STOCHASTIC MODELLING OF MINT EVAPOTRANSPIRATION UNDER CLIMATIC CONDITIONS OF UDAIPUR

mn;ij dh tyok; e inhuk dk ok"iu&ok"IkkR l tu dk çfr#i.k

By

KUMUD GUPTA

THESIS

MASTER OF ENGINEERING
IN
AGRICULTURAL ENGINEERING

(SOIL AND WATER CONSERVATION ENGINEERING)

2012

DEPARTMENT OF SOIL AND WATER ENGINEERING
COLLEGE OF TECHNOLOGY AND ENGINEERING
MAHARANA PRATAP UNIVERSITY OF AGRICULTURE
AND TECHNOLOGY, UDAIPUR-313001(RAJASTHAN)

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR – 313 001

Dated: 26 /6/2012

CERTIFICATE – I

This is to certify that **Ms. Kumud gupta,** has successfully completed the comprehensive examination held on 10/04/2012 as required under the regulation for **Master of Engineering** in **Agricultural Engineering (Soil and Water Conservation Engineering)**.

(**Dr. S.R. Bhakar**)
Head
Department of Soil and Water Engineering,
C.T.A.E., Udaipur

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR – 313 001

Dated: 26 /6/2012

CERTIFICATE – II

This is to certify that this thesis entitled **"Stochastic Modelling of Mint Evapotranspiration under Climatic Conditions of Udaipur"** submitted for the degree of **Master of Engineering** in the subject of **Soil and Water Conservation Engineering**, embodies bonafide research work carried out by **Ms. Kumud Gupta**, under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation have been fully acknowledged. The draft of the thesis was also approved by the advisory committee on 29 /05/ 2012.

(Dr. S. R. Bhakar)
Major Advisor

(**Dr. S.R. Bhakar**)
Head
Department of Soil and Water Engineering,
C.T.A.E., Udaipur

(Dr. Narendra S. Rathore)
Dean
Collage of Technology and Engineering,

Udaipur

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR – 313 001

Dated: / / 2012

CERTIFICATE – III

This is to certify that this thesis entitled **“Stochastic Modelling of Mint Evapotranspiration under Climatic Conditions of Udaipur”** submitted by **Ms. Kumud Gupta to** Maharana Pratap University of Agriculture and Technology, Udaipur, in the partial fulfillment of the requirements for the degree of **Master of Engineering** in **Agricultural Engineering** in the subject of **Soil and Water Conservation Engineering**, was after recommendation by the external examiner and defended by the candidate before the following members of the examination committee. The performance of the candidate in the oral examination on her thesis has been found satisfactory; we therefore, recommend that the thesis be approved.

(Dr. S. R. Bhakar)
Major Advisor

(Dr. Dr.R.B.Dubey)
Advisor

(Dr. H. K. Jain)
Advisor

(Dr. S. R. Bhakar)
Professor and Head
Department of Soil and Water Engineering

(Dr. N.S.Rathore)
Professor and Dean
CTAE, Udaipur.

Approved
Director Resident Instruction

MAHARANA PRATAP UNIVERSITY OF AGRICULTURE AND TECHNOLOGY
COLLEGE OF TECHNOLOGY AND ENGINEERING, UDAIPUR – 313 001

Dated: / / 2012

CERTIFICATE – IV

This is to certify that **Ms. Kumud Gupta student of Master of Engineering** in **Agricultural Engineering** in the subject of **Soil and Water Conservation Engineering, Department of Soil and Water Engineering** has made all corrections/modification in the thesis entitled **"Stochastic Modelling of Mint Evapotranspiration under Climatic Conditions of Udaipur"** which were suggested by the external examiner and the advisory committee in the oral examination held on / / 2012. The final copies of the thesis duly bound and corrected were submitted on / / 2012.

(Dr. S. R. Bhakar)
Major Advisor

(Dr. . S. R. Bhakar)
Professor and Head
Department of SWE
C.T.A.E., Udaipur

(Dr. N.S.Rathore)
Professor and Dean
CTAE, Udaipur.

ABSTRACT

The study was undertaken to develop and evaluate evapotranspiration (ET) models for spring mint under climatic conditions of Udaipur. Pan evaporation data for the duration of twelve years (2000-2012) and measured spring mint evapotranspiration data by soil moisture depletion method were analyzed. A relationship was developed between spring mint evapotranspiration and pan evaporation. The crop coefficient curves were developed for spring mint by FAO-56 curve method, modified FAO-56 curve method and quadratic curve method. The performance of Modified FAO-56 curve method was found to be best FAO-56 curve method and quadratic curve method. Modelling of spring mint evapotranspiration was made with the help of pan evaporation method. The climatological data were taken from the Meteorological Observatory established at the Instructional Farm of Rajasthan college of Agriculture, Udaipur.

