EFFECT OF MICROCLIMATE ON THE PERFORMANCE OF SALAD CUCUMBER UNDER NATURALLY VENTILATED POLYHOUSE

By

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(2012-18-102)

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

2014

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THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF TECHNOLOGY
IN
AGRICULTURAL ENGINEERING

(Soil and Water Engineering)

Faculty of Agricultural Engineering & Technology
Kerala Agricultural University

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

2014

DECLARATION

I hereby declare that this thesis entitled **"Effect of microclimate on the performance of salad cucumber under naturally ventilated polyhouse"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or other similar title of any other University or Society.

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CERTIFICATE

Certified that this thesis, entitled **"Effect of microclimate on the performance of salad cucumber under naturally ventilated polyhouse"** is a record of research work done independently by **Ms. Preenu N. P (2012- 18- 102)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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ACKNOWLEDGEMENT

ACKNOWLEDGEMENT

It is a matter of profound privilege to give sincere thanks to **Dr. K.V Levan**, Associate Professor, Dept. of IDE, KCAET, Tavanur for his valuable guidance, encouragement and immense help throughout the course of work.

I would like to express my sincere thanks to **Dr. Sivaswami, M.**, Dean, KCAET, Tavanur, for his interest and kind advice given to me at all stages of my study.

It is my privilege to acknowledge the sincere help and proper suggestions from **Dr. Sasikala, D.,** Associate professor & Head, Dept. of IDE, KCAET, Tavanur, **Dr. Abdul Hakkim V.M.,** Associate professor & Head, Dept. of LWRCE, KCAET, Tavanur and **Dr. Berin Pathrose,** Assistant professor, KVK, Malappuram, as a member of my advisory committee.

I take this opportunity to express my sincere gratitude and heartfelt thanks to **Er. Anu Varghese**, Assistant Professor, Dept. of IDE, KCAET, Tavanur, for her sustained interest, advices and moral support extended to me to complete this research work.

I am immensely thankful to **Dr. Rema, K.P.,** Associate Professor, Dept. of IDE**,** KCAET, Tavanur for giving valuable suggestions and constant backing at all stages of this research work.

I consider it as a pleasure to express my profound gratitude to **Mrs. Jisha Chand, A.R.**, Research Assistant, PFDC, Tavanur, for her sincere help and co-operation extended towards me for the completion of this work.

I acknowledge my gratitude to **Dr. Krishnan, S.**, Associate Professor and Head, Dept. of Agricultural Statistics, College of Horticulture, Vellanikkara, for explaining me the statistical techniques required for the study.

I am highly thankful to **Dr. Sudheer, K.P.**, Associate Professor, Dept. of PHT & AP, KCAET, Tavanur, for his valuable advices throughout my research work.

My heartfelt gratitude to **Mrs. Sreeja**, Assistant Professor, Dept. of PHT & AP, KCAET, Tavanur**,** for her timely help and support.

I also like to thank all my classmates namely **Shijila Erikottil**, **Navneet Sharma**, **Praveena, K.K.** and **Chintana, D.T.** for their timely help and earnest assistance given during the conduct of project work.

Last but not the least, I thank **Kerala Agricultural University** for awarding me the Junior Fellowship during the entire period of study.

I am thankful to Research Assistants, Skilled Assistants and all the workers of PFDC, Malappuram for their catalytic comments and creative suggestions.

I express my deep sense of gratitude to my loving **parents** and family **members** for their continuous support and inspiration all through my studies.

Above all, I bow my head before the Almighty for his blessings and procurement which empowered me to complete this work.

Tavanur Preenu, N.P

Date: 28/08/2014

Dedicated to

My loving family

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SYMBOLS AND ABBREVIATIONS

%	Percentage
&	and
’	Minute
”	Second
=	equal to
±	plus or minus
μm	micrometer
cm	Centimeter
CWR	Crop Water Requirement
E	East
et al.,	and others
ET	Evapotranspiration
etc.	etcetera
FAO	Food and Agricultural Oganisation
g	gram
G	Granule
g/cc	gram per cubic centimeter

g/m^2	gram per square meter
IW/CPE	Irrigation water requirement/ Cumulative pan evaporation rate
K	Potassium
KAU	Kerala Agricultural University
KCAET	Kelappaji College of agricultural Engineering and Technology
kg/ha	Kilogram per hectare
kg/ha-mm	Kilogram per hectare milli meter
km/day	kilometer per day
kPa	Kilo Pascal
lph	litre per hour
m	meter
m^3	cubic meter
MAP	Mono Ammonium Phosphate
min	minute
$MJ/m^2/day$	mega joules per square meter per day

Mm	milli meter
mm/dec	millimeter per decade
mm/sec	millimeter per second
N	Nitrogen
N	North
N.sec	Neuton second
nm	nanometer
^{o}	Degree
^{o}C	Degree Celsius
PE	Pan Evaporation
PFDC	Precision Farming Development Centre
q/ha	Quintal per hectare
q/ha/cm	Quintal per hectare per centimeter
RARS	Regional Agricultural Research Station
SDSM	Statistical Downscaling Model
SPSS	Statistical Package for the Social Sciences

t/ha-cm	tonne per hectare centimeter
USDA	United States Department of Agriculture
UV	Ultraviolet
VPD	Vapour Pressure Deficit
Wm^{-2}	watt per square meter

INTRODUCTION

CHAPTER 1

INTRODUCTION

Land and water are basic resources in agriculture. Proper utilization of these basic resources is essential to meet the demands in tune with the increasing population. Current projections indicate that world population will increase from 6.9 billion people today to 9.1 billion in 2050 (FAO, 2011). In addition, economic progress, notably in the emerging countries, translates into increased demand for food and diversified diets. India has less land resources and irrigation water supply because of expansion of urbanization. To achieve the level of agricultural productivity it is necessary to meet the ever-growing demands of a growing population. The high-tech farming practices like precision farming is a feasible approach for sustainable agriculture.

Precision farming is defined as the precise application of agricultural inputs based on soil, weather and crop requirements to maximize sustainable productivity, quality and profitability. Precision farming systems have been rapidly developed in recent decades in India. For maximum production, there has been a tendency to adopt high application rate of fertilizer and irrigation water (Hussain and AI- Jaloud, 1995). Over-irrigation can reduce yields because the excess soil moisture often results in plant diseases, nutrient leaching and reduced pesticide effectiveness, in addition, water and energy are wasted. Under-irrigation stresses the plant and causes yield reduction. Excess amount of fertilizer application results in loss of nutrients to the ground water. Soluble chemicals and nutrients move with the wetting front. Hence a precise scheduling of irrigation and fertilizer applications is essential for sustainable crop production.

1.1 Irrigation scheduling

Irrigation scheduling is the process of determining the time to irrigate and quantity of water is to be applied in each irrigation. Proper scheduling is essential for the efficient use of water and other inputs in crop production. Irrigation scheduling inside polyhouse is an important parameter for the appropriate design and successful operation and management of drip irrigation system. It directly affects the quality and quantity of crop production system inside the polyhouse. Scheduling water application is very critical to make the most efficient use of drip irrigation system, as excessive irrigation can reduce yield, while inadequate irrigation causes water stress and reduces production. On the other hand, the intensity of operation requires the water supply to be kept at the optimum level to maximize the returns to the farmer. The optimal use of irrigation can be characterized as the supply of sufficient water according to plant needs in the rooting area and at the same time, avoiding the leaching of nutrients into deeper soil levels.

Numerous irrigation scheduling methods are available, varying in complexity and functionality. These include evaporation pans, soil-based methods using tensiometers or gypsum blocks, weighing lysimeters and computer models.

1.2 CROPWAT

CROPWAT is a practical tool for the personal computer that can complete standard calculations for evapotranspiration and crop irrigation requirements. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions and the assessment of production under rain-fed conditions or deficit irrigation. CROPWAT is a powerful simulation tool which analyzes complex relationships of on-farm parameters such as the crop, climate and soil for assisting in irrigation management and planning.

1.3 Drip irrigation

Drip irrigation is the method of applying uniform and precise rate of water directly to the root zone of the plants as per the requirement through emitters at frequent intervals over a long period of time using a low pressure pipe network comprising of mains, submains and laterals. Adoption of drip irrigation for crops is reported to be effective in increasing agricultural production. The benefits of drip irrigation which include water saving, precise application and increased water use efficiency make the system highly acceptable.

The drip irrigation system facilitates water application at regular interval thereby maintaining optimum moisture level in the root zone for a longer period and prevents moisture stress or shock associated with other methods of irrigation. This promotes optimum plant performance resulting in higher yield and better quality produce. There is considerable saving in labour costs due to reduced interculturing operations, lesser number of weeding and elimination of manual application of fertilizers. Using drip irrigation, vast area of waste lands such as undulating terrain, saline, water-logged, sandy and hilly lands can be brought under productive cultivation. It also eliminates the need of land levelling and removal of productive top soil. Disease control is enhanced under micro irrigation system because the soil moisture and chemical additive levels can be closely controlled. Water is applied directly in the root zone, wetting only a fraction of the soil eliminating weed growth.

Quantitative achievements of micro irrigation compared to surface irrigation are shown in Table 1.1.

Table 1.1 Result of studies on micro-irrigation

Sl no	Crop	Yield (q/ha)		Irrigation (cm)		WUE (q/ha/cm)		Advantage of MI (%)	
		Surface	Drip	Surface	Drip	Surface	Drip	Saving	Increase in yield
1	Brinjal	91.0	148.0	168.0	64.0	0.5	2.3	61.9	62.6
2	Chilli	42.3	60.9	109.0	41.7	0.4	1.5	61.7	44.0
3	Cucumber	155.0	225.0	54.0	24.0	2.9	9.4	55.6	45.2
4	Onion	284.0	342.0	52.0	26.0	5.5	13.2	50.0	20.4
5	Potato	172.0	291.0	60.0	27.5	2.9	10.6	54.2	69.2
6	Tomato	61.8	88.7	49.8	10.7	1.2	8.3	78.5	43.5
7	Banana	575.0	875.	176.0	97.0	3.3	9.0	45.0	52.2

Source : Singh (2005).

1.4 Fertigation

Fertigation is one of the recent techniques of applying nutrients via micro irrigation system. It is a process in which fertilizers are applied along with irrigation water in the crop root zone according to the crop requirement. Application of fertilizer through drip irrigation will increase the application efficiency. Water and nutrients are the major inputs contributing towards production in irrigated agriculture. Maximum production with lesser rate of water and fertilizer can be achieved by the adoption of drip irrigation. The field experiments on vegetables and fruit crops grown under drip and fertigation system are reported to have shown improved quality, higher yields and saving of chemicals and fertilizers. The adoption of fertigation and drip system has shown favorable results in terms of fertilizer use efficiencies and quality of produce.

1.5 Polyhouse farming

Partial control of the microclimatic conditions which have a major influence on plant growth characteristics, can be achieved in polyhouses. Polyhouse is a framed or inflated structure covered with a translucent material in which crops are grown under controlled or partially controlled conditions. The productivity of a crop is influenced not only by its heredity but also by the microclimate around it. Greenhouse technology enables protecting the plants from the adverse climatic conditions and providing optimum conditions of light, temperature, humidity and air circulation for the best growth of the plants to achieve maximum yield and best quality. Under open field conditions, it is not possible to control the light, temperature etc.

This methodology of farming reduces dependency on rainfall and makes the optimum use of land and water resources. The main advantage of polyhouse farming is that the production can be obtained round the year even in adverse climatic conditions. An obvious advantage of polyhouses is the protection from outside environment. The temperature and humidity can be monitored and adjusted accordingly. Different soil types can be brought in and supplements added as needed with no risk of external pollution or pesticides. The combination of polyhouse farming and drip irrigation can save water compared to the open drip irrigated farming system.

Cucumber (*Cucumis sativus*) is a common garden vegetable native to southern Asia, but cultivated as an annual in many parts of the world. Compared with other vegetables, cucumber occupies fourth place in importance around the world, following tomato, cole crops and onion. Cucumber also has many field problems such as insect pest attacks and diseases, deteriorated varieties and reduced fruit quality. However, cucumber is the highest export-processed product and its productivity is increasing annually. Cucumber demands high temperature and soil moisture for satisfactory yield and under unfavorable climatic conditions, several problems may occur such as the reduction of female flowers (Cantliffe, 1981), delay in fruit growth (Liebig, 1981) and mineral disorders (Bakker and Sonneveld, 1988). Cucumber can be grown in polyhouse because of its high economic and nutritive value and is widely cultivated in polyhouse in India.

In the present study, a naturally ventilated polyhouse was used for growing cucumber crop to investigate the effect of microclimate on the performance of salad cucumber under naturally ventilated polyhouse.

The specific objectives of the study are

- Determination of the water requirement of the salad cucumber using CROPWAT.
- Study of the variation of climatic parameters inside the naturally ventilated polyhouse.
- Scheduling irrigation for salad cucumber in naturally ventilated polyhouse.
- Scheduling fertigation for salad cucumber in naturally ventilated polyhouse.

REVIEW OF LITERATURE

CHAPTER 2

REVIEW OF LITERATURE

This chapter deals with comprehensive review of the research work done by various researchers related to the present study which gives general information on natural ventilated polyhouse, CROPWAT software and effect of irrigation and fertigation on yield.

2.1 Microclimate of a natural and fan-ventilated system

The prime aim of a greenhouse is to grow plants, and therefore high transmission of solar radiation in the wave band 400-700 nm is essential to maximize photosynthesis rates. The amount of structural material and the properties of the cladding will influence the proportion of incident radiation transmitted to the plants. The photosynthetically active radiation will be accompanied by radiation at other, mostly longer, wavelengths. All the radiation entering the greenhouse will contribute to the potential elevation of the greenhouse temperature above that of the external air. The greater the insulation properties of the house the greater will be the elevation, though as general rule those cladding materials that might be chosen for good thermal resistance will also tend to be less good at admitting radiation for plant growth (Day and Bailey, 1999).

Rose flower stems adapt to high VPD by decreasing leaf area for maintaining high sap flow rate per unit area. Dayan (2000) reported that rose flowers produced in greenhouses in Israel during summer had short thin stems carrying small buds with pale petioles, but cooling the air in the greenhouse improved flower quality.

Cooling has always been an important problem for polyhouse operators in warm climates, potentially limiting production and constraining profits. Polyhouse cooling is typically accomplished by ventilation, either mechanically, via exhaust fans or naturally and via wind (Willits, 2003).

Leaf area and other morphological properties (such as ratio of leaf area to stem cross- section area) of rose flower stem may change during growth under different environmental conditions. Stem length is the primary indicator for the economic value of cut-flower rose production. Shoots with length lower than 30 cm could be considered unmarketable, shoots with length between 30 to 60 cm could be considered of mean economic value and shoots longer than 60 cm could be considered of relatively high quality (Katsoulas *et al*., 2005).

Greenhouse cooling is quite difficult and complicated task, far more difficult than heating, since the cooling devices used in other kind of building demand huge investments and high energy consumption. The net solar radiation in the greenhouse, reaches 500-600 Wm^{-2} during summer. In order to obtain greenhouse air temperatures close to outside ones, a total of about 200-250 Wm^{-2} of sensible heat needs to be removed. Low cost methods such as forced ventilation, cooling pads, fog systems, screens, etc., or in most cases, a combination of the previous methods are used for the removal of redundant energy. The most common methods used for greenhouse cooling in Mediterranean areas are natural or forced ventilation (Kittas *et al*., 2005).

Elevated temperatures will only be desirable when outside temperature conditions are below the optimum for plant growth. To make full use of an expensive structure through as much of the year as possible generally requires methods of cooling the house to be available. The most common is by natural ventilation, exchanging hot and humid air inside the house with cooler, drier air from outside.

2.2 Effect of microclimate on fruit yield

Ganesan (1999) conducted a study to define the effect of changes in microclimate produced by poly greenhouse conditions on plant growth characteristics and fruit yield of tomato. The UV stabilized plastic film covered greenhouse recorded higher day temperature than the open environment but relative humidity at 8 am was lower inside the greenhouse except from May to August. The light intensity inside the greenhouse was lower than in the open. Height of the plant, number of nodes, internodal length, total dry matter production and average fruit weight increased under greenhouse conditions as compared to open field condition. The fruit yield inside the greenhouse was nearly two times more than in the open field condition.

Parvej *et al*. (2010) conducted an experiment in a covered polyhouse along with an open field to compare the phenological development and production potentials of two tomato varieties viz. BARI Tomato-3 and Ratan under polyhouse and open field conditions. Photosynthetically active radiation inside the polyhouse was reduced by about 40% compared to the outside (i.e. open field) while air and soil temperatures always remained higher. Relative humidity had opposite trends with that of air temperature i.e. it was lower inside the polyhouse as compared to open field. The above microclimatic variabilities inside polyhouse favoured the growth and development of tomato plant through increased plant height, number of branches/plant, rate of leaf area expansion and leaf area index over the plants grown in open field. Polyhoused plants had higher number of flower clusters/plant, flowers/cluster, flowers/plant, fruit clusters/plant, fruits/cluster, fruits/plant, fruit length, fruit diameter, individual fruit weight, fruit weight/plant and fruit yield over open field condition.

