ustun, H. 2006. Determination of evapotranspiration and basal crop coefficient of alfalfa with a weighing lysimeter. *Agricultural Water Management*. **81(3)**:358-370.
- Baldocchi, D., Valentini R., Running S., Oechel, W. and Dahlman, R. 1996. Strategies for Measuring and Modelling Carbon Dioxide and Water Vapour Fluxes over Terrestrial Ecosystems. *Global Change Biology*. **2**: 159-168.
- Black, T. A., Thurtell, G. W. and Tanner, C. B. 1968. Hydraulic load cell lysimeter, construction, calibration, and tests. *Soil Science Society of America Journal*. **32(5)**: 623-629.
- Bowen, I. S. 1926. The ratio of heat losses by conduction and by evaporation from any water surface. *Physical Review*. **27**: 779–787.
- Burkart, S., Manderscheid, R. and Weigel, H. J. 2007. Design and performance of a portable gas exchange chamber system for CO₂ and H₂O-flux measurements in crop canopies. *Environmental and Experimental Botany*. **61**: 25–34.

- Campbell, G. S. and Norman, J. M. 1998. The Light Environment of Plant Canopies. In: An Introduction to Environmental Biophysics. Springer Science & Business Media. pp. 247-278.
- Conceicao, M. 2002. Reference evapotranspiration based on class A pan evaporation. *Scientia Agricola*. **59(3)**: 417-420.
- Doorenbos, J. and Pruitt, W. O. 1977. Guidelines for predicting crop water requirements. *FAO-ONU, Rome, Irrigation and Drainage Paper no. 24* (rev.).
- Fisher, D. K. 2012. Simple weighing lysimeters for measuring evapotranspiration and developing crop coefficients. *International Journal of Agricultural and Biological Engineering*. **5(3)**: 35-43.
- Garrity, D. P., Sullivan, C. Y. and Watts, D. G. 1984. Rapidly determining sorghum canopy photosynthetic rates with a mobile field chamber. *Agronomy Journal*. **76**: 163–165.
- Giovanni, P., Ko, J. Marek, T. and Howell, T. 2009. Determination of growth-stage-specific crop coefficients (Kc) of maize and sorghum. *Agricultural Water Management*. 96(12):1698-1704.
- Gowda, P. H., Howell, T. A., Paul, G., Colaizzi, P. D., Marek, T. H., Su, B. and Copeland, K. S. 2013. Deriving hourly evapotranspiration rates with SEBS: A lysimetric evaluation. *Vadose Zone Journal*. **12(3)**: 102-109.
- Garcia, C. A., Johnson, M. J, Andraski, B. J., Halford, K. J. and Mayers C. J. 2008. Portable Chamber Measurements of Evapotranspiration at the Amargosa Desert Research Site near Beatty, Nye County, Nevada, 2003–06. *Scientific Investigations Report 2008–5135* U.S. Department of the Interior U.S. Geological Survey.
- Grau, A. 1995. A closed chamber technique for field measurement of gas exchange of forage canopies. *New Zealand Journal of Agricultural Research*. **38**: 71-77.

- Hewitt, Ian, C., Alexander, G. F. and Samani, Z. A. 2018. Calculating Field-Scale Evapotranspiration with Closed-Chamber and Remote Sensing Methods. *Journal of the American Water Resources Association (JAWRA)*. **54(4)**: 962-973.
- IPCC. 2001: “Intergovernmental Panel on Climate Change (IPCC) third assessment report climate change 2001.” IPCC. Geneva, Switzerland. Available at <http://www.ipcc.ch/> accessed 19 August, 2018.
- Jagtap, S. S. and Jones, J. W. 1989. Stability of crop coefficients under different climatic and irrigation management practices. *Irrigation Science*. **10**: 231–244.
- Ko, J., Piccinni, G., Marek, T. and Howell, T. 2009. Determination of growth-stage-specific crop coefficients (Kc) of cotton and wheat. *Agricultural Water Management*. **96**: 1691-1697.
- Kumar, R., Singh, R. D. and Sharma, K. D. 2005. Water Resources of India. *Current Science*. **89(5)**: 794-811.
- Liu, C., Zhang, X. and Zhang, Y. 2002. Determination of daily evaporation and evapotranspiration of winter wheat and maize by large-scale weighing lysimeter and micro-lysimeter. *Agricultural and Forest Meteorology*. **111(2)**: 109-120.
- Luo, C. 2015. Portable canopy chamber measurements of evapotranspiration in corn, soybean and reconstructed prairie. *Agricultural Water Management*. **198**: 1-9.
- McJannet, D.L., R.A. Vertessy, N.J. Tapper, S.K. O’Sullivan, J. Beringer, and H. Cleugh. 1996. Soil and litter evaporation beneath re-growth and old-growth mountain ash forest. *Cooperative Research Centre for Catchment Hydrology Report*. p. 60.
- McLeod, M. K., Daniel, H., Faulkner, R. and Murison, R. 2004. Evaluation of an enclosed portable chamber to measure crop and pasture actual evapotranspiration at small scale. *Agricultural Water Management*. **67**: 15–34.