Models of spring mint evapotranspiration rate and cumulative spring mint evapotranspiration were developed on the basis of time and plant growth parameters, like leaf area index and plant height. A relationship was developed between leaf area index and plant height for spring mint. The performance of all these developed models was found quite satisfactory under climatic conditions of Udaipur.

Stochastic model was developed for the estimation of daily spring mint evapotranspiration using twelve years data (2000-2011). Validation of these developed models for spring mint was done by the comparison of estimated values with measured values. The developed stochastic model for spring mint evapotranspiration was found to predict the daily spring mint evapotranspiration very accurately.

Keywords: Evapotranspiration, crop coefficient, leaf area index, spring mint, modelling.

lkjk"k

iLrr v/;;u mn;ij dh tyok; e clr inhuk dh ok"iu ok"ikRltu d ifr#i.k d fodkl ,o lR;kiu gr fd;k x;k g A ok"iu ik= l iklr ok"iu d 12 o"kk ½2000&2011½ ,o o"k 2011 d clr ekle e inhuk ok"iu ok"ikRltu d enk ty àkl i)fr l iklr vkdMk dk fo'y"k.k fd;k x;kA clr inhuk ok"iu ok"ikRltu vkj ok"iu ik= l iklr ok"iu d vkdMk d e/; ,d lc/k LFkkfir fd;k x;kA lnHk ok"iu ok"ikRltu dk vkdyu iueu ekUVh;Fk ,Q- ,- vk- 56 }kjk fd;k x;k A tyok; vkdM] tyok; o/k'kkyk l fy; x; tk fd vkj.lh-, d f'k{kk lc/kh df"k {k= e fLFr gA

,Q- ,- vk- 56] l'kkf/kr ,Q- ,- vk-&56 f,o f}?kkrh; Qly x.kkd fof/k;k d }kjk clr inhuk d Qly x.kkd fodflr fd; x;A l"kkf/kr ,Q- ,- vk-&56 od fof/k dk fuLiknu ,Q-,- vk&56 od fof/k ,o f}?kkfr; od fof/k l vPNk ik;k x;kA clr inhuk ok"iu&ok"ikRltu dk ik= ok"iu l ifr:i.k fd;k x;kA Qly x.kkd od fof/k ok"iu dk fuLiknu ik= ifr:i.k l J'B ik;k x;kA

le; ,o ikni of} ?kVdk ij vk/kkfjr ifr:ik dk clr inhuk ok"iu&ok"ikRltu nj ,o lp;h clr inhuk ok"iu&ok"ikRltu d fy; fodkl fd;k x;kA clr inhuk Qly d fy; iRrh {k= lpd ikni Åpkb d e/; Hkh lEc/k LFkkfir fd;k x;kA bu lHkh ifr:ik dh n{krk mn;ij dh tyok; d fy; lrk"ktud ik;h x;hA

clr inhuk ok'iu&ok'ikRltu d 12 o"kk d nfud vkdMk d vk/kkj ij ilHkkO; ifr:lk dk fodkl fd;k x;kA ifr:lk }kjk ekid ekuk dh vuekfur eku l ryuk djd ifr:lk dk lR;kiu fd;k x;kA fodflr ilHkkO; ifr:lk clr inhuk dh Qly d nfud ok"iu&ok"ikRltu d iokuekuk d fy; J'B ik;k x;kA

e[; fcUn% ok"ikRltu, f}l[;d Qly x.kkd, iRrh {k= lpd, clr inhuk ifr:i.kA

I – INTRODUCTION

1.1 GENERAL

Mint (*Mentha arvensis* L) is a perennial herb and belongs to the family *Lamiaceae*. Mint is cultivated in many countries like Argentina, China, Japan, Taiwan, Paraguay, Thailand, USA and India. In India it is cultivated in Jammu & Kashmir, Himachal Pradesh, Punjab, Haryana, U.P, Uttrakhand, M.P. Maharashtra and Gujrat.