Rajasekar *et al*. (2013) took up studies to screen ten vegetables for cultivation under shadenet house (33% shade) and open field for year round production of vegetables. Tomato, eggplant, chilli, cucumber, cluster bean, radish, amaranthus, coriander and capsicum were grown in the summer and winter. The influence of environmental variables temperature, relative humidity and light intensity were studied. Relative humidity was always higher under shadenet house than in open field during both seasons. Light intensity in the shadenet house was lower than in the open field. Mean weekly temperature during summer and winter were higher under open field conditions than in the shadenet house. Lower temperature caused plant height, number of branches, internodal length, average fruit weight and yield per plant to be higher in the shadenet house than in the open field.

2.3 Water requirement

2.3.1 Water requirement in the open field

There exist a multitude of methods for estimation of reference evapotranspiration (ET_0). One of the approaches normally used to quantify the potential ET of irrigated crops is the crop coefficient-reference evapotranspiration (K_cET_0) procedure. In this procedure, reference evapotranspiration (ET_0) is computed for grass or alfalfa reference crop and is then multiplied by an empirical crop coefficient (K_c) to produce an estimate of crop evapotranspiration (ET_c). The ET_0 represents the non-stressed ET based on weather data taken from a grassed weather surface. The K_cET_0 approach has been a preferred approach for estimating the ET for most irrigation projects because of difficulties in applying inflow- outflow water balances. Inflow-outflow balances require estimating deep percolation components before computing ET as a residual (Allen, 2000).

The Penman-Monteith equation is the most widely used method for reference evapotranspiration prediction, based on the relevant climatic data such as net radiation absorbed by leaves, temperature, vapour pressure deficit and wind speed.

2.3.2 Water requirement inside polyhouse

Greenhouse cultivation reduces evapotranspiration (ET) to about 70% of open field, therefore improving the water use, relative to unprotected cropping (Stanghellini, 1993).

Baille (2001) found that by applying a dense white paint to glass, a reduction of about 50% on solar radiation resulted. This drastic change in the greenhouse radiation load led to indirect modifications of other microclimatic variables such as air temperature and vapour pressure deficit, through the microclimate interactions.

The use of greenhouse in arid regions decreases crop water requirements by reducing evapotranspiration. The plastic cover utilized on these structures changes locally the radiation balance by entrapping long-wave radiation and creates a barrier to moisture losses. As a result ET_0 is reduced by 60 to 85% compared to outside the greenhouse (Fernandes *et al*., 2003). This leads to clear reduction in water demand when compared to field agriculture. Thus, greenhouse agriculture provides a way of increasing crop water use efficiency.

Crop water requirement of drip irrigated tomatoes grown in greenhouse in tropical environment has been investigated in the past. Greenhouse farming system performed better than open farming systems in terms of crop yield, irrigation water productivity and fruit quality. The results revealed that the crop evapotranspiration inside the greenhouse matched 75-80% of the crop evapotranspiration computed with the climate parameters observed in the open environment. In other words, the greenhouse farming can save about 20-25% of water compared to the open drip irrigated farming system (Harmato *et al*., 2004).

Orgaz *et al*., 2005 conducted an experiment to determine K_c for horticultural crops under greenhouse (melon and watermelon). The K_c values were found to be similar to those under field conditions.

In Penman-Monteith method at optimum level of 75-80% of ET_c was used for estimating crop water requirement under the greenhouse based on daily microclimate outside and beyond greenhouse environment where the temperature, relative humidity and wind speed were not very different between inside and outside the greenhouse.

For other climates where these differences are very large the method could probably not work and hence the need for the present research on comparison of crop water requirement of greenhouse using the microclimate inside the greenhouse.

Contemporary polyhouse operations require control of irrigation and nutrient supply in order to optimize crop growth and minimise cost and pollution due to effluents.

2.4 CROPWAT

The field experimental data from the Hsueh Chia Experimental Station of Chia Nan Irrigation Association in Taiwan were collected and analyzed then input the results to the CROPWAT irrigation management model that was developed by the Food Agricultural Organization (FAO). The results from CROPWAT model show that the annual potential evapotranspiration and effective rainfall in Hsueh Chia area are 1444 mm and 897 mm, respectively. In the paddy fields, the crop water requirements and deep percolation are respectively 962 mm and 295 mm for the first rice crop and 1114 mm and 296 mm for the second rice crop. The research shows that the irrigation management model can effectively and efficiently estimate the crop water requirements (Kuo, 2001).

Muhammad (2009) conducted a study on CROPWAT simulation under irrigated and rainfed conditions for maize crop, in order to provide information necessary in taking decisions on irrigation management. Simulation results analysis suggests that areas, where the maize water requirements exceeds the water supply, by application of adequate irrigation scheduling the yield losses can be significantly reduced.

The assessment of irrigation water needs at Muda Irrigation Scheme, Kedah, Malaysia due to climate change can lead to better irrigation water management for the operating systems of Pedu-Muda Reservoir in the future. Nurul and Sobri (2012) conducted a study with the objective of measuring irrigation water requirement of Pedu-muda reservoir for paddy plantation (two seasons) using two different methods, (Blaney Criddle method and CROPWAT model), compare the capability of both methods, and to evaluate the reliability of CROPWAT version 8.0 model in predicting future trend of irrigation water. In this study, the SDSM tool was used to simulate future climate trend from the year 2010 to 2099 and revealed that the temperature and rainfall are estimated to increase in the future year. In effort to measure the irrigation needed at the region, CROPWAT model was found to be more reliable and capable compared to the Blaney-Criddle method. From year 2010 to 2099, the annual irrigation requirement is estimated to slightly decrease at every interval year even though the ET_{crop} is expected to increase due to the effect of rising temperature in the future.

Sudip *et al*. (2012) carried out a study to assess the impact of climate change on crop water requirement. In this study, potato was taken as the reference crop for its growing period and its high response to irrigation. The ET values from the potato field were measured using field water balance method and the data was used to validate the CROPWAT model. After proper validation of CROPWAT model, the model was used to determine the irrigation requirement of potato using current and future (prediction years: 2020 and 2050) weather data. It was observed that irrigation water requirement will be increased by 7 to 8% during 2020, while it may increase about 14 to 15% during 2050.

Ali (2013) conducted a study for the simulation of peanut with CROPWAT model under Irrigated and Rainfed Conditions in order to provide information necessary in taking decisions is on irrigation management. Analysis suggests that from the month august the values of soil moisture deficit remained higher than readily available moisture values due to which severe yield reduction in peanut crop occurred 45.6% in growth stage three of peanut vegetation season. The loss in total yield reduction was 43.6%. The total available moisture remained higher from readily available moisture and soil moisture deficit throughout the peanut vegetation season. Simulation for irrigated field of peanut crop is done using the criteria of fixed interval of 6 days with irrigation application of fixed depth of 40 mm from the first day of sowing. During the first 3- irrigation application 207.3 mm of water is lost, the first irrigation lost 1.1 mm, the second lost 102.5 mm and third irrigation lost 103.7 mm water. The relation of soil moisture deficit and readily available moisture is just like rainfed condition but having little differences in value as compared to rainfed condition simulation. The largest yield reduction 45.4% occurred in growth stage three of peanut vegetation season. Simulation estimated 39.4% yield reduction under irrigated condition.

Megha and Sabeena (2013) conducted a study to determine the crop water requirement and irrigation schedule of eleven major crops. In the present study the CROPWAT model was used to estimate the CWR and irrigation scheduling by providing climate data taken from nearby Meteorological station at RARS, Pattambi, and Crop data required for the software were taken from FAO 56 and 24, 1996. The soil data which were the results of various experiments conducted in the KCAET laboratory were also input to the model. The crop water requirement of eleven crops viz Amaranthus, Snake gourd, Cowpea, Cucumber, Water melon, Pumpkin, Bhindi, Ashgourd, Sesamum, Banana and Rice were calculated and the results were 187.7 mm, 341.5 mm, 405.9 mm, 418,2 mm, 381.7 mm, 375.5 mm, 398.2 mm, 486.4 mm, 56.7 mm, 118.2 mm and 430.1 mm respectively. From the study it was clear that the computation of total CWR became effortless, less time consuming and more accurate.

2.5 Effect of drip irrigation on growth and yield of crop

Locascio and Smajstria (1996) studied the effect of amount of water application and mulches for 3 years on irrigated tomatoes by applying water at 0.00, 0.25, 0.5, 0.75 and 1.00 times pan evaporation in one application per day. They found that fruit yield gets doubled with drip irrigation. The total yield was found highest with quantities of 0.75, 0.5 and 1.00 times pan evaporation and significantly lower with 0.25 and 0.5 times pan evaporation values.

Singh *et al.* (2000) made an attempt to study the effect of drip irrigation compared to conventional irrigation on growth and yield of Apricot, to work out its irrigation requirement. Drip irrigation at 80 per cent evapotranspiration of water gave significantly higher growth and fruit yield of 8.6 tonnes per hectare compared to that surface irrigation. Plastic mulch plus drip irrigation further raised the fruit yield to 10.9 tonnes per hectare. Drip irrigation besides giving a saving of 98 percent irrigation resulted in 3.3 metric tonnes per hectare higher fruit yield.

Singh *et al*. (2000) studied the yield, water requirement and economics of drip irrigation in litchi orchard at farmer's field in Uttar Pradesh. It was found that good quality marketable yield of litchi varied from 12.5 to 16 metric tonnes per hectare for drip system. The total volume of water applied was 282 mm for drip irrigation during four months of system operation. The benefit cost ratio was found to be 3.91 for drip irrigated litchi orchard compared to 3.05 for surface irrigated litchi.

Jain *et al.* (2001) conducted experiments on the response of potato under drip irrigation and plastic mulching. The highest water use efficiency was found to be 3.24 t/ha-cm for the treatment irrigated with drip system at 80 per cent level with mulch as compared with to 2.17 t/ha-cm control treatment.

Singh *et al.* (2001) carried out experiments to study the effect of different irrigation regimes of 100 percent potential ET (V), 0.8V, 0.6V, 0.4V, 0.2V at four fertility levels on cauliflower yield with and without mulch under drip system and its comparison with the surface irrigation system. The highest curd yield was obtained under 100 percent recommended dose of fertilizer with volume of water applied equal to 22 cm through drip irrigation without mulch.

Singh *et al.* (2001) conducted studies on drip irrigation resulted in significant increase in production and water use efficiency of potato. At Udaipur it was reported that besides saving in water, the yield of potato tubers was high and weed growth was least in drip irrigation compared to surface irrigation.

Singandhube *et al.* (2003) conducted a study to determine the response to urea fertilizer with drip irrigation and compared with conventional furrow irrigation for two years. Application of nitrogen through the drip irrigation in ten equal splits at eight days interval saved 20 to 40 percent nitrogen as compared to the furrow irrigation when nitrogen was applied in two equal split. Similarly, 3.7 to 12.5 percent higher fruit yield with 31 to 37 percent saving of water was obtained in the drip system. Water use efficiency in drip irrigation, on an average nitrogen level was 68 and 77 percent higher over surface irrigation in 1995 and 1996, respectively. At a nitrogen application rate of 120 kg/ha, maximum tomato fruit yield of 27.4 and 35.2 tonnes per hectare in two years was recorded.

Yuan *et al*. (2006) studied the effects of different amount of irrigation water on the growth and yield of cucumber under a rainshelter for two seasons in Yamaguchi University, Japan. For spring experiment, the amount of irrigation water applied was 0.50, 0.75, and 1.00 times of water surface evaporation (Ep) and regimes were denoted as Ep0.50, Ep0.75, and Ep1.00. Same method for autumn experiment, regimes were denoted as Ep0.75, Ep1.00, Ep1.25, Ep1.50, and Ep1.75. The results showed that amount of irrigation water significantly affected plant growth and fruit production. Plant height and biomass increased, but specific leaf weight (SLW, g/m^2) decreased with increasing amount of irrigation water.

Stanislaw and Jacek (2008) carried out a study on the influence of surface and subsurface drip irrigation on the yield and quality of roots of parsley grown on ridges and on flat ground was carried out. Irrigation water was supplied via drip lines, which in subsurface irrigation were placed at a depth of 50 mm below the surface of the ridges, along the centre line between two rows of plants. In the case of surface irrigation, the drip lines were placed on the surface of the ridges between two rows of plants. Irrigation started when soil water potential was between -30 and -40 kPa. Nitrogen fertilizers (100 $kgha^{-1}$) were applied in two doses. The first dose was applied pre-plant, while the second one was delivered by fertigation. In the control treatment without irrigation, the second dose of nitrogen was applied by broadcasting. Both surface and subsurface irrigation used in the cultivation on ridges and on flat ground had a significant effect on the marketable yield of parsley roots. However, no significant differences in the yield between surface and sub- surface drip irrigation were found. The yield of non-marketable parsley roots in flat cultivation was twice as high as that in ridge cultivation. Parsley plants cultivated on ridges produced significantly longer, better-shaped storage roots compared to those cultivated on flat ground. Surface and subsurface drip irrigation significantly decreased the total N and K content in parsley roots.

Sefer *et al.* (2009) was conducted study to investigate the effects of drip irrigation methods and different irrigation levels on yield, quality and water use characteristics of lettuce cultivated in solar green house. The result showed that the highest yield was obtained from subsurface drip irrigation at 10 cm drip line depth and 100 percent of Class A Pan Evaporation rate treatment. The water use efficiency and irrigation use efficiency increased as the irrigation was reduced.

Deepa *et al*. (2010) conducted a study to standardize the irrigation requirement of salad cucumber grown in polyhouse. The experiment had five irrigation treatments with six replications. Two types of irrigation basin and drip were practiced. The irrigation treatments include drip irrigation with 1, 1.5, 2 and 2.5 lit/day of water. From the study it was found that drip irrigation has a positive effect on growth and yield of crop. Crops drip irrigated with 1.5 l/plant/day performed well with a water use efficiency of 121. Drip irrigation in comparison with the surface irrigation has given higher yield throughout the crop period. And also drip irrigation has shown larger soil moisture content a day after irrigation, while the conventional surface irrigation has least soil moisture content.

Majid and Fereydoun (2011) conducted a study to determine the effect of different irrigation methods on crop yield. Two irrigation methods, i.e. surface irrigation (SI) and drip irrigation (DI) were applied to cantaloupe between emergence and harvest during 2004 and 2005 growing seasons. The statistical results of study indicated that irrigation method significantly (P=0.01) affected crop yield. The maximum crop yield of 27.1 t $ha^{-1}$was obtained in case of DI treatment and the minimum crop yield of 22.5 t ha^{-1} was recorded in case of SI treatment.

Zhang *et al*. (2011) studied the effect of drip irrigation scheduling on the yield and quality of cucumber fruits. The irrigation water amounts were determined based on the 20 cm diameter pan (*Ep*) placed over the crop canopy, and cucumber plant was subjected to three irrigation water levels (I1, 0.6 *Ep*; I2, 0.8 *Ep*; and I3, 1.0 *Ep*). The results showed that the cucumber fruit yield increased with the improvement of irrigation water. Irrigation water increased yields by increasing the mean weight of the fruits and also by increasing fruit number.

Ghaderi *et al*. (2012) conducted a study to determine the effects of deficit irrigation after the onset of flowering on lint yield and seed quality of cotton (*Gossypium hirsutum* L.) with a drip irrigation system were evaluated during 2006 and 2007 in the northern Iran. After the onset of flowering, four irrigation regimes (0, 40, 70 and 100% of Class A pan evaporation (%PE)) were applied when the cumulative evaporation amount from class A pan reached approximately 40-50 mm. Lint yield showed a quadratic response to %PE and maximum lint yields were achieved with 82 and 91% PE irrigation regimes in 2006 and 2007, respectively and seed quality (based on standard germination and seed vigor tests) increased with a decrease in deficit irrigation. Thus when the amount of applied water was reduced by 30 (70% PE) and 60% (40% PE), decrease in lint yield was about 4 and 14%, respectively. The results of this study showed that irrigation treatments of 40-70% PE would be optimum for lint yield and seed quality production under drip irrigation.

2.6 Effect of fertigation on growth and yield of crop

The use of fertigation in drip irrigation system was reviewed by Haynes (1985). The advantages of the use of fertigation in a drip irrigation system included reduced labour, increased fertilizer efficiency and the increased flexibility of fertilizer application. Fertigation allows nutrient placement directly into the plant root zone during critical periods of nutrient demand (Mikkelsen, 1989).