- Odofin, A. J., Oldiran, J. A., Oladipo, J. A. and Wuya, E. P. 2011. Determination of evapotranspiration and crop coefficients for bush okra (*Corchorus olitorius*) in a sub-humid area of Nigeria. *African journal of agricultural research*. **6(17)**:3949-3953.
- Panase, V. G. and Sukhatme, P. V. 1967. Statistical Methods for Agricultural Workers. New Delhi, Indian Council of Agricultural Research. pp.57-67.
- Perez-Priego O., Testi L., Orgaz, F. and Villalobos, F. J. 2010. A large closed canopy chamber for measuring CO₂ and water vapour exchange of whole trees. *Environmental and Experimental Botany*. **68**: 131–138.
- Perez-Priego, O., Ballesteros, A. L., Sanchez-Canete, E. P., Serrano-Ortiz, P., Kutzbach, L., Domingo, F., Eugster, W. and Kowalski, A. S. 2015. Analysing uncertainties in the calculation of fluxes using whole-plant chambers: random and systematic errors. *Plant Soil*. **393**: 229–244.
- Rana, G. and Katerji, N. 2000. Measurement and Estimation of Actual Evapotranspiration in the Field under Mediterranean Climate: A Review. *European Journal of Agronomy*. **13**: 125-153.
- Reicosky, D. C. and Peters, D. B. 1977. A portable chamber for rapid evapotranspiration measurements on field plots. *Agronomy Journal*. **69**: 729-732.
- Reicosky, D. C., Sharratt, B. S., Ljungkull, J. E. and Baker, D. G. 1983. Comparison of alfalfa evapotranspiration measured by a weighing lysimeter and a portable chamber. *Agricultural Meteorology*. **28**: 205-211.
- Stannard, D. I. 1988. Use of a Hemispherical Chamber for Measurement of Evapotranspiration. *U.S. Geological Survey Scientific Investigations Report 1988-452*. 18 p.
- Stannard, D. I. and Wertz, M. A. 2006. Partitioning evapotranspiration in sparsely vegetated rangeland using a portable chamber. *Water Resources Research*. **42(2)**.

- Steduto, P., Cetinkoku, O., Albrizio, R. and Kanber, R. 2002. Automated closed-system canopy chamber for continuous field-crop monitoring of CO₂ and H₂O fluxes. *Agricultural and Forest Meteorology*. **111**: 171-186.
- Stewart, J. B. 1984. Measurements and predictions of evapotranspiration from forested and agricultural catchments. *Agricultural Water Management*. **8**: 1–28.
- Thomas, M. D. and Hill, G. R. 1937. The continuous measurement of photosynthesis, respiration, and transpiration of alfalfa and wheat growing under field conditions (I). *Plant Physiology*. **12**: 285–307.
- Tyagi, N. K., Sharma, D. K. and Luthra, S. K. 2000. Determination of evapotranspiration and crop coefficients of rice and sunflower with lysimeter. *Agricultural Water Management*. **45**: 41-54.
- UNESCO-WWAP. 2012. Facts and Figures Managing Water under Uncertainty and Risk. Available at www.unesco.org accessed 17 August, 2018.
- van Bavel, C. H. M. 1961. Lysimetric measurements of evapotranspiration rates in the eastern United States. *Soil Science Society of America Journal*. **25**:138–141.
- Wagner, S. W. and Reicosky, D. C. 1992. Closed-chamber effects on leaf temperature, canopy photosynthesis, and evapotranspiration. *Agronomy Journal*. **84**: 731–738.
- Wagner, S. W., Reicosky, D. C. and Alessi, R. S. 1997. Regression models for calculating gas fluxes measured with a closed chamber. *Agronomy Journal*. **89**: 279-284.
- World Bank. 2005. India's Water Economy: Bracing for a Turbulent Future. Washington D: World Bank. Available at <http://openknowledge.worldbank.org/handle/10986/8413> accessed 8 August, 2018.
- Yang, F., White, M. A., Michaelis, A. R., Ichii, K., Hashimoto, H., Votava, P., Zhu, A. X. and Nemani, R. R. 2006. Prediction of continental-scale evapotranspiration

by combining MODIS and AmeriFlux data through support vector machine. *IEEE Transactions on Geoscience and Remote Sensing*. **44**: 3452–3461.