The mint (*Mentha arvensis* L) is an important aromatic & Medicinal crop. Menthol is an important active principle of Mint menthol which is widely used in pharmaceutical industries, perfumery and food industry. No systematic study on modelling of mint (*Mentha arvensis* L) evapotranspiration was conducted under climatic conditions of Udaipur region. Present study was therefore undertaken to develop appropriate model of mint (*Mentha arvensis* L) evapotranspiration. The result obtained will be useful for planning the supplemental or life saving irrigation.

Mint (*Mentha arvensis* L) is a versatile, easy to grow plant that has a strong place in history for its medicinal and culinary uses. It also has some important cultural significance in ancient culture. Gardeners everywhere grow mint (*Mentha arvensis* L) for ground cover and in-home use.

Mint (*Mentha arvensis* L) just say the word and cool, refreshing image comes to mind: frosty glasses of lemonade garnished with curly springs of spearmint; the clean, chilling taste of a mint (*Mentha arvensis* L) candy cane. Even chewing gum, mouthwash, and toothpaste companies use images of crisp, clean snowy slopes to let us know how refreshing their mint flavored products are delicious recipes for soups and deserts.

Water is one of the most precious natural resource and its excess or deficit in the soil is a limiting factor for crop production. Successful crop production requires adequate and timely supply of soil moisture throughout crop period. Therefore, studies on water budgeting and evapotranspiration for various crops are of ulmost importance for the purpose of scientific planning and scheduling irrigation and determining water use efficiency of crops and water balance.

The primary reason for irrigation is to provide water to a crop when the frequency and amount of rainfall is not sufficient to replenish water used by a crop system. Water requirements of the crop system depend on growth and development needs as well as environmental demands. The levels of water used by the plant in growth and development are usually small compared to the atmospheric demands. Therefore, knowledge of the parameters involved with the water use process will help the irrigation scheduler to understand the driving forces associated with the water requirements of the crop.

An exchange process between incoming energy and outgoing water occurs at the crop surface, which can be evaluated by an energy balance. Water is transferred out of the plant system as a result of satisfying this balance. This transfer process is called evapotranspiration (**ET**), which refers to the evaporation (**E**) of water from plant and soil surfaces and the transpiration (**T**) of water through the plant to the atmosphere. The combination of these processes is termed evapotranspiration (**ET**).

1.2 EVAPOTRANSPIRATION

Evapotranspiration is simply a component of an energy budget of activities occurring at the crop surface. An energy budget is used to identify the individual components. These components are net radiation, sensible heat flux, soil heat flux, ET and solar radiation stored as photochemical energy.

The primary energy input to the system is solar radiation R_S. However, some of R_S is reflected while the remainder is absorbed and converted to other energy forms. The amount of R_S reflected depends on the albedo (α, solar radiation reflectivity) of the surface. Additional radiant energy transfered occurs in the form of thermal radiation generated by the temperature of the surface (upward long-wave radiation, R_l) and of the atmosphere (downward short-wave radiation, R_s). All of these terms are combined to define the net radiation (R_n) received at the crop or soil surface.

Sensible heat flux (**H**) is the transfer of heat energy due to the temperature difference between two surfaces, such as the plant surface and the atmospheric environment. If the plant surface is warmer than the environment, heat energy flux will be from the plant surface to the environment, and vice-versa. Similarly, soil heat flux (**G**) occurs due to a difference in driving force of solar radiation and wind are both dependent upon the temperature and vapour pressure condition of air. For the irrigation manager to understand the effect of varying atmospheric condition on the water demand of a crop, familiarization with this information is a must.

Efficient management of water resource, good crop production and environmental assessment requires in-depth knowledge of evapotranspiration. It affects the water balance from time water falls upon the land as a precipitation until residues reaches ocean. Evapotranspiration, which includes evaporation of water from land and water surface and transpiration by vegetation continuous to be of foremost importance in water resource planning and management. Problem of water supply, both surface and underground, water management and in the economics of multipurpose water projects for irrigation, power, water transportation, flood control, urban and industrial water uses and wastewater reuse system, involve evapotranspiration.

In negotiations related to water treaties and in the litigation and jurisdiction of water rights in major river systems in which the welfare of people in villages, cities, states and even nation are involved, the involvement of evapotranspiration is essential. Evapotranspiration data are essential for estimating water yields from watersheds, safe yield of ground water basins and stream flow depletion in river basins. Accurate prediction of evapotranspiration is required in many hydrologic studies. The science of evapotranspiration has advanced greatly during last many years and it is still evolving. It is important to adopt relationship that is based on sound physical laws and principles. After taking into consideration the above facts we come to the point that future estimates of evapotranspiration need to be more accurate than in the past as the value of water is increasing day by day.