Bachav (1995) conducted a field experiment on fertigation by comparing fertigation with NPK over farmer's fertilizer practice with conventional fertilizers in terms of yield, quality and monetary returns. Fertigation at weekly intervals was found more convenient and economically profitable for the farmers.

Drip irrigation generates a restricted root system requiring frequent nutrient supply. Nutrient requirement may be satisfied by applying fertilizers in irrigation water. Maximization of crop yield and quality and minimization of leaching losses below the rooting volume may be achieved by managing fertilizer concentration in measured quantity of irrigation water according to crop requirement (Hagin and Lowengart, 1996).

Highest fruit yield of 45.7 t/ha was obtained for tomato with application of recommended dose of fertilizers comprising polyfeed (19:19:19), MAP (12:60:0) and urea through fertigation. The yield were nearly 22 -27 percent higher compared to yields obtained in crop which was provided with normal fertilizers through soil application (Prabhakar and Hebber, 1996).

Pawar *et al.* (1997) took up studies to assess the effects of fertigation through drip on the growth, yield and quality of banana. The result revealed that, for banana the fruit yield was significantly higher in normal planting than paired row planting. The fruit yield increased significantly with water soluble complex fertilizers compared to Nitrogen alone and it also increased significantly with an increase in fertilizer levels.

Shindhe *et al.* (1997) conducted field experiment to study the effect of water soluble fertilizers through drip on the growth and yield of cotton. The expression of growth and yield contributing characters of cotton due to normal planting was at higher magnitude compared to paired row resulting in higher seed cotton yield by 7.75 percent. Maximum seed cotton yield of 3.4 t/ha was obtained due to 100 percent of recommended fertilizer dose.

Neelam *et al.* (1998) conducted field experiments at IARI, New Delhi with four fertilizer levels of 100, 80, 60 and 40 percent. The yields of onion realized under different treatments of fertigation were compared with that achieved by conventional methods. Fertigation resulted in 60 percent saving of fertilizer for achieving same level of production compared to conventional method of fertilizer application.

Application of soluble fertilizer like urea and muriate of potash through drip irrigation could bring about substantial savings of 20-25 percent in fertilizer use, besides minimizing pollution of ground waters through nitrate – nitrogen leaching to a considerable extent. Fertigation also offers the possibilities of using nutrients matching the crop demand at different stages of crop growth (Srinivas, 1999).

Singh *et al.* (2001) conducted field experiment in sandy loam soil to investigate the water and nutrient use efficiency of sprouting Broccoli grown on sandy loam soil using fertigation. Yields obtained showed that substantial saving in the fertilizer applied, to the extend of 20-40 percent could be accomplished through fertigation.

Singh *et al*. (2001) conducted field experiments to investigate the water and nutrient use efficiency of sprouting broccoli growing on sandy loam soil using fertigation. The treatments included application of the recommended fertilizer dose as soil application and irrigation through drip irrigation as well as three levels of fertigation viz. 100, 80, 60 percent of the recommended fertilizer doses. Flood irrigation with recommended doses was considered as control. Yield obtained indicated substantial saving in the fertilizer applied to the extent of 25 – 40 percent.

The effects of irrigation water level and nitrogen fertilizer on total canopy and wetted area basis of chilli in respect of yield, water saving and water use efficiency was studied on loamy sand soil by Singh *et al*. (2001). The highest yield of 3.03 kg/ha was recorded with water applied on total area basis along with 180 kg N/ha. The study suggested that it is better to schedule irrigation at 0.8 of E pan evaporation and apply on canopy area basis combined with 180 kg nitrogen per hectare to maximize the production.

Singh *et al*. (2001) conducted experiment on the response of drip irrigation and black plastic mulching on young mango trees. The study indicated that the biometric growth of the treatments irrigated at 60 percent level through drip system with plastic mulching performed better when compared to 80 percent and 100 percent levels of water use along with water saving of 20 – 40 percent.

Veeranna *et al.* (2001) conducted field experiments to investigate the effects of broadcast application and fertigation of normal and water soluble fertilizers at three rates through drip and furrow irrigation methods on yield, water and fertilizer use efficiency in chilli (*Capsicum annum*). Fertigation with 80 percent water soluble fertilizers was effective in producing about 31 and 24.7 percent higher yield over soil application of normal fertilizers at 100 percent recommended level in furrow and drip irrigation methods respectively, with 20 percent saving of fertilizers and 36 percent saving of irrigation water.

Shataroopa *et al.* (2005) conducted an experiment at the Assam Agricultural University to investigate the effect of drip irrigation and plastic mulch on yield of Broccoli as compared to that over furrow irrigation. The water use efficiency was highest at lower level of ET replenishment by drip and with mulch. Maximum yield was obtained under drip irrigation replenishing 120 percent of ET depletion and under mulch.

Subby *et al*. (2005) was conducted a study to compare the effect of subsurface and surface drip irrigation on soil moisture distribution and growth of three years old pre-bearing mango in Agricultural Research Station, Andhra Pradesh. Soil moisture at the surface and near the dripper was the highest in the case of surface dripper and subsurface dripper placed at 30 cm depth.

Anitha *et al.* (2006) did experiments on nutrient management in chilli based cropping system in Kerala. Nutrient levels significantly influenced the yield of crops in chilli based cropping system. Better growth and yield performance of chilli, French bean and amaranthus was observed when both chilli and intercrops were given 100 percent nutrient dose. The yield of intercropped chilli was 8917, 5598 and 4865 kg/ha at 100, 75 and 50 percent nutrient doses respectively

Vijayakumar *et al.* (2007) conducted studies at Agricultural Research Station Bhavanisagar to maximize the water and fertilizer use efficiency of drip system in brinjal crop. The experiments were laid out in Factorial Randomised Block Design with nine treatments which included three irrigation levels 100, 75 and 50 percent of pan evaporation along with three fertigation levels, viz. 125, 100 and 75 percent of recommended Nitrogen and Pottasium application by fertigation and replicated thrice. In brinjal higher yields with maximum shoot length and number of branches per plant were recorded for the treatment with 75 percent of PE with fertigation of 75 percent of recommended Nitrogen and Pottasium.

Yasser (2009) reported the impact of fertigation scheduling on tomato yield under arid ecosystem conditions. Results revealed that tomato yields, water and fertilizer use efficiency had been enhanced by 25.6, 49.3 and 20.3 percent respectively under surface drip in comparison with solid set sprinkler irrigation system. The cost of tomato production under fertigation was lower than that when using traditional method of fertilization.

2.7 Impact of drip irrigation on water and fertilizer savings

Pandey and Vijay (1998) studied the comparative performance of drip and surface methods of irrigation in tomato (var. Pusa early dwarf) and stated that there is a water savings of 20-52 % over surface method of irrigation.

Replenishment of evaporation losses to 75% under drip irrigation to grapes was sufficient wherein the total water requirement was 712 mm under drip as compared to 942 mm in surface irrigation (Srinivas et al, 1999).

The right combination of water and nutrients is the key for high yield and the quality of produce. Fertigation (application of fertilizer solution with drip irrigation) has the potential to ensure that the right combination of water and nutrients is available at the root zone, satisfying the plants total and temporal requirement of these two inputs (Patel and Rajput, 2001).

Patel and Rajput (2001) reported fertilizer savings of 40% fertilizers as compared to the broadcasting method of fertilizer application without affecting the crop yield in bhendi.

Srinivas (2001) reported water saving of 32% in grapes with drip irrigation over flood irrigation at Bangalore. Similarly Narayanamoorthy (2004) reported water saving of 37% in grapes from Maharastra.

Fertigation in addition to saving of fertilizers also permits applying fertilizer in small quantities according to the plants nutrient requirements. (Veeranna *et al*., 2001 and Bhoi *et al*., 2001).

Iqbal *et al.* (2014) carried out a study to determine the effect of drip irrigation compared to furrow irrigation. Three vegetables (tomato, cucumber and bell pepper) were grown in plastic tunnels as offseason crops for three years from 2009-10 to 2011-12 to evaluate comparative effectiveness. Irrigation was applied though drip and furrow irrigation systems. Each crop was planted on 20 x 27 ft under drip irrigation and on 20 x 9 ft under furrow irrigation system. All three crops consumed less water under drip irrigation as compared to furrow irrigation system. Average water use efficiency increased by 250% for tomato, 274% for cucumber and 245% for bell pepper under drip irrigation system as compared to furrow system.

2.8 Water use efficiency and fertilizer use efficiency

The use of fertigation in drip irrigation system was reviewed by Haynes (1985). Ramesh (1986) noticed that higher level of irrigation with drip method produced significantly higher irrigation water use efficiency of 20.86 kg/ha/mm compared to furrow irrigation which produced an yield of 15.64 kg/ha/mm. Pairing the rows also increased irrigation water use efficiency over uniform row planting.

The advantage of the use of fertigation in a drip irrigation system included reduced labour, increased fertilizer efficiency and the increased flexibility of fertilizer application. Fujiyama and Nagal (1987) reported that the nutrient solution brought about a high nutrient recovery rate and appears to be a suitable method for supplying nutrients and water. Palled *et al.* (1988) found maximum dry chilli yield of 1968 kg/ha and water use efficiency with irrigation at 0.5 IW/CPE ratio. Fertigation allows nutrient placement directly into the plant root zone during critical periods of nutrient demand (Mikkelesen, 1989).

Balasubrahmanyam *et al.* (1999) conducted studies on the evaluation of water requirement of mango. The results showed that mango plantation responds well to irrigation at 10950 litres/tree/year, whereas the bearing trees require a minimum 20080 litres/tree/year. The water use efficiency was maximum under drip system.

MATERIALS AND METHODS

CHAPTER 3

MATERIALS AND METHODS

The polyhouse cultivation is essential to get maximum profit from unit area. In polyhouse by controlling the microclimate, amount of irrigation water and fertilizer can create a favorable environment for plant growth and optimum production. Hence this study was mainly intended to determine the effect of microclimate on the performance of salad cucumber and to schedule irrigation and fertigation. This chapter includes materials used and methodology adopted during the study.

3.1 Study area

The experiment was conducted using salad cucumber during the wet seasons of 2013 under naturally ventilated polyhouse of PFDC, KCAET, Tavanur, Kerala. The site is situated on the cross point of 10^o 51'18" N latitude and 75^o 59' 11" E longitude at an altitude of 8.54 m above mean sea level.

The polyhouse was oriented east–west with an area of 292 m^2 (36 m in length and 8 m in width). The soil type of the experimental plot was sandy loam.

3.2 Water requirement of the crop

The estimation of water requirement of crop is essential for irrigation planning and management and also it is the basis on which irrigation project is designed. The key to effectiveness of irrigation water management lies in proper estimation of crop water requirements, which are primarily based on cropping pattern, rainfall in the area and other climatic factors. Computer model simulation is an emerging trend in the field of water management. CROPWAT is one of the models extensively used in the field of water management throughout the world. CROPWAT facilitates the estimation of the crop evapotranspiration, irrigation schedule and agricultural water requirements with different cropping patterns for irrigation planning.

CROPWAT for Windows uses the FAO Penman-Monteith method for calculation of reference crop evapotranspiration (Allen *et al.,* 1998). The development of irrigation schedules and evaluation of rainfed and irrigation practices are based on a daily soil-moisture balance using various options for water supply and irrigation management conditions. Scheme water supply is calculated according to the cropping pattern provided in the program (Clarke *et al*., 1998). Studies have shown that the Penman-Monteith method is more reliable than methods that use less climatic data (Jensen *et al.*, 1990).

$$ET_0 = \frac{0.408\,\Delta\,(R_n - G) + \gamma\,\frac{900}{T + 273}\,U_2(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,U_2)}$$

where,

ET_0 = Reference evapotranspiration (mm/day)

R_n = Net radiation (MJ/(m^2 day))

G = Soil heat flux density (MJ/(m^2 day))

U_2 = Wind speed at a height of 2 m (m/s)

e_s = Saturated vapor pressure (kPa)

e_a = Actual vapor pressure of the air at standard screen height (kPa)

γ = Psychrometer constant (kPa/°C)

Δ = Slope of the saturation vapor pressure curve between the average air temperature and dew point (kPa/°C)

T = Mean daily air temperature (°C)

ET_c is termed as the crop water requirement (CWR) in mm/day. It is defined as the depth of water needed to meet the water loss through evapotranspiration of a disease free crop, growing in fields under non-restricting soil conditions including soil water and fertility and achieving full production potential under the given growing environment (Doorenbos and Pruitt, 1977; Doorenbos and Kassam, 1979). ET_c can be calculated by the following equation.

$$ET_c = K_c \times ET_0$$

The crop water requirement (ET_c) of salad cucumber was computed by multiplying the crop coefficient (K_c) with ET_0 at different growth stages.

3.2.1 Data collection

3.2.1.1 Climate Data

In order to calculate ET_0, the respective climatic data was collected from the nearest and most representative meteorological station Thrissur. Meteorological data including daily solar radiation, precipitation, relative humidity, sunshine hours, minimum and maximum air temperature and wind speed of the year 2012 were collected (Appendix I).

3.2.1.2 Soil parameters

The physical properties of the soil required for the study were determined. Soil data including soil type and bulk density were determined using the following soil test.

3.2.1.2.1 Bulk density

A core cutter consisting of a steel cutter, 10 cm in diameter and 12.5 cm high, with a 2.5 cm high dolly was driven in to the cleaned surface with the help of a rammer, till about 1 cm of the dolly protruded above the surface. The cutter, containing the soil, was dug out of the ground. The dolly was then removed and the excess soil was trimmed off. Soil bulk density was determined from these undisturbed cores as mass per volume of dried soil. The samples were collected a day after the treatments were applied. Then bulk density was calculated by using the formula,

$$\rho = \frac{M}{V}$$

where,

ρ = bulk density in g/cm^3

M = mass of soil in g

V = volume of soil in cm^3

3.2.1.2.2 Particle size analysis

The analysis for grain size distribution of soils was done by sieving. Here dry sieve analysis was carried out using 4.75mm, 2mm, 1mm, 600µm, 425µm, 300µm, 212µm, 150µm, and 75µm size sieves. Sieving was done using sieve shaker. Weight of soil retained in each sieves were taken (Appendix II). The mass retained in the receiver was then subjected to sedimentation analysis by Hydrometer method (Appendix III).

3.2.2 Climate/ ET_o data input and output

This module is primary for data input, requiring information on the meteorological station (country, name, altitude, latitude and longitude) together with climatic data. The data of minimum and maximum temperature, humidity, wind speed and sunshine hours were used to calculate radiation and ET_c using the FAO Penman-Monteith approach. Climate module presented in Fig. 3.1.

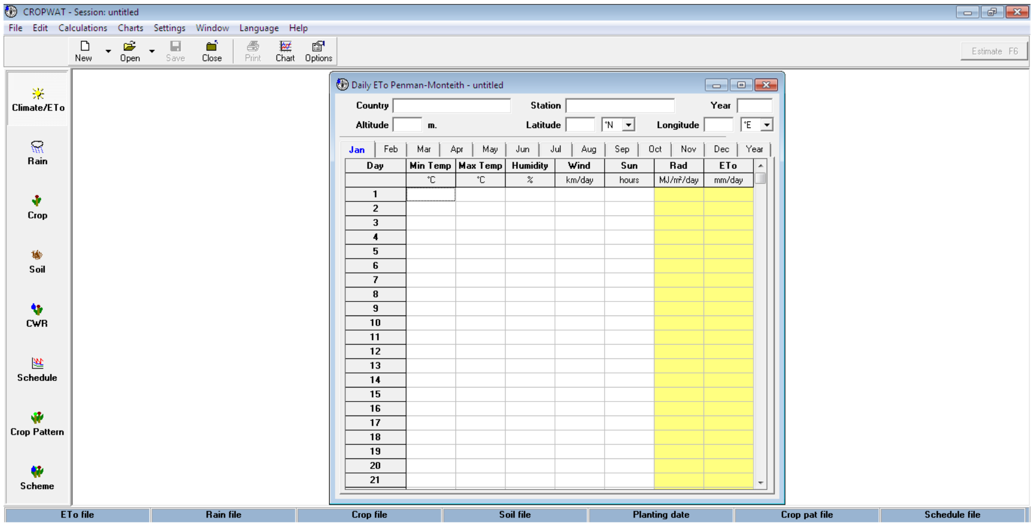


Fig. 3.1 Climate module

3.2.3 Rain module

Fig. 3.2 shows the rain module in the CROPWAT software. The daily rainfall was data fed in to the rain module. In order to account for the losses due to runoff or percolation, effective rain fall is calculated by empirical method called USDA method.