Zeleeke, K. and Wade, L. 2012. Evapotranspiration estimation using soil water balance, weather and crop data. *Evapotranspiration - Remote Sensing and Modeling*. **1**: 41-58.

APPENDIX

Appendix-A Date wise daily meteorological data of Junagadh for the experiment period (December 2018 to May 2019)

Date	Tmax	Tmin	RHmax	RHmin	WS kmph	BSS hrs	Evapo. mm
	°C		%				
10-12-18	31	15.1	77	45	3.5	6.8	05.1
11-12-18	30.5	18.8	87	49	03.2	05.2	03.0
12-12-18	30.0	16.1	82	33	02.3	01.7	02.7
13-12-18	30.6	14.5	63	21	06.2	04.6	05.9
14-12-18	28.3	17.4	38	23	07.9	08.0	06.8
15-12-18	27.8	16.0	62	30	08.1	06.8	06.9
16-12-18	29.7	19.3	48	31	06.0	03.6	06.0
17-12-18	28.7	13.4	52	21	07.3	00.1	05.8
18-12-18	28.6	10.9	56	19	04.4	07.0	05.3
19-12-18	30.1	9.6	67	15	03.5	07.7	04.8
20-12-18	31.0	9.0	64	29	02.7	08.7	04.4
21-12-18	30.0	10.4	73	31	02.5	07.0	04.0
22-12-18	30.5	11.5	74	27	02.2	06.6	04.4
23-12-18	31.0	11.1	82	31	02.0	08.2	04.0
24-12-18	31.1	13.4	76	31	02.7	08.0	04.6
25-12-18	30.1	18.9	33	19	06.8	02.5	03.5
26-12-18	29.0	11.6	42	22	07.0	05.2	05.8
27-12-18	27.9	11.9	74	29	05.1	05.8	06.1
28-12-18	28.6	7.0	61	21	03.0	06.5	04.2
29-12-18	28.5	6.5	52	17	03.0	07.9	03.9
30-12-18	30.1	9.1	65	22	02.9	09.2	04.3
31-12-18	30.6	9.7	60	22	02.1	07.6	04.2
1-1-19	31.6	9.9	71	15	02.7	7.0	04.3
2-1-19	32.1	10.9	63	30	01.9	5.9	04.6
3-1-19	31.0	9.9	77	32	02.9	6.7	04.4
4-1-19	32.9	10.6	81	27	02.3	8.3	04.2
5-1-19	31.4	11.4	77	32	02.0	7.4	04.3
6-1-19	29.3	18.7	85	32	05.2	4.9	04.0
7-1-19	29.5	17.4	61	21	07.2	5.3	06.0
8-1-19	28.5	9.0	63	23	04.1	6.6	05.6
9-1-19	29.0	9.6	68	50	04.0	7.1	04.3
10-1-19	29.1	10.5	91	31	03.9	4.3	04.3
11-1-19	31.5	11.9	56	25	03.1	3.6	03.9
12-1-19	28.6	13.5	61	34	03.0	2.1	03.5
13-1-19	29.2	15.6	73	35	04.0	3.0	04.2
14-1-19	29.0	16.1	77	33	07.7	1.4	04.4
15-1-19	29.6	12.0	72	32	05.0	04.9	06.0