1.3 EVAPOTRANSPIRATION PARAMETERS

Net radiation, $\mathbf{R_n}$, is the net level of solar and thermal radiation energy at the crop surface. It can be broken down into the components of short-wave and long-wave radiation.

Short-Wave Radiation

Short-wave radiation is the radiation flux resulting directly from solar radiation and has wavelengths of 0.3 to 4 micrometers (Campbell, 1977). Short-wave radiation received by an object may be the result of direct, diffuse, or reflected solar radiation. Direct radiation is highly directional and depends on the angle between the surface and the sun. Radiation scattered and reflected by clouds has no specific direction and is called diffuse radiation. Additional reflection of short-wave radiation can occur from the ground surface or other objects. As with diffuse radiation, this ‘terrestrial’ reflected and diffuse radiation has no specific direction.

The reflectivity of a surface to short-wave solar radiation is known as the albedo of the surface. The higher the reflectivity of the surface, the higher the albedo. The level of reflected radiation is the product of the albedo and the incoming short-wave radiation.

Long-Wave Radiation

Long-wave (infrared) radiation is also called terrestrial radiation and has wavelengths in the range of 4 to 80 micrometers (Campbell, 1977). Long-wave radiation is emitted and absorbed by both the atmosphere and terrestrial objects. Atmospheric long-wave radiation is emitted and absorbed by water vapour and carbon dioxide present in the atmosphere. Similarly, terrestrial long-wave radiation is emitted by objects on the earth's surface.

Basically, long-wave radiation depends on the temperature and emissivity of the emitting surface. As temperature increases, so does the emitted level of long-wave radiation. Emissivity is a value which characterizes the efficiency of emittance of the surface. A black body has the highest efficiency of emittance and has an emissivity of 1. Clear sky emissivity will depend on the levels of water vapour and carbon dioxide in the atmosphere.

Latent Heat of Vapourization

The latent heat of vapourization (**L**) represents the amount of energy required for water to change from a liquid to a gas (water vapour). Water is in a liquid state in the plant and is changed to a vapour during ET.

Vapour Pressure

Air contains water vapour and can be either saturated or partially saturated. Saturation conditions exist when the air contains the maximum possible level or density of water vapour for the existing temperature conditions. Generally, the air is partially saturated where the density of water vapour in the air is less than the maximum possible level. The amount of water vapour that can be held in the air is temperature dependent. As temperature increases, the amount of water vapour that it can hold also increases. Vapour pressure, the partial pressure exerted by the water vapour, is more commonly referred to and is related to vapour density and temperature by the perfect gas law.

Temperature

Air temperatures are classed as dry bulb or ambient, wet bulb, and dewpoint. Ambient air temperature is the most common temperature reported, and it is measured using a standard thermometer. Wet bulb and dew point temperatures characterize the moisture properties of the air. As air moves over a wet surface, such as a wet leaf, the temperature of the surface decreases until the air surrounding the surface is saturated, resulting in a temperature lower than ambient and is called the wet bulb temperature.

Wind

The previously discussed parameters indicate how moisture can move from the plant surface into the atmosphere. The air surrounding the plant can approach saturation with water vapour from the plant. When air movement is zero, this saturated air mass moves very slowly away from the plant, and the vapour pressure deficit is minimized. Therefore, air movement plays a major role in transporting the water vapour transpired from the plant into the atmosphere. Wind can help to maintain a significant vapour pressure deficit around the plant surface. Wind speed varies with height above a crop surface. Wind will be at a minimum near the crop surface, and it increases with height above the crop.

1.4 STOCHASTIC MODELLING OF EVAPOTRANSPIRATION

Study of the hydrologic system reveals that it is so complex, that no exact laws have yet been established which can explain completely and precisely the hydrologic phenomena. Before such laws can be established, simulation and mathematical modelling can approximate complicated hydrologic system. In this way, the hydrologic system may be treated in various degrees of complexity from deterministic to purely probabilistic and further from probabilistic to stochastic.

The second order model approach is of major value in the construction of mathematical models of hydrologic time series. Observed data are treated directly to produce efficient estimates of spectral representation (variance spectral) or moment functions (correlograms) of stochastic process. A stochastic model is the mathematical abstraction of an empirical process and is governed by probabilistic laws (Doob, 1953).