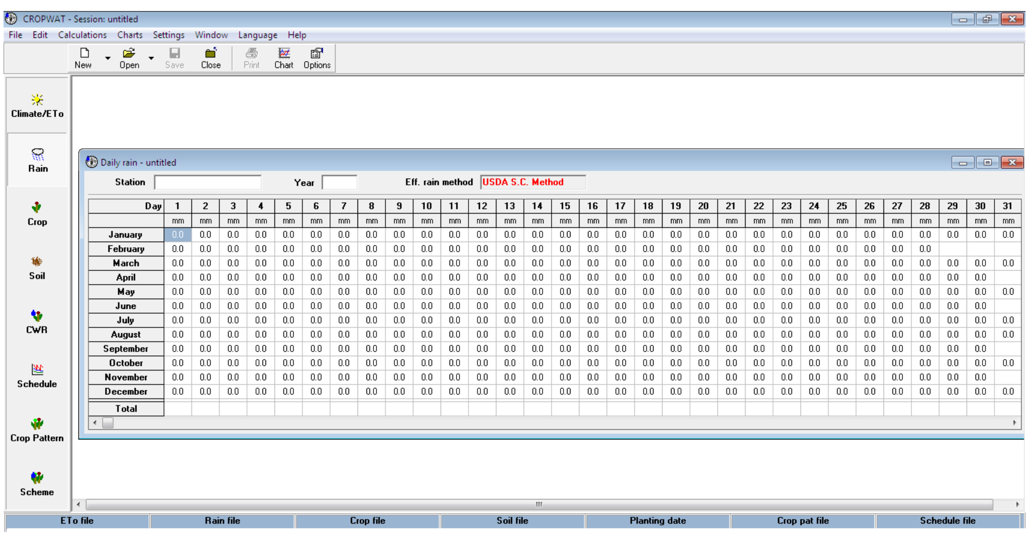


Fig. 3.2 Rain module

3.2.4 Crop module

Fig. 3.3 shows crop module of the software. The details of crop related to the study such as crop coefficient, critical depletion, yield response, root depth and crop height over different development stages were fed in to this module.

Different development stages defined as follow:

- Initial stage: it starts from planting date to approximately 10% ground cover. The length of this period is highly dependent on the crop, the crop variety, the planting date and the climate.
- Development stage: it runs from 10% ground cover to effective full cover. Effective full cover for many crops occurs at the initiation of flowering. For row crops where rows commonly interlock leaves, effective cover can be defined as the time when some leaves of plants in adjacent rows begin to intermingle so that soil shading becomes nearly complete. In densely sown vegetation, such as cereals and grasses, the effective full cover can be difficult to be visualised, the more easily detectable stage of flowering is generally used.
- Mid-season stage: it runs from effective full cover to the start of maturity. The start of maturity is often indicated by the beginning of the ageing, yellowing or senescence of leaves, leaf drop, or the browning of fruit. It is the longest stage for perennial and for many annual crops, but it can be relatively short for vegetables that are harvested fresh for their green vegetation.

- Late season stage: it runs from the start of maturity to harvest or full senescence.

Fig. 3.3 Crop module

3.2.5 Soil module

Fig. 3.4 shows soil module. The Soil module is essentially data input, requiring the following general soil data:

- Total available water (TAW)
- Maximum infiltration rate
- Maximum rooting depth
- Initial soil moisture depletion

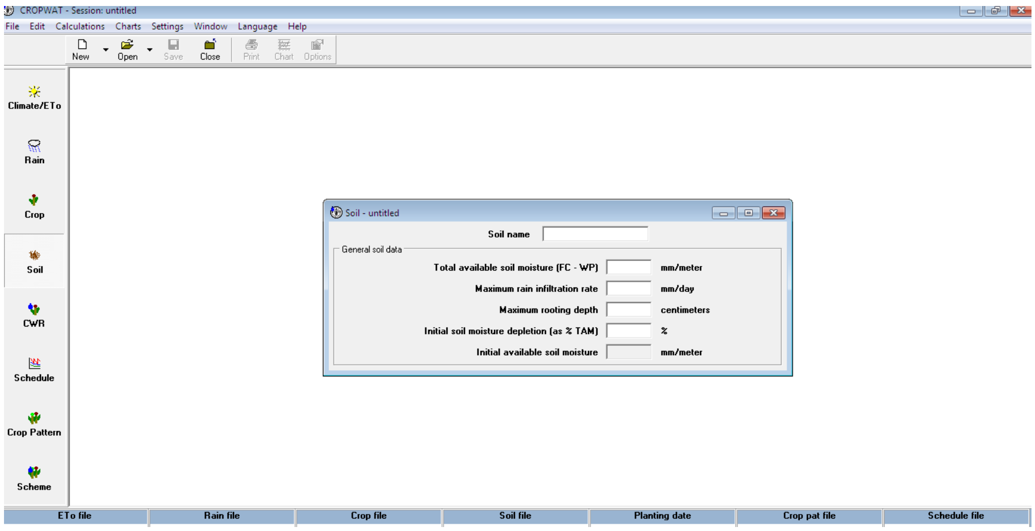


Fig. 3.4 Soil module

3.2.6 CWR module

The CWR module includes calculations, producing the irrigation water requirement of the crop on a decadal (Ten days) basis and over the total growing season, as the difference between the crop evapotranspiration under standard conditions (ET_c) and the effective rainfall.

3.3 Determination of effect of microclimate on the yield of cucumber

The climatic data of maximum and minimum temperature, air temperature and relative humidity were collected from polyhouse during entire crop period. Then the climatic conditions of salad cucumber were compared and suitable climatic conditions were suggested.

3.4 Cultural operations

3.4.1 Land preparation

The land was ploughed thoroughly using mini tiller**.** As salad cucumber is a heavy consumer of fertilizer, soil improvement using manures was done during land preparation for the early nourishment of the plant. Farm yard manure was mixed to the soil at a rate of 20 t/ha. Beds of 36 m length and 1 m width were prepared. The bed was raised to a height of 40 cm. The layout of the experimental plot is shown in Fig. 3.5.

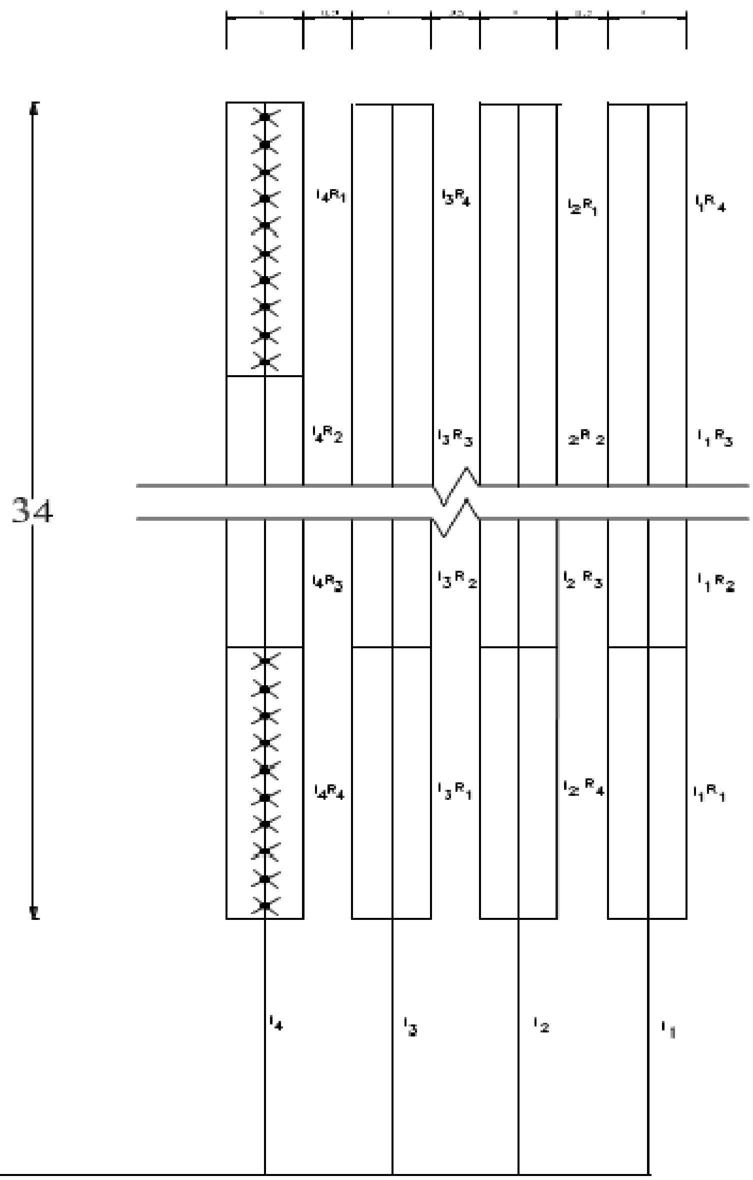
3.4.2 Nursery preparations

Salad cucumber variety ***Hilton*** (Nickerson-Zwaan) was chosen for cultivation. Seeds were sown in pro trays and fifteen days old seedlings were transplanted to the main field. For sowing the seeds, the mixture of cocopeat, vermiculite and perlite in a ratio of 3:1:1 were filled in the trays. After sowing the seeds, trays were irrigated with a rose can daily in the morning. Plate 3.1 shows the seedling of salad cucumber before transplanting.

Plate 3.1 Seedling of salad cucumber

3.4.3 Transplanting

Transplanting was done on 28th May for the irrigation trial and 14th October for the fertigation trial. The plants were transplanted at a spacing of 90 × 90 cm with 40 plants in each bed (Plate 3.2). The total plant population was 160 numbers. Gap



× Plants

• Emitter

I_1 : 50% of the daily irrigation requirement of the crop

I_2 : 65% of the daily irrigation requirement of the crop

I_3 : 80% of the daily irrigation requirement of the crop

I_4 : 95% of the daily irrigation requirement of the crop

Fig 3.5 Layout of the experimental plot

filling was done within a week after transplanting to ensure optimum plant population.

Plate 3.2 Transplanting of seedlings

3.5 Experiment details

The field experiment using salad cucumber mainly involves the standardization of the rate of irrigation water and ferilizer. The irrigation treatments were formulated for different levels of water requirement of the crop. The crop water requirement of salad cucumber was computed using the CROPWAT model. The fertilizer treatment was selected based on the adhoc recommendation of KAU. The irrigation trial was conducted during 28th May to 2nd September. The objective was to standardize the irrigation requirement of salad cucumber grown in a naturally ventilated polyhouse. The second trial was conducted to standardize fertigation during 14th October to 30th December. The soil in the field plot was well drained sandy loam. In these experiments, the land under the polyhouse was leveled and beds were raised. The plot was divided into four rectangular beds having four treatments with four replications. Ten salad cucumber plants were coming under each replication. Plate 3.3 shows the transplanted seedlings in the polyhouse.

Plate 3.3 Transplanted seedlings in the polyhouse

Irrigation schedules was planned to provide the estimated water requirement of the crop. In order to determine the optimum water requirement of the crops, four irrigation levels were adopted which were 50, 65, 80 and 95 percent of water requirement of salad cucumber. Table 3.1 shows the time of irrigation in each treatment. In this experiment, fertilizers were applied as per adhoc recommendations with different rate of irrigation. The details of irrigation treatments are given below.

I_1 : 50% of the estimated irrigation requirement from CROPWAT

I_2 : 65% of the estimated irrigation requirement from CROPWAT

I_3 : 80% of the estimated irrigation requirement from CROPWAT

I_4 : 95% of the estimated irrigation requirement from CROPWAT

Table 3.1 Time required for irrigating each treatment

Treatments	Time required for irrigation (min)	Amount of water required (l/day/plant)
I_1	15.0	1.0
I_2	19.5	1.3
I_3	24.0	1.6
I_4	28.5	1.9

The second experiment was conducted to determine the optimum fertilizer requirement of the salad cucumber. Water soluble fertilizers like urea, MOP and polyfeed (19:19:19) were used in the experiment. The recommended dose of fertilizer for the salad cucumber was 175: 125: 300 kg/ha. The recommended soluble fertilizers were applied simultaneously in a combined form to the plant root zone. The fertilizers were applied at a rate of 80, 90, 100 and 110% of fertilizer requirements. The amount of fertilizer required for each treatment is listed in the table 3.2. Details of fertigation are given below.

F_1 : 80% of the adhoc fertilizer recommendation of KAU

F_2 : 90% of the adhoc fertilizer recommendation of KAU

F_3 : 100% of the adhoc fertilizer recommendation of KAU

F_4 : 110% of the adhoc fertilizer recommendation of KAU

Table 3.2 Quantity of fertilizer requirement for each treatment

(Recommended dose of N: P: K is 175: 125: 300 $kgha^{-1}$)			
Treatment	**Fertilizer required (g)**		
	Urea	**Polyfeed**	**MOP**
F_1	36	48	57
F_2	40	54	65
F_3	44	60	72
F_4	48	66	79

3.5.1 Method of irrigation

The field was prepared and the drip system was installed. Laterals of 12 mm were used in the experimental plot. Each plant was irrigated with an emitter having discharge of 4 lph.

3.6 Pest and disease management

Crops vary in their tolerance to insect pests and disease attack depending on the type of damage and stage of growth. Seedlings have little tolerance to insect attack and relatively small numbers can cause economic damage. Most crops can withstand considerable insect pressure in the vegetative stage but considerably less damage at critical growth stages such as establishment, flowering and grain fill. Monitoring and management during these high risk periods is essential to minimise economic loss.

Crop protection consisted of controlling the incidence of pest and disease. Different pest and disease which were present in the polyhouse are listed below.

3.6.1 Downy mildew

Downy mildew caused by *Pseudoperonospora cubensis* is a common and serious disease of cucurbit crops. This disease occurs in cucumbers grown both in open field and greenhouse conditions. A downy mildew infection acts as a sink for plant photosynthates causing reductions in plant growth, premature foliage loss and consequently a reduction in yield. The yield loss is proportional to the severity of the disease and the length of time that plants have been infected.

Famoxadone 16.6% + Cymoxanil 22.1% SC (Equation Pro) was sprayed at a rate of 1 ml/lit on the leaves to control downy mildew.

3.6.2 Root-knot nematode

Root-knot nematode, *Meloidogyne incognita* symptoms on plant roots are dramatic (Plate 3.4). As a result of nematode feeding, large galls or "knots" can form throughout the root system of infected plants. Severe infections result in reduced yields on numerous plants.

Plate 3.4 Root-knot nematode

As a control measure against root knot nematode Carbosulfan 6% G was applied at a rate of 20-40 g per plant at the initial stage of nematode incidence.

3.6.3 Root wilt

Root wilt caused by *Rhizoctonia* and *Fusarium* leads to sudden wilting of plants, resulting in loss of plant population. To prevent this disease *Pseudomonas flourescens* was drenched at a rate of 20 g/lit in the root zone of cucumber at fortnightly intervals.

3.6.4 Mites

Red spider mite, *Tetranychus urticae* sucks sap from the foliage of plants, causing a mottled appearance and in severe cases leads to leaf loss and even plant death. Its incidence is severe in polyhouses. Spiromesifen (Oberon 240 SC) was applied at the rate of 1 ml/lit in the polyhouse for managing the incidence of mites.

3.7 Data collection

3.7.1 Biometric observations

For analyzing the growth pattern of the crop, four plants were selected randomly from the net plot area in each treatment and were tagged to record the various observations. The main crop growth parameters like height / length of main vine, number of female flowers and number of leaves per plant were measured at seven days interval from the day of transplanting.

3.7.1.1 Height / length of the main vine

The average height of the randomly selected plants grown under each treatment was taken. The measurement was taken from the ground surface to the vine tip for the selected plants at seven days interval.

3.7.1.2 Dry root mass

After the crop period the roots were collected from selected plants under each treatment. Then these roots were dried at 65°C for 4 hours after hand sieving and weight was noted.

3.7.2 Yield (kg/ha)

Harvesting of the crops was done treatment wise after attaining maturity. After the first harvest, other harvests were done at an interval of minimum 3 days. The first yield was taken two month after transplanting. The total of 14 harvests for irrigation trial and 16 harvests for fertigation trial gave the total yield. Fruit weight in each treatment was taken. Plate 3.5 shows the harvested cucumber.

Plate 3.5 Harvested salad cucumber

3.7.2.1 Fruit characteristics

The fruit characteristics such as number of fruits, fruit diameter and fruit length were observed. And the effect of different treatments on these parameters was studied.

3.7.3 Quality analysis

The quality of the salad cucumber was analyzed in terms of texture and colour. The effect of different levels of irrigation and fertigation on the quality of salad cucumber was observed in terms of texture and colour.

3.7.3.1 Texture analysis

Textural properties of the salad cucumber samples were determined using food texture analyzer (stable micro systems, UK; Plate 3.6). The instrument had a micro processor regulated texture analysis system interfaced to a personal computer. The instrument consists of two separate modules; the test-bed and the control console (keyboard). Both are linked by a cable which route low voltage signal and power through it. The texture analyzer measures force, distance and time and hence provide a three-dimensional product analysis. Forces may be measured to achieve set distances and distances may be measured to achieve set forces.