Date	Tmax	Tmin	RHmax	RHmin	WS kmph	BSS hrs	Evapo. mm
	°C		%				
16-1-19	31.1	11.6	79	35	02.5	03.2	04.4
17-1-19	31.2	10.6	74	43	02.8	06.0	05.0
18-1-19	31.5	12.5	76	40	03.0	06.9	04.7
19-1-19	33.1	12.4	78	21	03.0	08.5	04.8
20-1-19	34.0	13.5	71	27	02.5	08.9	05.1
21-1-19	33.4	14.6	68	26	03.3	09.0	05.5
22-1-19	29.1	15.5	60	33	05.6	05.2	05.8
23-1-19	28.1	15.2	72	36	05.9	06.6	04.8
24-1-19	26.6	14.9	74	20	05.3	09.0	04.2
25-1-19	26.7	12.4	72	24	07.4	09.1	05.1
26-1-19	26.5	14.8	76	22	09.1	09.3	05.8
27-1-19	25.6	14.5	69	21	07.0	08.7	06.8
28-1-19	26.6	15.0	81	19	07.0	08.6	07.0
29-1-19	26.5	12.0	78	20	06.9	09.6	07.1
30-1-19	28.5	7.8	74	20	04.0	09.6	05.8
31-1-19	30.4	11.4	72	20	03.4	09.6	04.1
1-2-19	29.1	15.9	70	26	05.8	08.5	04.4
2-2-19	28.5	14.0	72	27	10.2	07.8	06.3
3-2-19	28.4	12.3	61	28	09.4	08.6	06.1
4-2-19	30.5	14.7	62	22	04.4	07.4	06.1
5-2-19	33.6	15.4	68	29	04.0	04.8	04.8
6-2-19	31.7	17.9	54	36	05.2	07.7	04.9
7-2-19	29.5	14.9	58	21	05.1	08.1	06.5
8-2-19	26.0	9.8	71	19	06.7	03.6	07.7
9-2-19	26.0	9.3	71	28	03.8	08.9	04.8
10-2-19	27.5	8.0	72	38	04.0	09.0	06.0
11-2-19	30.1	9.5	79	30	03.7	09.4	05.6
12-2-19	31.5	11.1	82	21	02.8	09.3	04.9
13-2-19	35.0	18.4	62	20	04.1	09.5	05.6
14-2-19	32.0	17.5	30	21	05.2	08.7	04.6
15-2-19	31.5	16.4	48	23	05.0	07.5	05.4
16-2-19	30.1	13.6	56	19	04.7	07.4	06.0
17-2-19	31.5	13.3	53	17	03.7	08.7	06.5
18-2-19	32.0	13.1	62	16	02.7	09.3	05.7
19-2-19	32.5	18.6	63	20	05.0	09.4	06.4
20-2-19	34.0	17.9	77	22	04.0	09.7	05.6
21-2-19	34.3	19.4	45	23	05.2	09.2	05.6
22-2-19	33.0	20.6	67	23	05.0	09.3	06.2
23-2-19	33.1	15.4	75	19	06.2	07.6	06.0
24-2-19	33.5	15.2	50	24	04.4	05.1	05.8
25-2-19	32.4	17.1	59	22	04.0	03.0	05.9
26-2-19	33.4	18.9	60	16	04.9	04.8	04.2

Date	Tmax	Tmin	RHmax	RHmin	WS kmph	BSS hrs	Evapo. mm
	°C		%				
27-2-19	31.9	18.9	53	19	06.6	02.5	05.8
28-2-19	30.5	18.5	52	17	06.0	09.7	06.5
1-3-19	31.6	14.0	40	21	03.7	10.2	05.9
2-3-19	33.5	15.9	37	17	03.2	09.6	06.5
3-3-19	35.5	20.0	40	20	07.0	09.5	07.3
4-3-19	31.5	20.0	48	27	06.2	06.2	05.6
5-3-19	31.0	19.1	79	22	05.9	09.7	06.5
6-3-19	31.1	18.9	82	20	05.7	09.7	06.8
7-3-19	31.0	18.4	68	21	05.0	10.0	06.5
8-3-19	32.5	19.7	84	20	05.2	09.7	05.9
9-3-19	32.7	21.5	78	25	06.0	08.2	06.3
10-3-19	34.0	16.7	83	21	04.9	09.1	07.0
11-3-19	35.0	21.6	69	20	05.4	05.4	07.8
12-3-19	32.0	19.0	75	14	05.8	10.1	05.8
13-3-19	32.7	18.4	55	11	05.7	10.3	06.6
14-3-19	32.4	18.4	30	14	06.0	09.8	07.5
15-3-19	32.0	16.5	65	16	06.1	10.3	07.0
16-3-19	34.5	15.5	75	18	04.6	10.5	07.1
17-3-19	36.0	23.8	66	21	06.3	09.9	07.8
18-3-19	36.6	17.5	54	20	05.9	10.2	09.7
19-3-19	37.2	19.0	68	25	03.7	10.3	09.2
20-3-19	38.0	18.9	59	21	05.2	10.0	09.3
21-3-19	35.0	19.0	68	21	06.8	10.5	07.5
22-3-19	34.8	21.0	79	23	05.3	10.1	07.9
23-3-19	37.1	21.7	86	23	05.2	10.1	09.3
24-3-19	38.9	24.9	32	19	06.0	09.5	09.7
25-3-19	39.2	26.8	31	17	07.8	10.4	10.6
26-3-19	40.0	27.5	35	14	08.8	09.9	10.9
27-3-19	39.9	25.5	37	16	06.0	10.0	12.8
28-3-19	40.6	25.6	42	11	06.0	10.2	09.4
29-3-19	41.5	23.1	52	18	07.4	09.7	11.5
30-3-19	41.9	22.0	81	16	05.7	09.9	11.4
31-3-19	41.5	20.9	90	12	06.4	10.1	11.0
1-4-19	40.0	21.4	85	22	05.9	10.2	10.9
2-4-19	40.5	20.6	85	17	05.0	10.0	10.7
3-4-19	41.6	21.5	82	17	05.2	09.9	10.1
4-4-19	41.6	20.2	74	19	05.1	10.0	10.8
5-4-19	41.5	21.0	49	24	05.2	10.2	10.8
6-4-19	39.4	21.1	78	15	07.0	10.0	10.0
7-4-19	37.5	23.8	85	23	06.7	08.9	07.8
8-4-19	40.0	23.1	82	33	05.8	10.1	09.6
9-4-19	40.0	22.9	84	20	05.9	10.1	08.0