The word stochastic (which was apparently suggested 300 years ago by Jacob Bernoulli of Switzerland) means, according to its Greek origin, to contemplate or to conjecture. Roughly speaking it can be regarded as synonymous with chance, random or probabilistic but more precisely the interdependence of random variables should be accounted for.

Stochastic process deals with continuous or discrete state and time parameters. The analysis of time series is done to understand the mechanism that generate the data and to produce likely future sequences if required. These are attempted by making inferences regarding the underlying laws of the stochastic process from one or more sequences of recorded observations and then to postulate a model that fits the data, which are again used for estimation purposes. At first it is necessary to identify and analyze the different components of time series and then generate future sequences (Kottegoda, 1980).

Models developed to date are recognized procedures for estimating evapotranspiration. Since no single model is universally adequate under all climatic conditions, it is difficult to select the most appropriate evapotranspiration model for a given region. This is partly because of the availability of many equations for determining evapotranspiration, the wide range of data expertise needed to use the various equations correctly. More importantly, objective criteria for model selection are lacking. Consequently, the conditions under which one evapotranspiration model would be more suitable are not always spelled out.

The models developed from meteorological data involve empirical relationships to some extent. The empirical relationship accounts for many local conditions. Therefore, most models give reliable results when applied to climatic conditions similar to those for which they were developed. Without some local or regional calibration, the use of such models for climatic conditions that are generally different may give results that may differ considerably.

Forecasting of evapotranspiration particularly in water resource projects planning, design and operation is of paramount importance. It is increasingly recognized that time series analysis is of considerable practical use in dealing with forecasting of hydrological variables (Hipel and Mcleod, 1978, Salas *et al.*, 1980). Employing a mathematical model that represents the stochastic process of evaporation, the likely synthetic sequences of future evapotranspiration values can be obtained. A mathematical model representing a stochastic process is called ‘stochastic model’.

A time series is a set of observed data recorded at specific times, usually spaced at equal intervals. It has a certain mathematical form or structure and a set of parameters. A time series is often composed of trend, periodic and stochastic component. However, pan evaporation series is periodic-stochastic in nature. The periodic component can be modeled using the harmonic analysis and stochastic component is commonly modeled using Autoregressive model. Therefore, modeling of the evapotranspiration series by decomposing into periodic and stochastic components provides an improved methodology for short and intermediate forecasting.

1.5 JUSTIFICATION

As we observe that the demand for irrigation water is increasing, it seems quite essential that the water has to be used more efficiently. Improving water use efficiency requires the development of satisfactory means to estimate evapotranspiration. Hence, the estimation of evapotranspiration is of for most importance in water resource planning and management and irrigation development. The evapotranspiration estimation is particularly important in arid and semi-arid areas because of the scarcity of water for irrigation purposes. A common procedure for estimating evapotranspiration from a well-watered agricultural crop is to first estimate reference evapotranspiration from a standard surface or reference crop and then apply empirical crop coefficients. The evapotranspiration is usually estimated through direct or indirect methods. The direct methods are precise and accurate, but laborious and time consuming. However gravimetric method is most precise and used for research work. None of these empirical methods can be applied generally for all purposes as they are developed under different agro-climatic conditions.

It has been observed that the World Bank and other donor agencies usually insist to use the Food and Agriculture Organization (FAO) methods of estimation of crop evapotranspiration in the command areas of irrigation projects before granting the loan for construction of water resource development projects in different parts of the country. It is therefore, utmost necessary that the FAO method (i.e. Penman-Monteith) for estimation of crop evapotranspiration should be evaluated under different climatic conditions of the country.

The Penman-Monteith method was developed on the basis of grass evapotranspiration measured by weighing lysimeters at different locations in U.S.A. and European countries (Allen *et al*., 1998). However, no evapotranspiration data from Asian countries were used in development and testing of the Penman-Monteith model. As a matter of fact, Asian countries have more irrigated area than North American and European countries. Therefore, it is essential that the Penman-Monteith model should be evaluated under the climatic conditions of the Asian countries.

The crop coefficient, Kc, which is ratio of crop ET to grass reference ET, is needed to estimate crop evapotranspiration for irrigation planning for regional sector. The crop coefficient value represent crop specific water use and is required for accurate estimation of irrigation requirement of different crop grown under different climatic conditions are have been suggested by (Doorenbos and Pruitt 1977, Allen *et al*., 1998). These values are commonly used in places where local data are not available. Therefore it is felt that crop coefficient must be determined under different climatic conditions. Crop coefficient based on lysimeter studies has not been developed for important crops under semi humid climatic conditions of Southern Rajasthan. That’s why the present study has been undertaken to determine the crop coefficient of spring mint crop.