The sample was kept on the flat platform of the instrument. The samples were compressed using a cylindrical probe (dia 5 mm) under measure force in compression mode with a test speed of 10 mm/sec during which various textural parameters were determined. From the force deformation curve, the firmness or hardness (peak force), and toughness (area under the curve) were determined.

Plate 3.6 Textural Analyser

3.7.3.2 Colour

Hunter Lab colourimeter (Mini Scan XE Plus) was used for the colour measurement involved in the study (Plate 3.7). It works on the principle of collecting the light and measures energy from the sample reflected across the entire visible spectrum. The meter uses filters and mathematical models which rely on “standard observer curves” that defines the amount of green, red and blue primary lights required to match a series of colours across the visible spectrum and the mathematical model used is Hunter model. It provides reading in terms of ‘L’, ‘a’ and ‘b’. The ‘L’ coordinate measures the value or luminance of a colour and ranges from black at 0 to white at 100. The ‘a’ coordinate measures red when positive and green when negative and ‘b’ measures yellow when positive and blue when negative.

Plate 3.7 Hunter Lab colourimeter

3.7.4 Determination of Irrigation water use efficiency

The fruit yield obtained for each treatment was divided by the quantity of water used consumptively for the respective treatments by this method. Water use efficiency was worked out and expressed in kg/ha and the total water utilized in mm.

$$\text{IWUE} = \frac{\text{Yield (kg/ha)}}{\text{Total amount of water applied (mm)}}$$

3.7.5 Determination of Fertilizer use efficiency

Estimation of fertilizer use efficiency includes calculation of nitrogen use efficiency, phosphorus use efficiency and potassium use efficiency. These fertilizer efficiencies are calculated using following equations.

$$\text{NUE} = \frac{\text{Yield (kg/ha)}}{\text{Total quantity of nitrogen applied (kg/ha)}} \times 100$$

$$\text{PUE} = \frac{\text{Yield (kg/ha)}}{\text{Total quantity of phosphorus applied (kg/ha)}} \times 100$$

$$\text{KUE} = \frac{\text{Yield (kg/ha)}}{\text{Total quantity of potassium applied (kg/ha)}} \times 100$$

3.8 Statistical analysis

Statistical analysis was carried out to study the effect of irrigation and fertigation treatments on crop growth parameters, yield and fruit qualities. SPSS 16.0 software was used to analyze data. Analysis of variance (ANOVA) was performed using the General linear model (GLM) procedure from SPSS software. Where possible, treatments means were separated using a Tukey post-hoc test and differences were considered significant at the 0.05 level.

RESULTS AND DISCUSSION

CHAPTER 4

RESULTS AND DISCUSSION

Results obtained from the experiment "Effect of microclimate on the performance of salad cucumber under naturally ventilated polyhouse" are presented and discussed in this chapter after analyzing the observations taken during the course of work.

4.1 Evaluation of soil physical properties

The soil physical properties such as bulk density, field capacity, permanent wilting point and saturated permeability were studied. The various characteristics of the soil used for determining the water requirement of the crop was tabulated.

Table 4.1 Physical properties of soil

<table>
<tr><th>Sl. No</th><th colspan="2">Soil property</th><th>Values</th></tr>
<tr><td>1</td><td colspan="2">Bulk density</td><td>1.75 g/cc</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">Texture</td><td>Sand</td><td>74.00 %</td></tr>
<tr><td>Silt</td><td>20.00 %</td></tr>
<tr><td>Clay</td><td>06.00 %</td></tr>
<tr><td>3</td><td colspan="2">Field capacity</td><td>16.54%</td></tr>
<tr><td>4</td><td colspan="2">Permanent wilting point</td><td>02.12%</td></tr>
</table>

4.2 Crop water requirement

The details of climate, soil and the crop which is related to the study were fed to the CROPWAT model to estimate the crop water requirement. The crop data, soil data and crop water requirement of the crop are shown in the following tables and the corresponding graphs are plotted.

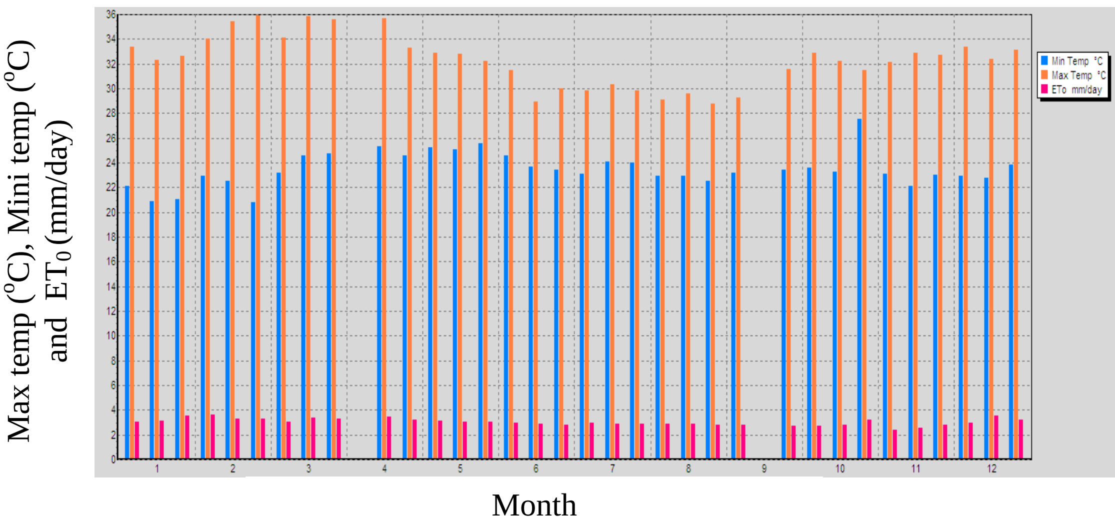


Fig. 4.1 Variation of Minimum Temperature (°C), Maximum Temperature (◦C) and ET_0 (mm/day) with respect to month

Fig. 4.1 shows the minimum temperature (°C), maximum temperature (°C) and ET_0 variation during the year. The maximum temperature was recorded during the month February and minimum temperature was recorded during the month June. Figure revealed that ET_0 value is varying with temperature and maximum ET_0 recorded during the month with maximum temperature.

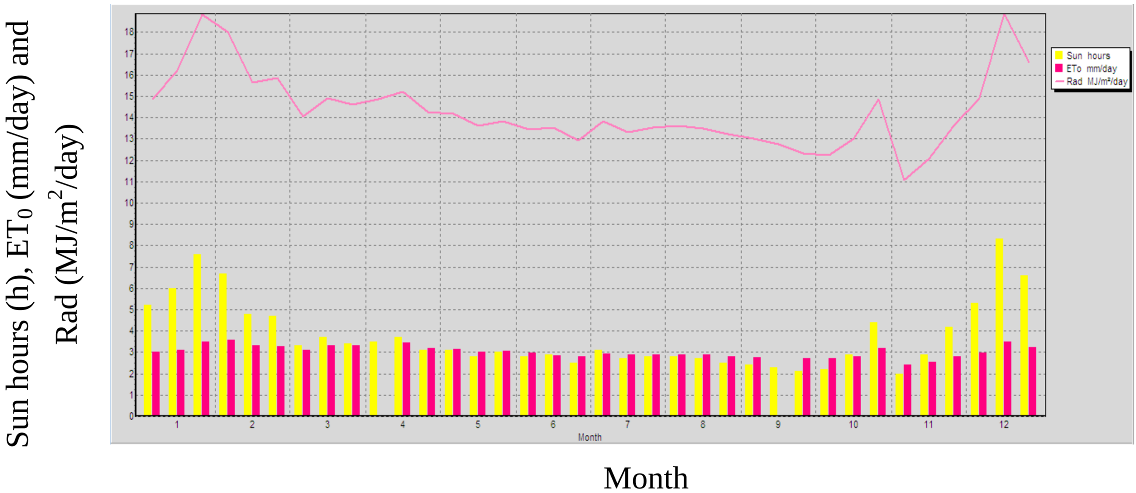


Fig. 4.2 Variation of Sun shine duration (h), ET_o (mm/day) and Radiation (MJ/m^2/day) with respect to month

The Fig. 4.2 presents variation of sun shine duration (h), ET_0 (mm/day) and radiation (MJ/m^2/day) during the year 2012. The maximum sunshine hour was recorded during the month December and maximum ET_0 was recorded during the month February. The maximum radiation was recorded during the month January. From this Fig.4.2 it is evident that sunshine and radiation influences the reference evapotranspiration.

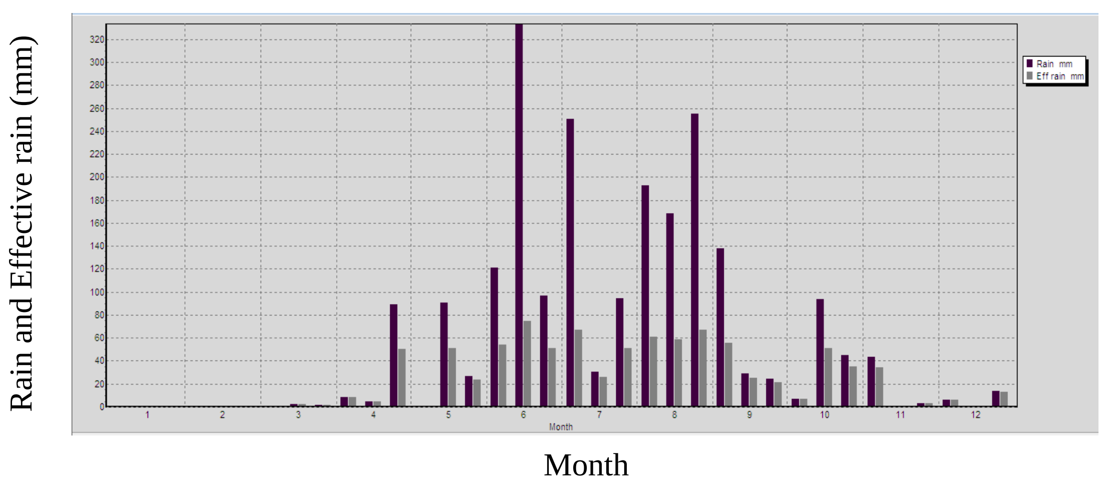


Fig. 4.3 Rain (mm) and Effective rain (mm) variation during the month

Fig. 4.3 shows the variation of rainfall (mm) and effective rainfall (mm) during the year. The maximum rain and effective rain were recorded during the month June. And the results revealed that only 35% of the rain was effective.

4.2.1 Model input and output parameters for selected crops

The various climate, crop and soil data related to the study area are listed in the Tables 4.2, 4.3, 4.4 and 4.5 respectively.

Table 4.2 Climatic data

Country : India Year : 2012						Station : Thrissur	
Month	**Min Temp**	**Max Temp**	**Humidity**	**Wind**	**Sun**	**Rad**	**ETo**
	°C	°C	%	km/day	Hours	$MJ/m^2/day$	mm/day
Jan 2012	21.3	32.8	75	6	9.5	21.1	3.93
Feb 2012	22.2	35.1	74	5	9.1	22.0	4.33
Mar 2012	24.2	35.2	86	3	7.6	20.8	4.49
Apr 2012	24.8	34.7	89	3	6.6	19.8	4.34
May 2012	25.3	32.6	88	3	6.0	18.4	3.97
Jun 2012	23.9	30.1	94	3	2.8	13.4	2.90
July 2012	23.7	30.0	95	3	3.2	14.1	3.01
Aug 2012	23.0	29.2	95	3	2.9	13.8	2.94
Sep 2012	23.3	30.4	94	2	4.6	16.2	3.41
Oct 2012	23.5	32.2	90	3	6.2	18.2	3.80
Nov 2012	22.7	32.6	85	3	7.5	18.5	3.67
Dec 2012	23.2	33.0	73	7	8.1	18.7	3.57
Average	23.4	32.3	87	4	6.2	17.9	3.70

Table 4.3 Crop data

Crop name: Salad Cucumber			**Planting date**: 28/05		
Stages (days)	Initial	Develop	Mid	Late	Total
Length (days)	20	30	43	20	113
K_c values	0.6		1	0.75	
Rooting depth (m)	0.5			0.8	
Critical depletion (fraction)	0.5		0.5	0.5	0.5
Yield response f.	1.1	1.1	1.1	1.1	1.1
Crop height (m)			0.3		

Table 4.4 Soil data

Soil name : sandy loam	
Total available soil moisture (FC - WP)	37 mm/m
Maximum rain infiltration rate	95 mm/day
Maximum rooting depth	150 cm
Initial soil moisture depletion (% TAM)	50%
Initial available soil moisture	18.5 mm/m

Table 4.5 Estimation of crop water requirement

ET_0 station : Thrissur Rain station : Thrissur						Crop : Salad cucumber Planting date : 28/05	
Month	**Decade**	**Stage**	**K_c**	**ET_c**	**ET_c**	**Eff. rain**	**Irr. Req.**
			coeff	mm/day	mm/dec	mm/dec	mm/dec
May	3	Init	0.60	2.04	10.2	19.7	0.0
Jun	1	Init	0.60	2.52	25.2	0.0	25.2
Jun	2	Deve	0.61	2.58	25.8	44.5	0.0
Jun	3	Deve	0.68	2.64	26.4	38.3	0.0
Jul	1	Deve	0.76	2.44	24.4	24.4	0.0
Jul	2	Mid	0.81	2.03	20.3	56.4	0.0
Jul	3	Mid	0.82	2.45	24.5	75.7	0.0
Aug	1	Mid	0.82	2.48	24.8	52.7	0.0
Aug	2	Mid	0.82	2.58	25.8	57.3	0.0
Aug	3	Late	0.81	2.55	25.5	51.6	0.0
Sep	1	Late	0.71	2.08	20.8	17.6	3.2
Sep	2	Late	0.61	1.84	11.0	38.7	0.0
					264.6	476.9	28.4

Table 4.5 presents the output of CWR calculations for salad cucumber. Total irrigation requirement is computed by adding irrigation requirement of each stage of the salad cucumber and the value obtained was 28.4 mm for ten days.

4.3 Microclimate inside the polyhouse

The climatic parameters viz. maximum and minimum temperature, relative humidity, average air temperature, wet and dry bulb temperatures were observed from the polyhouse. Based on the climatic data, variation of climatic parameters inside the naturally ventilated polyhouse during the crop period was determined (Appendix IV).

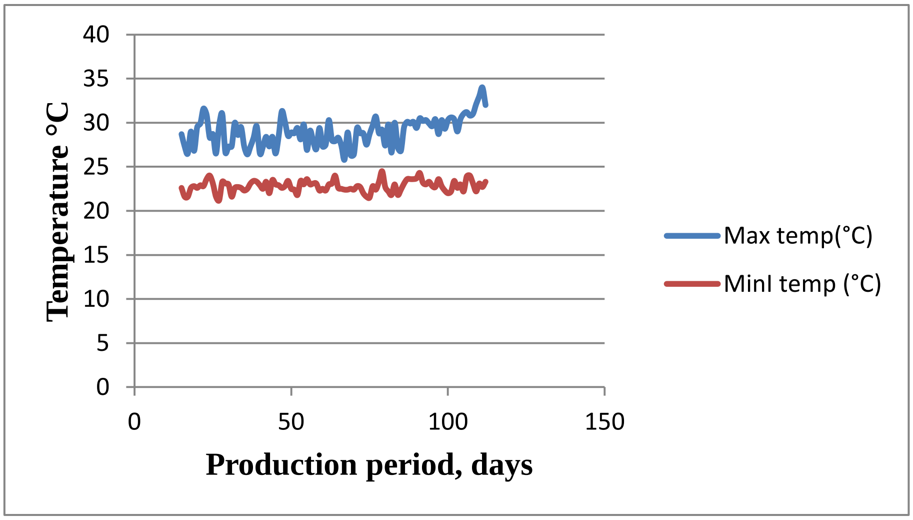


Fig. 4.4 Maximum and minimum temperature variation inside the polyhouse during the crop period

Fig. 4.4 shows variation of maximum and minimum temperature inside the polyhouse during crop period. The maximum temperature ranges from 25.8 to 34^{o}C and the maximum value recorded during the last days of production period of crop. The minimum temperature inside the naturally ventilated poluhouse ranges from 21.6 to 24.5^{o}C. The least value of minimum temperature recorded is 21.6^{o}C during the early stages of crop development. The atmospheric temperature inside the polyhouse is slightly higher than outside. The rise in atmospheric temperature inside the polyhouse ranges from 0.5°C to 3.0°C. Similar readings were reported by Farguesa et al. (2005). It indicates that there is considerable increase in the inside temperature of the polyhouse. The temperature shows lower value at high rainfall and a high temperature is observed at minimum rainfall. Hence rainfall is a major factor affecting the microclimate of the crop. Rainfall during the crop duration has a major role in the soil and atmospheric temperature, hence crop water requirement affects the rate of evaporation depends on the temperature. At high rainfall the inside and outside temperature shows almost the same value. The temperature inside the polyhouse is higher than outside temperature on days without rainfall.