Date	Tmax	Tmin	RHmax	RHmin	WS kmph	BSS hrs	Evapo. mm
	°C		%				
10-4-19	39.0	24.0	83	21	06.3	10.6	07.8
11-4-19	40.0	22.8	80	31	04.7	10.1	08.2
12-4-19	41.7	23.9	86	22	06.3	10.4	07.0
13-4-19	40.8	23.0	57	17	06.1	10.6	09.0
14-4-19	41.2	25.1	81	19	06.0	10.2	09.6
15-4-19	40.6	27.3	77	21	05.3	07.4	08.8
16-4-19	38.4	25.4	86	21	07.8	06.3	09.7
17-4-19	36.3	20.5	56	20	08.6	09.3	09.6
18-4-19	34.7	23.0	45	10	07.8	10.7	09.4
19-4-19	37.6	24.5	53	13	05.0	11.0	11.8
20-4-19	39.0	25.2	83	19	06.0	11.2	12.0
21-4-19	39.7	24.9	81	21	06.9	11.2	10.1
22-4-19	40.4	22.6	68	17	06.0	10.7	09.8
23-4-19	40.5	23.5	57	7	05.1	10.9	09.5
24-4-19	41.6	24.9	33	8	08.2	11.3	10.2
25-4-19	40.2	23.5	35	18	06.3	11.1	10.4
26-4-19	41.0	25.4	75	28	05.7	11.0	10.4
27-4-19	43.0	27.0	84	29	05.7	10.9	10.3
28-4-19	44.7	27.6	87	25	07.8	11.0	09.3
29-4-19	44.6	25.4	84	24	04.3	11.1	09.3
30-4-19	43.7	25.2	80	31	6.7	11.1	10.3
1-5-19	39.6	25.5	85	24	9.3	10.2	09.1
2-5-19	39.6	25.4	80	28	7.9	10.4	09.5
3-5-19	40.0	25.2	83	32	7.0	11.0	09.9
4-5-19	38.0	26.0	83	35	8.8	9.9	10.2
5-5-19	37.5	25.4	85	16	8.7	9.7	08.4
6-5-19	36.9	24.4	85	16	7.9	10.4	10.1
7-5-19	40.2	25.1	79	26	06.3	11.1	10.5
8-5-19	41.4	25.5	78	21	08.3	11.2	10.8
9-5-19	38.0	24.9	80	22	08.0	11.4	11.3
10-5-19	34.6	24.5	78	16	08.6	05.3	11.6
11-5-19	38.6	25.2	78	26	09.2	10.7	11.2
12-5-19	37.3	26.3	76	26	07.9	10.7	09.4
13-5-19	38.9	26.2	83	30	08.0	10.1	10.1
14-5-19	38.5	25.8	81	29	08.0	09.9	10.2
15-5-19	38.2	25.2	86	27	09.9	11.0	10.4