The process of evapotranspiration is stochastic in nature. Usually, the deterministic models do not consider the random effects and may not represent the evapotranspiration quite accurately. On the other hand, the stochastic models are based on the time dependent variations and consider random effects involved in the process. Stochastic models explain the extent of dependence of a present observation on the past observations, therefore; stochastic modelling of ET may provide good insight and understanding of the processes for useful applications in water resources development.

Mint is an important crop of Udaipur region. Realizing all factors mentioned above a study was planned in the region on the spring mint crop. It is learnt that very less research work has been carried out on the study of mint especially on evapotranspiration. Under this study, an attempt has been made to study evapotranspiration or consumptive use requirement spring mint crop as this crop has higher irrigation requirement. Therefore, it becomes necessary to estimate evapotranspiration of mint for proper irrigation scheduling. Present study was, therefore, proposed so as to develop appropriate stochastic modelling of mint evapotranspiration. The results obtained will be useful for planning the supplemental or life saving irrigation.

1.6 OBJECTIVES

The objectives of the present study are:

1. To develop crop coefficient curve for Spring Mint. (*Mentha arvensis* L).
2. To develop relationship between pan evaporation and Mint evapotranspiration.
3. To develop Mint evapotranspiration model on the basis of growth parameters.
4. To develop and validate appropriate stochastic model for Mint evapotranspiration.

REVIEW OF LITERATURE

Modelling of evapotranspiration process in a particular climatic condition is essential as evapotranspiration is the basic component of hydrological cycle. The scientific study of this process has been under way for many years. The literature on evapotranspiration is extensive and some excellent reviews and books are available on the subject (Rosenberg *et al.*, 1968; Brutsaert, 1982; Rosenberg *et al.*, 1983; Sharma1985; Monteith and Unsworth, 1990; Allen *et al.*, 1998; Singh, 2000). A brief review on this topic related to present study is presented under following headings:

- Measurement of Evapotranspiration
- Variation of Evapotranspiration
- Estimation of Evapotranspiration
- Development of Crop Coefficients
- Estimation of Leaf Area Index
- Stochastic Modelling of Evapotranspiration

2.1 MEASUREMENT OF EVAPOTRANSPIRATION

The measurement of evapotranspiration for given vegetation type can carried out in following ways:

2.1.1 Soil Moisture Depletion Method

Evapotranspiration under field condition can be determined by measuring the change of soil water content over a period of time. The soil water content can be measured by gravimetric sampling or with neutron probe. Other methods used for measuring soil water content include use of tensiometer and gypsum block. These techniques require calibration with each particular soil to determine the amount of water that must be applied to refill the profile. The average rate of evapotranspiration (ET) in mm day^{-1} between sampling dates, Δt can be calculated using the following equation:

$$ET = \sum_{i=1}^{n} \frac{(\theta_1 - \theta_2)\Delta S_i (R_e - W_d)}{\Delta t} \qquad ...(2.1)$$

Where,

n is the number of layers to the depth of the effective root zone,
ΔS_i is the thickness of each layer in mm,
θ_1 and θ_2 are the volumetric water content on the first and second date of sampling respectively in $m^3\ m^{-3}$.
R_e is rainfall that does not runoff the area in mm;
W_d is drainage from the root sampled in mm (Singh, 2000).

2.1.2 Lysimeter

A lysimeter is device in which a volume of soil, with or without crop is located in a container to isolate it hydrologically from the surrounding. For accurate and reliable measurement of evapotranspiration the lysimeter should be constructed, installed and operated properly. Singh (1987) has discussed the design requirements for installation and proper use of lysimeter.

Lysimeter contains either disturbed or undisturbed soil profile. Lysimeter with disturbed soil are called ‘filled in type’ and those with undisturbed soil block are designated as ‘monolith type’. The nature of evapotranspiration data to be obtained dictates the suitability of lysimeter. When lysimeter is employed to measure actual evapotranspiration it is desirable that it should contain an undisturbed representative soil profile. On the other hand when the objective is to measure reference crop evapotranspiration the physical constitution of the soil is of less significance and lysimeter may contain disturbed soil profile.