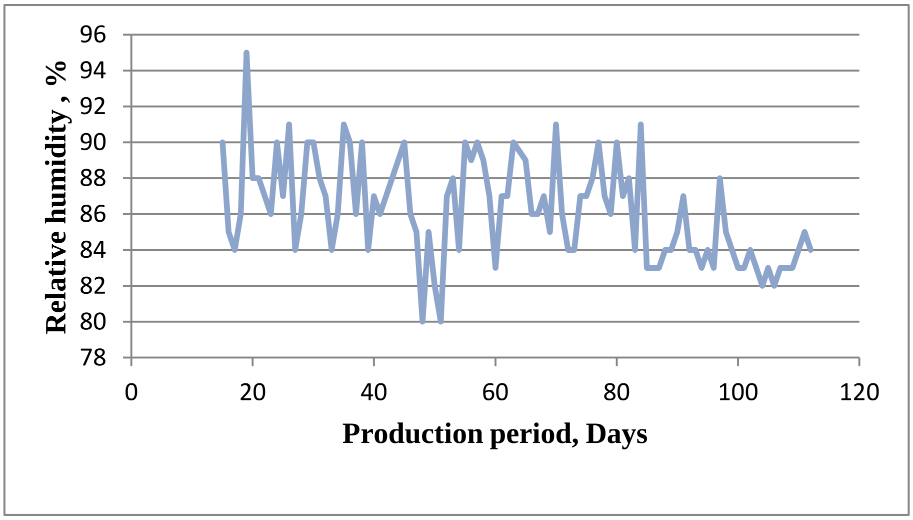


Fig. 4.5 Relative humidity inside the polyhouse during the crop period

Fig. 4.5 shows variation of relative humidity during the crop period. From the figure it is seen that the relative humidity was higher during the initial stage of crop development. Figure revealed that the maximum humidity recorded was 95% and the minimum humidity recorded was 80%.

4.4 Crop growth parameters

Crop growth parameters such as length of wine, number of leaves, number of flowers and dry root mass for each treatment were observed during different stages of crop growth. The influence of irrigation and fertigation on these crop growth parameters are discussed below.

4.4.1 Length of main wine

The data on length of main wine at different stages of crop growth after planting as influenced by different irrigation and fertigation treatments are presented in the Tables 4.6 and 4.7.

Table 4.6 Length of main wine as influenced by different irrigation level

Production periods	Irrigation treatments			
	I_1	I_2	I_3	I_4
15	15.3	15.8	15.3	15.3
22	62.3	63.5	64.3	65.3
29	96.7	108.0	105.0	118.0
36	135.0	138.0	143.0	145.0
43	170.0	185.0	200.0	205.0
50	270.0	270.0	273.0	273.0
Non significant				

Table 4.7 Length of main wine as influenced by different fertigation level

Production periods	Fertigation treatments			
	F_1	F_2	F_3	F_4
15	15.4	14.7	15.0	14.9
22	60.0	61.4	64.5	60.9
29	95.4	98.2	100.0	96.7
36	140.0	143.0	150.0	141.0
43	180.0	192.0	186.0	190.0
50	276.0	284.0	285.0	281.0
Non significant				

Data on length of main wine were recorded at seven days interval from the day of transplanting. As shown in Tables 4.6 and 4.7, it is seen that average lengths of wine were increased with crop growth and reached a maximum value of 273 cm in the irrigation trial and 285 cm in the fertigation trial. Wine lengths changed minimally at the final stage because irrigation did not affect wine elongation any longer. The statistical results indicate that the length of main wine of cucumber plant at different growth stages did not differ significantly with respect to irrigation and fertigation level.

4.4.2 Number of leaves

The data on number of leaves as influenced by different irrigation and fertigation treatments are presented in the Tables 4.8 and 4.9.

Table 4.8 Number of leaves as influenced by different irrigation level

Production periods	Irrigation treatments			
	I_1	I_2	I_3	I_4
15	4	4	4	4
22	8	7	6	8
29	13	14	13	15
36	21	23	23	24
43	31	33	32	33
50	38	55	47	50
Non significant				

Table 4.9 Number of leaves as influenced by different fertigation level

Production periods	Fertigation treatments			
	F_1	F_2	F_3	F_4
15	5	4	6	5
22	10	11	12	10
29	15	11	20	15
36	30	32	34	32
43	40	34	39	25
Non significant				

Tables 4.8 and 4.9 shows that the number of leaves were increased with crop growth and reached a maximum value of 55 at the maturity stage. From the tables it is seen that number of leaves did not differ significantly with respect to irrigation or

fertigation levels at different stages of plant growth. Analysis of variance shows that there is no significant difference in fruit length among treatments.

4.4.3 Number of flowers

The data on number of flowers at seven days interval after planting as influenced by different irrigation and fertigation treatments are presented in the Tables 4.10 and 4.11.

Table 4.10 Number of flowers as influenced by different irrigation level

Production periods	Irrigation treatments			
	I_1	I_2	I_3	I_4
36	2	2	3	2
43	9	10	12	10
50	13	14	17	15
66	16	18	19	18
Non significant				

Table 4.11 Number of flowers as influenced by different fertigation level

Production periods	Irrigation treatments			
	F_1	F_2	F_3	F_4
35	3	2	1	3
42	12	14	13	13
49	16	15	17	16
65	16	17	18	17
Non significant				

The maximum number of flowers observed was 19 for the irrigation trial and 18 for fertigation trial. The statistical results indicate that the number of flowers at different growth stages did not differ significantly with respect to irrigation and fertigation levels.

The crop growth parameters did not differ significantly either due to the levels of irrigation or fertigation. The results indicate that the different levels of irrigation and fertigation did not influence considerably the length of wine, no of leaves, number of female flowers or dry root mass after transplanting. Similar results were reported by Khan *et al.* (2013).

4.5 Effect of irrigation and fertigation treatments on fruit yield of salad cucumber

Crop yield is always an important effective and economic index consideration in the crop development. The aim of planting any crop is to get the highest yield of good quality fruits. Yield of cucumber with respect to different irrigation and fertigation levels is shown in Appendix V and VI.

Table 4.12 and 4.13 shows that irrigation and fertigation amount significantly affected the yield of cucumber.

Table 4.12 Effect of irrigation treatments on yield of salad cucumber

Treatment	Average yield per plant (kg)	Yield (t/ha)	Increase in yield (%)	Water saving (%)
I_1	4.29	29.33[b]		50
I_2	9.02	61.70[a]	52	35
I_3	5.97	40.81[b]	39	20
I_4	5.53	37.85[b]	29	05

The irrigation trial was carried out with four levels of irrigation such as 50, 65, 80 and 95% of daily irrigation requirement. Under the same fertilizer amount, the highest yield was obtained in I_2, followed by I_3 and I_4, the lowest yield was obtained in I_1 due to plants suffering water deficit by limited application of water. Excessive irrigation results in reduction of yield. Because up to certain limit yield increases with increase in quantity of water but afterwards yield reduces (Mathieu, 2007). This is supported by results observed by Simsek *et al*. (2005) which suggests that cucumber plants are sensitive to excessive watering and yield losses can occur. I_2 had the highest yield of 61.71 t ha^{-1} and I_1 had the lowest yield of 29.33 t ha^{-1}. Compared to I_2 other treatments I_3, I_4 and I_1 decreased salad cucumber yield by 34, 39 and 52%.

The irrigation trial with four different levels of water requirement showed that drip irrigation with 1.3 lit/day or 65% of the daily irrigation requirement can give maximum production of salad cucumber in a naturally ventilated polyhouse.

Table 4.13 Effect of fertigation treatments on yield of salad cucumber

Treatment	Average yield per plant (kg)	Yield (t/ha)	Increase in yield (%)
F_1	2.31	15.80^{b}	
F_2	2.66	17.27^{b}	09
F_3	2.92	19.96^{a}	26
F_4	2.53	18.19^{b}	15

In the fertigation trial for the treatment F_3, the yield increased significantly compared to F_1, F_2 and F_4 under the same rate of irrigation. The rate of irrigation in this trial was I_2 which recorded highest yield in the irrigation trial. Compared to F_3 other treatments F_1, F_2 and F_4 decreased yield by 20, 13 and 8%. Because excess fertilizer application results reduction in yield (Cabello, 2009)

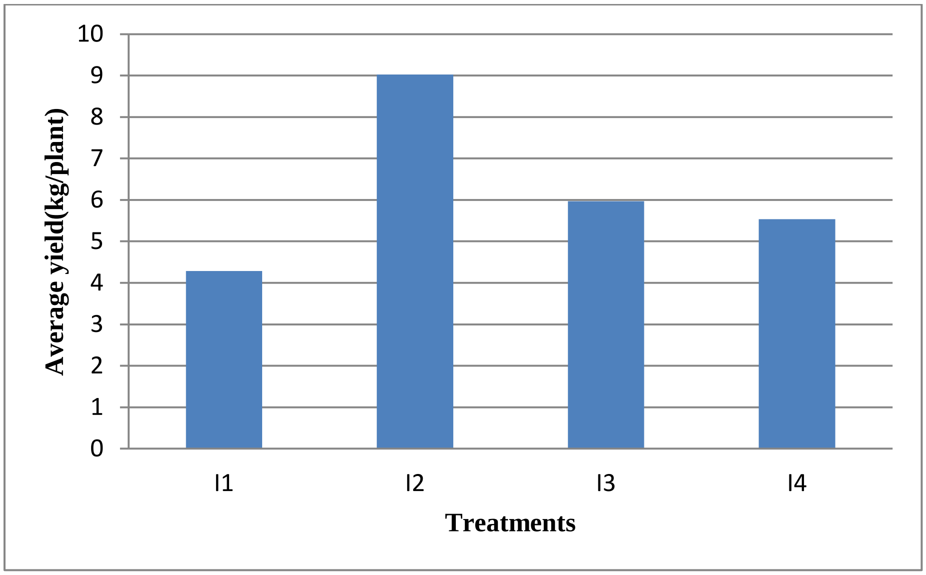


Fig. 4.6 Average yield per plant (kg) as influenced by different irrigation level

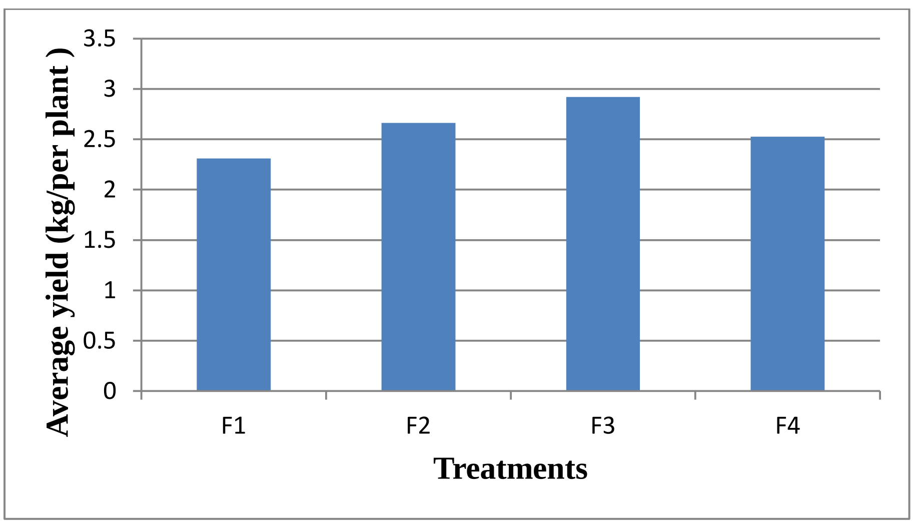


Fig. 4.7 Average yield per plant (kg) as influenced by different fertigation level

Fig. 4.6 and 4.7 shows the significance of irrigation and fertigation level on average yield per plant. Fig. 4.6 shows that more average yield per plant is obtained for the irrigation treatment I_2 (65% of irrigation treatment). Fig. 4.7 shows that more average yield per plant is obtained with increasing amount of fertigation except treatment F_4.

4.6 Effect of treatments on fruit characteristics

The various fruit characteristics i.e. the number of fruits, average length and diameter of the fruits obtained in different treatments are given in the Tables 4.14 and 4.15.

Table 4.14 Fruit characteristics for various irrigation treatments

Treatment	Number of fruits	Diameter of fruit (cm)	Length of fruit (cm)
I_1	320^b	4.40^a	15.63^a
I_2	608^a	4.35^a	15.50^a
I_3	425^b	4.13^a	15.65^a
I_4	383^b	4.40^a	15.97^a

Table 4.15 Fruit characteristics for various fertigation treatments

Treatment	Number of fruits	Diameter of fruit (cm)	Length of fruit (cm)
F_1	96^b	4.15^a	15.73^a
F_2	185^b	4.37^a	15.90^a
F_3	226^a	4.28^a	15.73^a
F_4	205^b	4.40^a	15.58^a

4.6.1 Fruit number

The number of fruits per plant is an important factor in the yield of salad cucumber. Variation in number of fruit with different treatments of irrigation is shown in the Table 4.14. From the observations, treatment I_1 shows the least no of fruits and I_2 shows the maximum number of fruits.

The detailed comparison among the treatments shows that the treatment with 50% of irrigation requirement (I_1) gives the least number of fruits. Fewer number of fruits was one of the predominant reasons for least yield in I_1 (Drip irrigation with 50% of irrigation requirement). The number of fruits increased with increase in quantity of water but after a limit it decreases. Hence it is evident that treatment I_2 gives more number of fruits with quantity of irrigation water. But after a certain limit, further increase in water will decrease the yield as in treatment I_3 and I_4. Thus it is clear that 65% of irrigation requirement is significantly superior over other treatments for producing maximum number of fruits in salad cucumber grown in naturally ventilated polyhouse.

Variation of fruit numbers with different levels of fertigation are shown in Table 4.15. The observation shows that the treatment which applied 80% of the fertilizer requirement gave the least number of fruits. The treatment which applied 100% of fertilizer requirement gave significantly higher number of fruits. The result shows that the most suitable fertilizer amount for the optimum production is 100% of the fertilizer requirement.

4.6.2 Fruit length

Fruit length is one of the external quality parameter which influences market value. Average fruit lengths obtained from various treatments are shown in table 4.14 and 4.15. Average fruit length observed was approximately 15 cm. Analysis of variance shows no significant difference in fruit length among treatments.

4.6.3 Fruit diameter

The diameter of fruits obtained in various treatments is shown in Table 4.14 and 4.15. Average fruit diameter observed was approximately 4 cm. Results of the analysis show that there is no significant difference in fruit diameter among the treatments. All the fruits have almost same diameter. Hence the irrigation and fertigation treatments have no significant effect on fruit diameter

4.7 Irrigation water use efficiency

Table 4.16 shows the water use efficiency for different irrigation treatments.

Table 4.16 Water use efficiency of various irrigation treatments

Treatments	Average yield (kg/ha)	Water used (mm)	Water use efficiency (kg/ha mm)
I_1	29331^b	132	222
I_2	61705^a	172	358
I_3	40813^b	212	193
I_4	37852^b	252	150

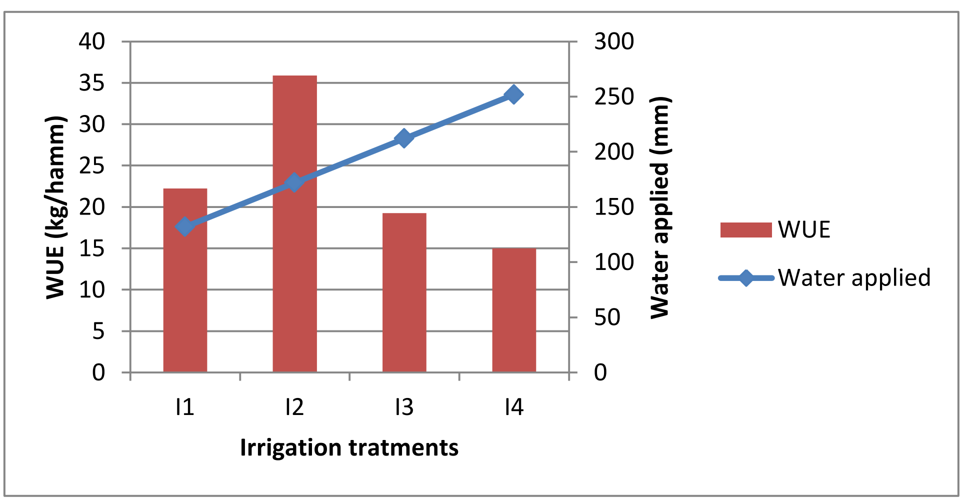


Fig. 4.8 IWUE influenced by different irrigation level

From the figure it is seen that irrigation rate significantly affected irrigation water use efficiency (IWUE). IWUE ranged from 150 kg/ha mm in I_4 to 359 kg/ha mm in I_2 (Table 4.16). Under the same amount of fertigation, IWUE increased with increased irrigation. But after a certain limit, further increase in water will decrease the IWUE as in treatment I_3 and I_4 due to decreased yield.