According to the system used for estimating the water loss two general type of lysimeter are in use (i) non- weighing type and (ii) weighing type. Non- weighing lysimeters are well suited for measuring the long-term evapotranspiration data. Non- weighing lysimeters can be classified as (a) constant water table type and (b) percolation type. Constant water table non-weighing lysimeter provides reliable data in areas of high water table conditions. Percolation type non – weighing lysimeters are often used in the area of high rainfall.

Weighing lysimeters furnish evapotranspiration data for short periods but their installation and operation cost is too high. Weighing lysimeter differs not only in the mode of weighing but also in features of construction. Different investigators have developed four types of weighing systems:

2.1.2.1 Mechanical weighing lysimeter

The most common type of mechanical weighing lysimeter employs mechanical balance to measure the weight loss.Precision mechanical weighing lysimeter has been developed by Pruitt and Angus (1960), Van Bavel and Myers (1962) and Ritchie and Burnett (1968), Mottram and De Jagger (1973), Bharadwaj and Shastry (1979), Hutson et al., (1980), and Reyenga *et al*. (1988) also explained the working of mechanical weighing lysimeter for measurement of evapotranspiration.Mechanical balances permit large counter weight to offset the container and soil mass container and soil mass to permit precise measurement of the mass change of water within the lysimeter. Several weighing lysimeter installation have used air conditioning / heating / dehumidification equipment to prevent condensation on mechanical scale.

Bharadwaj (1992) developed and installed five simple and improved mechanical weighing type lysimeters using undisturbed soil monolith. The system has a sensitivity of 200g with the provision of hourly/daily monitoring of the complete hydrologic balance (rainfall, dew, soil profile moisture, runoff, seepage and ET). Total ET values were found for different crops.

2.1.2.2 Electronic weighing lysimeter

Load cells are used in electronic weighing lysimeter. Load cell electronic weighing lysimeters usually measure the total lysimeter mass without counter weight so the accuracy is dictated by the load cell accuracy, data processing and recording instrumentation. Allen and Fisher (1990) described the working of the load cell lysimeter for measurement of evapotranspiration. Tyagi *et al*. (2000 a & b) discussed the installation of electronic weighing lysimeter at Central Soil Salinity Research Institute, Karnal.

2.1.2.3 Hydraulic load cell weighing lysimeter

Hydraulic load cell type weighing systems are used where economy and simplicity of the system are important. Temperature sensitivity of the liquid on which the soil mass rests limits the convenience and accuracy of such systems. With proper correction of temperature sensitivity, however, these units can be made accurate enough for daily and possibly more frequent observations of evapotranspiration. Hydraulic load cell lysimeters have been developed by Hanks and Shawcroff (1965), Black et al., (1968) and Korven and Pelton (1972).

2.1.2.4 Floating type weighing lysimeter

King *et al.* (1956) described a floating type weighing lysimeter for measuring evapotranspiration. The lysimeter floated within a water- filled tank and a mass change was measured by the depth change of the fluid in a stilling well. Lysimeters have been successfully installed in many countries and have been tested under a variety of soil and climatic conditions. McMillan and Paul (1961) used a $ZnCl_2$ solution (specific gravity of 1.9) instead of water to reduce the buoyance chamber within the lysimeter. The $ZnCl_2$ solution was found to have larger thermal expansion error than water. Aslyng and Kristensen (1961) used floatation to partially offset the dead mass of lysimeter.

Singh (1987) discussed the design requirements on lysimeter depth, water control, drainage, area, filling of soil, soil moisture, soil heat flux and comparability of plant cover which may be helpful in proper installation of lysimeter.

Singh (1988) discussed the design and construction of a battery of twelve monolith lysimeters installed at Pantnagar University for quantitative evaluation of agriculture hydrology. The lysimeters were installed with the help of a dragline. These lysimeters contain the undisturbed soil cores of silty clay loam soil. The inside diameter of lysimeter was kept 112.8 cm to provide an enclosed area of one square meter. The depth of lysimeter was kept 142 cm, which provides sufficient root zone depth for most of the crops. Water balance, management and operation aspects of lysimeteric set up are also discussed.

2.1.3 Remote Sensing Technique

A technique of remotely sensed canopy temperature, air temperature and vapour pressure deficit of the air (Jackson *et al.*, 1980) was developed for indirectly estimating the evaporation on a real time basis. This technique provides an interesting concept for estimating evapotranspiration. However the results and the techniques developed for measuring evapotranspiration are complex and raise questions in term of the limitations and constraints in the use of various instruments (Singh, 2000).