4.8 Fertilizer use efficiency

The fertilizer use efficiency with respect to various fertigation treatments are shown in Table 4.17 and Fig. 4.9.

Table 4.17 Fertilizer use efficiency of various fertigation treatments

Treatment	Fruit yield (kg/ha)	FUE (%)		
		Nitrogen use efficiency	Phosphorous use efficiency	Potassium use efficiency
F_1	15800[b]	112	158	65
F_2	17273[ab]	115	162	67
F_3	19960[a]	114	159	66
F_4	18197[a]	89	125	52

Nitrogen, phosphorus and potassium use efficiency were estimated to get an idea as to how effectively the nitrogen, phosphorus and potassium were used by the crop under different treatments during the crop experiment. The data on Nitrogen, phosphorus and potassium use efficiency under different levels of fertilization are shown in Fig. 4.9. The highest NUE of 115 kg of produce / kg of N was recorded in the treatment F_2. Similar findings were observed by Vijayakumar *et al.* (2007). The lowest NUE of 112 kg of produce / kg of N was observed for the treatment F_4.

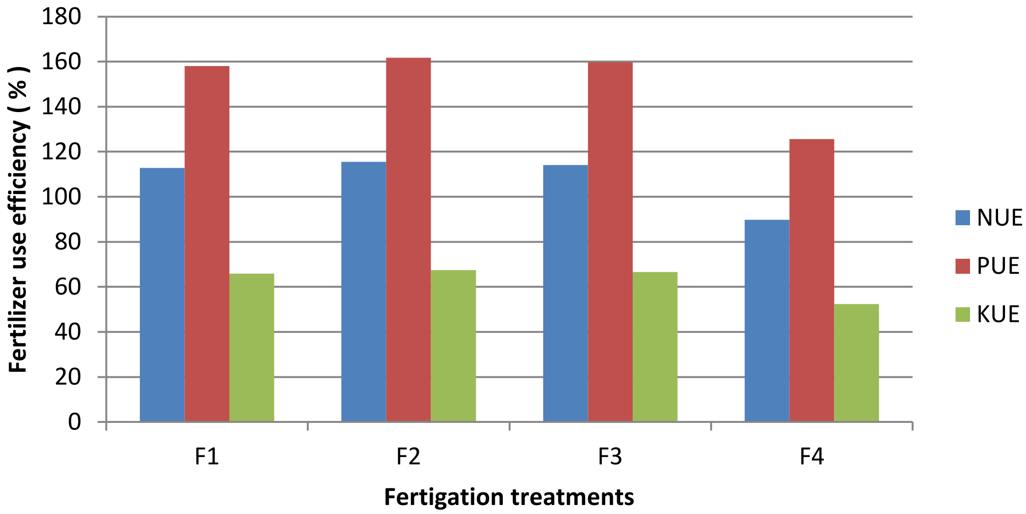


Fig. 4.9 FUE with respect to various fertigation treatments

The similar trend was observed in PUE. The maximum PUE of 162 kg of produce / kg of P was observed in the case of the treatment F_2. The lowest PUE of 125 kg of produce / kg of P was observed for the treatment F_4.

The highest KUE was recorded in the treatment F_2 and it was 67 kg of produce / kg of K. All fertilizer use efficiencies were increased with increase in level of fertilization up to a certain limit and after that it decreases. From the figure it is seen that the potassium use efficiency is less for all the treatments ie; there is no effect of potassium level on yield. This may be due to the reason that the level of potassium is more as per adhoc recommendation. Hence by reducing the amount potassium, the KUE can improve.

4.9 Effect of microclimate on the yield of salad cucumber

Fig. 4.10 and 4.11 shows the relation between yield and microclimate. The yield is represented in terms of number of fruits and microclimate in terms of maximum and minimum temperatures and relative humidity.

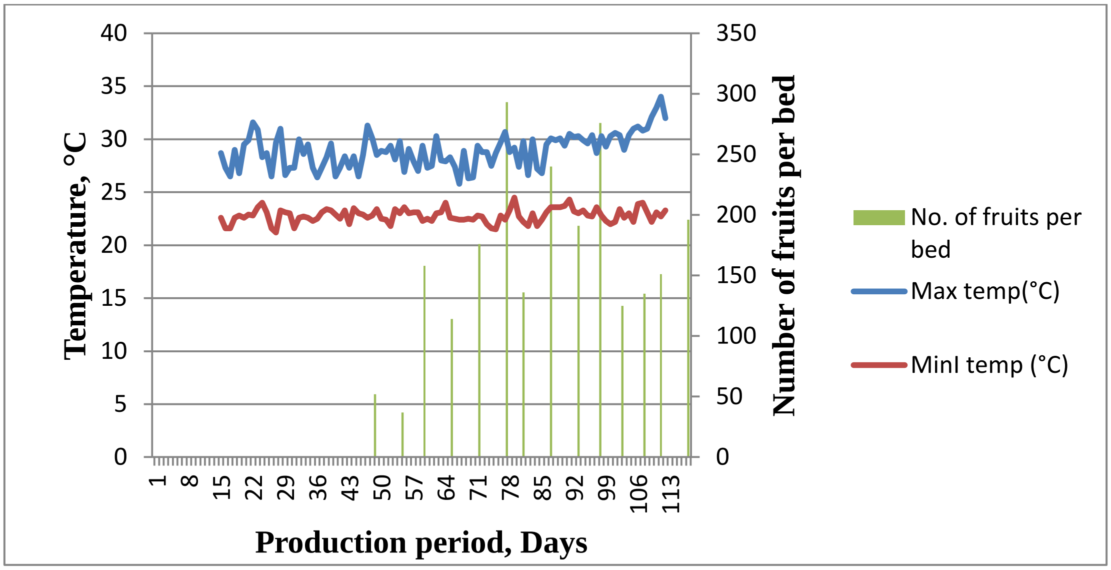


Fig. 4.10 Variation of yield with respect to maximum and minimum temperature

The Fig. 4.10 reveals that higher production was observed during the period of 70 to 100th day of production period. During these days maximum temperature was less compared to other days. From the study it was observed that, the most suitable temperature range for the optimum production is 22 to 32 °C.

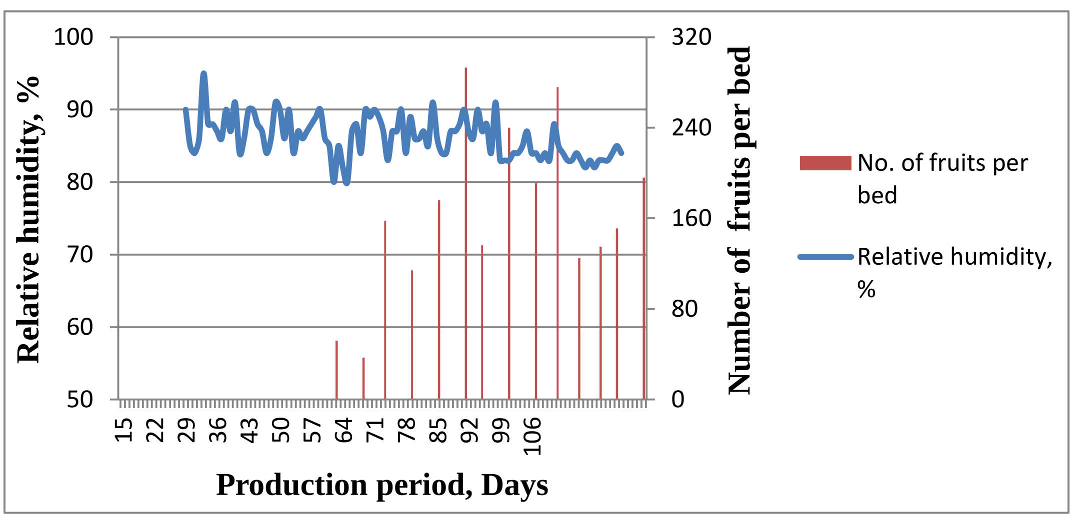


Fig. 4.11 Variation of yield with respect to relative humidity

From the Fig. 4.11 it is seen that the relative humidity is decreased during the crop period. There is no change in yield with respect to relative humidity. The variation of relative humidity inside the polyhouse was ranged from 80 to 95%. Hence the most suitable humidity for optimum production is taken as 80 to 95%.

4.10 Quality analysis

The effect of irrigation and fertigation on the quality of salad cucumber in terms of colour and texture was studied. The texture and hunter colourimeter readings are presented in the following table.

Table 4.18 Effect of irrigation and fertigation treatments on texture and colour of samples

Treatment	Colour			Texture	
	L	a	B	Firmness (kg)	Toughness (kg sec)
I_1	28.9 [a]	-7.38[a]	15.68[a]	1.14[a]	1.92[a]
I_2	28.4 [a]	-7.88[a]	15.21[a]	1.11[a]	1.92[a]
I_3	29.15 [a]	-8.16[a]	15.47[a]	1.14[a]	1.90[a]
I_4	26.99 [a]	-8.16[a]	15.71[a]	1.14[a]	1.94[a]
F_1	27.07 [a]	-8.06[a]	14.53[a]	1.10[a]	1.93[a]
F_2	27.57 [a]	-7.60[a]	14.81[a]	1.13[a]	1.96[a]
F_3	27.65 [a]	-7.74[a]	14.61[a]	1.20[a]	1.95[a]
F_4	26.45 [a]	-7.60[a]	14.74[a]	1.20[a]	1.91[a]

4.10.1 Colour

The Hunter colour parameters ('L', 'a' and 'b') of salad cucumber fruit samples due to the effect of different irrigation and fertigation treatments are shown in Fig.4.12 and 4.13.

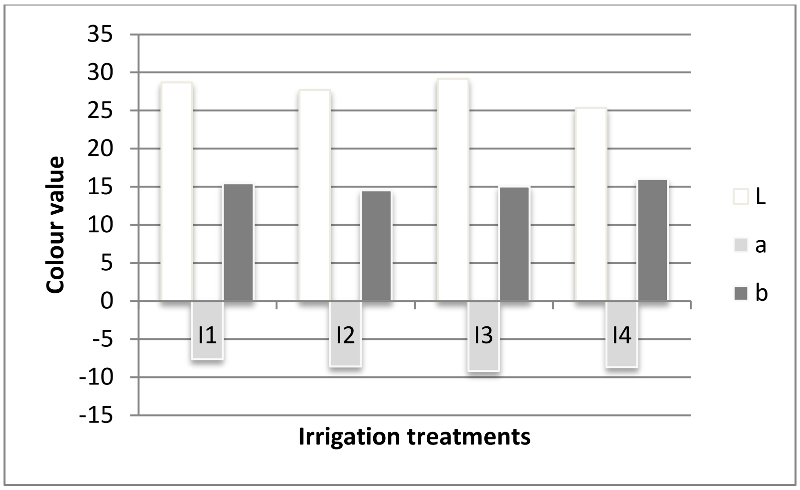


Fig. 4.12 Effect of irrigation treatments on colour of salad cucumber

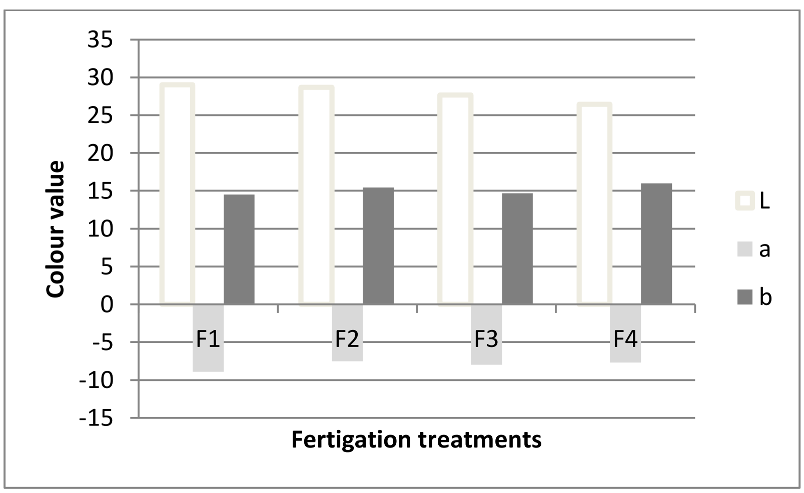


Fig. 4.13 Effect of fertigation treatments on colour of salad cucumber

Fig. 4.12 and 4.13 shows that irrigation and fertigation treatments have no significance in the colour of fruit. Fruit colour is not varying with treatments. The 'L' value was in a range of 25.3 to 28.7 represents the dark colour and 'a' value shows the negative reading represents the green colour. And the positive value of 'b' represents the yellow colour. These values especially 'a' value, gave the impression that the colour of the salad cucumber fruit would tend towards green colour.

4.10.2 Texture

The texture of salad cucumber slices were subjected to compression tests on the texture analyser and the results are shown in Fig. 4.14 and 4.15. The texture was defined by two general terms namely, firmness and toughness. The firmness (Kg) and toughness (Kg.sec) values for the salad cucumber was 1.09 ± 0.09 and 1.91 ± 0.19 respectively. The Fig. 4.14 and 4.15 presented that the firmness and toughness of salad cucumber is not varying with respect to treatment.

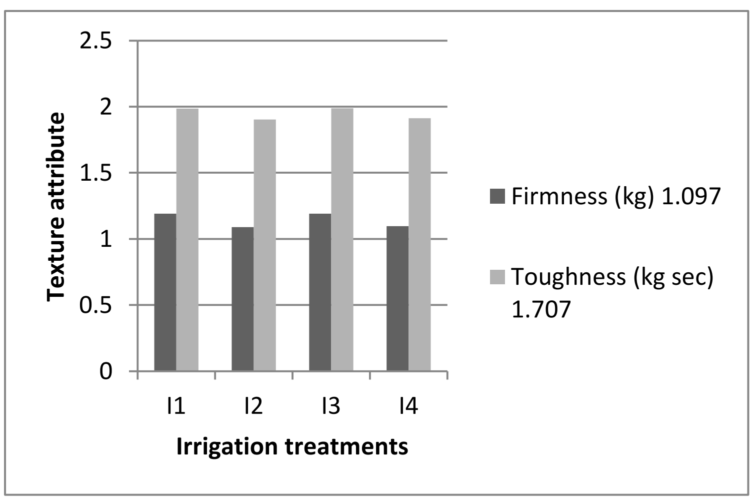


Fig. 4.14 Effect of irrigation treatments on texture of salad cucumber

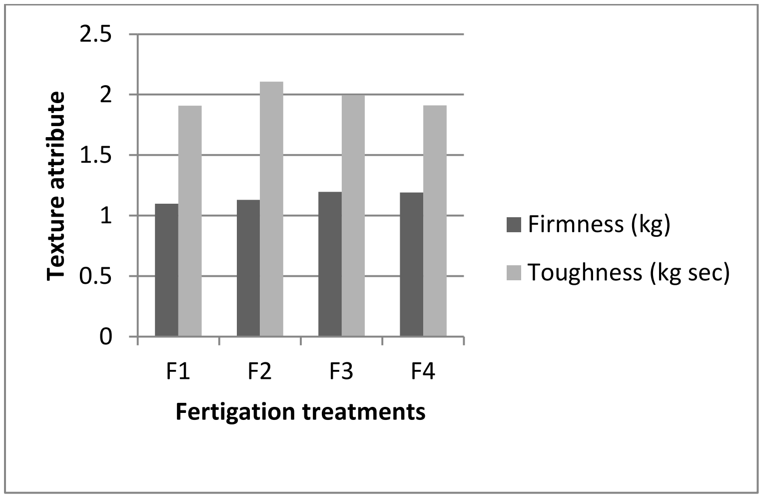


Fig. 4.15 Effect of fertigation treatments on texture of salad cucumber

The analysis of variance (ANOVA) associated with Tukey post-hoc test was implemented to find the most suitable irrigation and fertigation level in terms of fruit texture and colour. It was observed that the texture and colour were not significantly influenced by the irrigation and fertigation treatments.

SUMMARY AND CONCLUSION

CHAPTER 5

SUMMARY AND CONCLUSION

Polyhouse cultivation gives higher yield, higher productivity, better quality produce and production throughout the year. However, excessive irrigation and fertilization are commonly practiced in the polyhouse production systems. Consequently, redundant water and fertilizers affect environmental protection by nutrient accumulation and soil salinization. The present study was conducted at the experimental plot of PFDC farm, KCAET, Tavanur to determine the effect of microclimate on fruit yield and to standardize irrigation and fertigation for salad cucumber grown in naturally ventilated polyhouse.

The crop water requirement of the salad cucumber was determined using the irrigation management and planning model CROPWAT. The details of climate, soil and the crop were fed to the CROPWAT model to estimate the crop water requirement. The daily crop water requirement of salad cucumber obtained was 2.84 mm.

The variation of climatic parameters such as maximum and minimum temperature, sunshine hours and rain outside the polyhouse during the crop period was studied. The maximum and minimum temperatures were recorded during the month February and June respectively. The maximum sunshine hour was recorded during the month December and the maximum reference evapotranspiration (ET_0) was recorded during the month February. The maximum radiation was recorded during the month January. The study revealed that the maximum and minimum temperature, sunshine hours and radiation influences evapotranspiration. The maximum ET_0 recorded during the month with maximum temperature. The maximum rain and effective rain were recorded during the month June. The study shows that only 35% of the rain was effective.

To study the effect of microclimate on the production of salad cucumber, the climatic parameters during the entire crop period was observed. From the study it is clear that the atmospheric temperature inside the polyhouse is higher than outside. The rise in atmospheric temperature inside the polyhouse ranges from 0.5°C to 3.0°C. During the period of high rainfall, temperature inside the polyhouse is less compared to outside. The rainfall is a major factor affecting the microclimate of the crop. Rainfall during the crop duration has a major role in the soil and air temperature. The crop water requirement depends on the rate of evaporation and thereby temperature. At high rainfall the inside and outside temperature shows almost the same value. On days without rainfall the temperature inside the polyhouse is higher than outside. The maximum and minimum humidity recorded inside the polyhouse was 90 and 80% respectively.

The main pest and disease attack observed in the polyhouse due to the presence of downy mildew, root-knot nematode, rout wilt and mites. It was controlled by the adoption of proper remedial measures.

Crop growth parameters such as length of wine, number of leaves, number of flowers and dry root mass for each treatment were observed during various crop growth stages. The results indicated that the different treatments of irrigation and fertigation did not influence length of wine, number of leaves, number of female flowers and dry root mass after transplanting.

The yield obtained from the irrigation and fertigation treatments were observed. The irrigation trial was carried out with four levels of irrigation such as 50, 65, 80 and 95% of daily irrigation requirement of crop. Under the same fertilizer amount, the highest yield was obtained for the irrigation treatment with 65% (I_2) of daily irrigation requirement, followed by 80 (I_3) and 95% (I_4), the lowest yield was obtained in 50% (I_1) due to plants suffering water deficit by limited application of water. The treatment I_2 had the highest yield of 61.71 t ha^{-1} and I_1 had the lowest yield of 29.33 t ha^{-1}. Compared to I_2, the yield for other treatments I_3, I_4 and I_1 was decreased by 33, 38 and 52%. The study revealed that drip irrigation with 1.3 lit/day or 65% of the daily irrigation requirement can give maximum production of salad cucumber in a naturally ventilated polyhouse.

In the fertigation trial for the treatment with 100% of fertilizer requirement, the yield increased significantly compared to 80, 90 and 110% under the same rate of irrigation. Compared to the treatment with 100% of fertilizer requirement other treatments with 80, 90 and 110% of fertilizer requirement decreased yield by 20, 13 and 8%. From this study it is clear that irrigation and fertigation amount significantly affected the yield of cucumber.

Variation in number of fruits with different treatments of irrigation and fertigation was observed. The detailed comparison among the treatments by multiple comparisons shows that treatment with 50% of irrigation requirement (I_1) gives the least number of fruits. From irrigation trial, it is evident that 65% of irrigation requirement is enough for producing maximum number of fruits in salad cucumber grown in naturally ventilated polyhouse. The result from the fertigation trial shows that the most suitable fertilizer amount for the optimum production is 100% of the adhoc fertilizer recommendation by KAU.

The fruit length and diameter is not varying with respect to variation in irrigation and fertigation. The statistical analysis showed that the fruit diameter and length do not change significantly.

Irrigation rate significantly affected irrigation water use efficiency (IWUE). It ranged from 150 kg/ha mm in I_4 (95% irrigation requirement) to 359 kg/ha mm in I_2 (65% irrigation requirement).

Nitrogen, phosphorus and potassium use efficiency were estimated to get an idea as to how effectively the nitrogen, phosphorus and potassium were used by the crop under different treatments during the field trial. Fertilizer use efficiency increased with increase in level of fertilization up to certain limit and after that it decreases. The maximum NUE, PUE and KUE were reported for the treatment F_2 (90% fertilizer requirement) and minimum for the treatment F_4 (110% fertilizer requirement).

The effect of microclimate on the performance of salad cucumber was studied. More production was observed during the period of 70 to 100th day of production period. During these days maximum temperature was less compared to other days. From the study, the most suitable temperature range for the optimum production was 22 to 32°C and most suitable relative humidity was 80 to 95%.

From the quality analysis, it is clear that the irrigation and fertigation treatments have no significant effect on quality of fruits in terms of colour and texture. The colour and texture do not change significantly with irrigation and fertigation levels.

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APPENDICES

Appendix I
Daily climatic data – January 2012

Date	Temperaure(°C)		Relative Humidity (%)	wind speed (km/hr)	sunshine hours (hrs)	rainfall (mm)
	MAX	MIN				
01/01/12	32.5	22.6	72	4.4	10.0	0.0
02/01/12	32.5	18.8	92	4.0	9.9	0.0
03/01/12	33.6	19.5	91	4.2	10.2	0.0
04/01/12	33.3	21.2	88	4.6	9.8	0.0
05/01/12	33.7	23.1	90	7.2	9.8	0.0
06/01/12	33.4	24.0	76	7.4	9.9	0.0
07/01/12	32.7	22.2	80	7.0	9.3	0.0
08/01/12	33.5	24.0	84	5.6	10.4	0.0
09/01/12	34.0	23.4	81	4.2	9.8	0.0
10/01/12	34.3	22.3	86	3.6	9.6	0.0
11/01/12	33.3	21.3	91	3.0	7.9	0.0
12/01/12	33.5	21.9	86	5.7	10.0	0.0
13/01/12	32.0	22.6	69	9.6	9.7	0.0
14/01/12	32.0	22.8	72	10.3	9.8	0.0
15/01/12	31.0	22.2	54	10.3	9.7	0.0
16/01/12	31.2	20.3	65	7.9	10.3	0.0
17/01/12	31.8	19.9	73	4.5	9.6	0.0
18/01/12	33.8	17.3	64	3.3	9.7	0.0
19/01/12	33.5	19.9	83	2.8	9.6	0.0
20/01/12	30.7	21.0	91	2.6	5.1	0.0
21/01/12	33.4	21.1	67	4.7	9.5	0.0
22/01/12	32.9	21.2	59	7.7	9.8	0.0
23/01/12	32.7	21.4	66	9.6	10.2	0.0
24/01/12	32.0	21.9	68	8.6	10.1	0.0
25/01/12	31.9	19.6	63	7.3	10.2	0.0
26/01/12	32.3	20.3	57	11.1	10.2	0.0
27/01/12	33.0	19.5	73	5.4	9.6	0.0
28/01/12	33.2	21.4	80	6.1	8.6	0.0
29/01/12	33.1	21.0	79	6.7	8.7	0.0
30/01/12	32.6	21.9	66	7.7	7.5	0.0
31/01/12	32.0	21.7	65	8.9	9.5	0.0

APPENDIX II

Grain size distribution of the soil sample

Sl. No.	IS Sieve	Particle Size D (mm)	Mass retained (g)	% retained	Cumulative % retained	Cumulative % finer
1	2 mm	2.00 mm	065.50	19	19	81
2	1 mm	1.00 mm	057.00	17	36	64
3	600 µ	0.60 mm	027.00	08	44	56
4	475 µ	0.48 mm	029.00	08	52	48
5	300 µ	0.30 mm	025.00	07	59	41
6	212 µ	0.21 mm	101.00	30	89	11
7	150 µ	0.15 mm	010.50	03	92	08
8	75 µ	0.07 mm	022.50	07	99	01

Appendix III

Hydrometer Analysis of soil sample

Time	density	Rh	He	D	Wd	N
30sec	1.015	15.0	13.60	0.07600	24.86×10^{-3}	49.73
1min	1.014	13.5	14.60	0.05400	22.40×10^{-3}	44.80
5	1.012	11.5	15.30	0.02480	19.00×10^{-3}	38.00
10	1.009	9.50	15.75	0.01780	15.75×10^{-3}	31.50
20	1.008	8.00	16.40	0.01285	13.26×10^{-3}	26.50
30	1.007	7.00	17.00	0.01068	11.60×10^{-3}	23.20
1hr	1.006	6.00	17.20	0.00759	09.94×10^{-3}	19.80
2	1.006	5.50	17.50	0.00542	09.11×10^{-3}	18.20
4	1.005	5.00	17.70	0.00385	08.29×10^{-3}	16.58
8	1.005	5.00	17.70	0.00273	08.29×10^{-3}	16.58
12	1.005	5.00	17.70	0.00223	08.29×10^{-3}	16.58
24	1.004	4.00	18.10	0.00159	06.63×10^{-3}	13.26

Appendix IV

Daily climatic data during crop period (inside polyhouse)

Date	Maximum temperature	Minimum temperature	Relative humidity
	°C	°C	%
28/05/13	28.7	22.6	96
29/05/14	27.3	21.6	96
30/05/15	26.5	21.6	97
31/05/16	29	22.6	95
01/06/13	26.8	22.8	96
02/06/13	29.5	22.6	98
03/06/13	29.9	22.9	97
04/06/13	31.6	22.8	89
05/06/13	30.9	23.6	92
06/06/13	28.3	24.0	97
07/06/13	28.7	23.1	97
08/06/13	26.5	21.6	96
09/06/13	29.7	21.2	98
10/06/13	31.0	23.3	98
11/06/13	26.6	23.1	96
12/06/13	27.3	23.0	98
13/06/13	27.3	21.6	96
14/06/13	30.0	22.6	98
15/06/13	28.6	22.7	96
16/06/13	29.5	22.6	98
17/06/13	27.3	22.3	96
18/06/13	26.4	22.5	98
19/06/13	27.3	23.1	98
20/06/13	28.3	23.4	97
21/06/13	29.6	23.3	96
22/06/13	26.5	22.9	98
23/06/13	27.3	22.5	98
24/06/13	28.4	23.3	98
25/06/13	27.3	22.0	96
26/06/13	28.4	23.5	97
27/06/13	26.5	23.0	96
28/06/13	28.5	22.9	96
29/06/13	31.3	22.6	96
30/06/13	30.1	22.8	95

Date	Maximum temperature	Minimum temperature	Relative humidity
	°C	°C	%
01/07/13	28.5	23.4	97
02/07/13	28.9	22.5	95
03/07/13	28.8	22.4	96
04/07/13	29.4	21.8	96
05/07/13	28.1	23.4	98
06/07/13	29.8	23.0	98
07/07/13	26.9	23.6	98
08/07/13	29.1	23.0	96
09/07/13	27.9	23.1	96
10/07/13	27.0	23.1	96
11/07/13	29.4	22.3	96
12/07/13	27.3	22.5	97
13/07/13	27.5	22.3	97
14/07/13	30.3	23.0	98
15/07/13	28.0	23.1	96
17/07/13	28.3	22.6	98
18/07/13	27.4	22.5	95
19/07/13	25.8	22.4	98
20/07/13	28.9	22.4	96
21/07/13	26.3	22.5	98
22/07/13	26.4	22.4	96
23/07/13	29.4	22.8	97
24/07/13	28.8	22.7	96
25/07/13	28.8	22.0	96
26/07/13	27.5	21.6	96
27/07/13	28.7	21.5	97
28/07/13	29.7	22.8	96
29/07/13	30.7	22.4	97
30/07/13	28.8	23.3	95
31/07/13	29.2	24.5	95

Date	Maximum temperature	Minimum temperature	Relative humidity
	°C	°C	%
01/08/13	27.4	22.7	96
02/08/13	29.8	22.2	96
03/08/13	26.6	21.8	97
04/08/13	30.0	23.0	98
05/08/13	27.2	21.8	94
06/08/13	26.8	22.4	97
07/08/13	29.5	23.1	98
08/08/13	30.1	23.6	94
09/08/13	29.9	23.6	96
10/08/13	30.1	23.6	96
11/08/13	29.4	23.7	96
12/08/13	30.5	24.3	95
13/08/13	30.2	23.2	94
14/08/13	30.3	23.0	98
15/08/13	29.9	23.3	96
16/08/13	29.6	22.8	96
17/08/13	30.4	22.7	98
18/08/13	28.7	23.6	95
19/08/13	30.3	22.8	97
20/08/13	29.3	22.3	96
21/08/13	30.3	22.0	96
22/08/13	30.6	22.2	98
23/08/13	30.4	23.4	97
24/08/13	29.0	22.6	98
25/08/13	30.4	23.0	96
26/08/13	31.0	22.2	97
27/08/13	31.2	23.9	95
28/08/13	30.8	24.0	95
29/08/13	31.0	23.1	95
30/08/13	32.1	22.2	93
31/08/13	33.0	23.1	92
01/09/13	34.0	22.7	93
02/09/13	32.0	23.3	93

Appendix V

Yield obtained from irrigation different treatments

Production period, days	Yield obtained from different Irrigation treatments (kg/ha)			
	I_1	I_2	I_3	I_4
55	1965	2947	300	279
60	1224	1526	1235	1847
64	4247	6835	4132	6000
69	3918	6368	4050	5118
74	4435	10735	6971	5421
79	6279	13241	7691	13294
82	3059	6176	5088	1779
87	6044	11074	6838	5162
92	6132	11565	7485	6656
96	5097	11744	8803	8735
100	1450	4656	3721	2641

APPENDIX VI

Yield obtained from different fertigation treatments

Production period, days	Yield obtained from different fertigation treatments (kg/ha)			
	F_1	F_2	F_3	F_4
52	265	315	659	456
56	1288	1244	2300	1379
59	2715	1629	2788	2550
61	674	906	803	776
64	1459	1635	1626	1979
67	2800	2085	2303	2376
71	2679	3132	3012	2703
74	2315	1871	2306	1641
78	1576	1706	2000	2500
81	1729	2156	1641	2112
84	1141	1082	1838	1147
87	1926	3253	3397	2971
91	2256	3356	2571	2056
94	1441	2274	2632	1406
97	1494	2051	2926	2191

ABSTRACT

EFFECT OF MICROCLIMATE ON THE PERFORMANCE OF SALAD CUCUMBER UNDER NATURALLY VENTILATED POLYHOUSE

By

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(2010 - 18 - 102)

ABSTRACT OF THE THESIS

Submitted in partial fulfilment of the requirement for the degree of

MASTER OF TECHNOLOGY
IN

AGRICULTURAL ENGINEERING

(Soil and Water Engineering)

Faculty of Agricultural Engineering & Technology

Kerala Agricultural University

DEPARTMENT OF LAND &WATER RESOURCES AND CONSERVATION ENGINEERING

KELLAPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR - 679573, MALAPPURAM

2014

ABSTRACT

A study was conducted to determine the effect of microclimate on the plant growth characteristics and fruit yield of salad cucumber grown in a naturally ventilated polyhouse at PDFC, KCAET, Tavanur, Kerela. The crop water requirement of the salad cucumber was determined using the irrigation management and planning model CROPWAT. The calculated total evapotranspiration during the crop period was 264.6 mm. The daily crop water requirement of salad cucumber obtained was 2.84 mm. The microclimate change in a naturally ventilated polyhouse was also evaluated. The results were then discussed with respect to yield of salad cucumber. It was seen that the most suitable temperature range for the optimum crop production is 22 to 33^{o}C and most suitable relative humidity range was 80 to 95%.

The irrigation trial was carried out with four levels of irrigation viz. 50, 65, 80 and 95% of daily irrigation requirement. Under the same fertilizer amount, the highest yield was obtained for the treatment with 65% of daily irrigation requirement and the lowest yield was obtained with 50%. This may be due to the reason that plants suffer due to water deficit by limited application of water. Irrigation amount significantly affected irrigation water use efficiency (IWUE). It ranged from 150 kg/ha-mm to 359 kg/ha-mm.

In the fertigation trial, the treatment which applied 100% of fertilizer requirement increased the yield significantly compared to 80, 90 and 110% under the same amount of irrigation. The fruit characteristics and quality did not vary significantly with respect to irrigation and fertigation levels.