2.2 VARIATION OF EVAPOTRANSPIRATION

For irrigation scheduling and effective water management accurate estimation of evapotranspiration is required. However, factors which affect evapotranspiration such as humidity, solar radiation, wind speed, crop growth stages and type and soil hydraulic and physical properties vary both in space and time. Evapotranspiration can be seen as an integrated response to all these factors in and a major contributor to irrigation requirement.

Therefore, it would be helpful to measure the variability in evapotranspiration caused by these factors in preparation for management of irrigation. Related reviews are as follows:

Lepton and Parton (1996) designed an ecosystem model to simulate the long-term dynamics of soil-vegetation-atmosphere interactions require information on the properties of the land surface and the temporal pattern of the microclimate variables and describes the seasonal distributions of microclimatic factors in a semi-arid short grass steppe and a potential method for estimating evapotranspiration in sparse vegetation. Precipitation showed wide variability between the years and could significantly account for the seasonal differences in growth and biomass yield of the native vegetation. Small (0.5 cm or less) precipitation (rain and/or dew) events, determined from the positive increments in hourly lysimeter measurements, contribute 8-10% to the total annual precipitation at the site. The total net radiation (R_n) was found to be 47% of the total incident solar radiation. The ratio of surface soil heat flux to R_n (G_s/R_n) was found uniformly equal to 0.167 during the vegetated season (April-October). Midday sensible heat flux (H) was found to be linearly related to the difference between the temperatures of the soil measured at 0.025 m depth and the air above the canopy. The ratio of H and R_n taken at midday was found to be linearly proportional to the ratio of the daily totals of H and R_n. A method for estimating daily evapotranspiration (ET_{day}) based on the energy balance approach was developed. This method was found suitable for estimating ET_{day} in the short grass steppe under high soil moisture conditions and/or on days following rainfall.

Murakami *et al*. (2000) conducted field experiments to measure evapotranspiration (ET) both a young (stand age 4-7) and a mature (stand age 62-66) forest basin covered with a mixed stand of Japanese cypress (*Chamaecyparis obtusa*) and Japanese cedar (*Cryptomeria japonica*). To obtain ET, runoff data were analyzed on a monthly basis using a short-time period water-budget method. Canopy interception (I) was also measured in the mature (stand age 72-75) forest basin. Annual ET changes in the young forest basin showed a clear upward trend, and ET had higher values in hot summer (1994) than in the other summers. A model based on the Penman-Monteith equation simulated these results, and results agree with field measurements. This model predicts an ET-stand age relationship, which shows a peak in ET at 20 years, reflecting an LAI-stand age relationship data obtained from the literature. The response of ET to hot (1994), cool (1993), and mean (1981-1994 average) summer conditions was simulated for both the young and the mature forest basins. In hot summer ET was large for the young forest in comparison with a mean summer but the same level in the mature forest. In cool summer, however, ET was smaller in the mature forest than that of a mean summer but at the same level in the young forest.

Hupet and Vanclooster (2001) conducted an experiment to quantify the effect of the temporal sampling frequency of commonly measured climatic variables on the estimation of the reference crop evapotranspiration. Using a set of data sampled on an intensive basis (i.e. one measurement each minute) during a period of 6 months, the effect of the temporal sampling frequency on the estimation of the daily means of the short-wave solar radiation, the wind speed, the dry and wet temperatures, and on the estimation of the daily maximum and minimum dry temperature. Subsequently, a sensitivity analysis of a reference crop evapotranspiration model is carried out to determine the most sensible meteorological variables. The sensitivity coefficients were then combined with the errors due to the temporal sampling to quantify for each variable the impact of the sampling frequency on the estimation of daily ETo. The results showed that the solar radiation and the wind speed are the most sensitive to bias induced by inadequate temporal sampling frequency. Moreover, the impact of inappropriate temporal sampling on the estimation of ETo can be significant with respective maximum bias of 0.62 mmd^{-1} due to inappropriate solar radiation sampling and 0.36mmd^{-1} due to inappropriate maximum temperature sampling. A non-intensive hourly temporal sampling schedule of all meteorological variables may induce errors on the daily ETo so high as 0.76mmd^{-1} or 27 %. Fortunately, the errors generated on the estimation of the long-term integrated evapotranspiration are clearly lower (3.8%).

Liu-Yu and Zhi-gong (2009) described the evapotraspiration as a combination of energy circulation and terrestrial water circulation. It is also a bond between ecological processes and hydrological processes for land surface. It has significant meanings of accurately monitor and estimate evapotranspiration for climate change research, water resources planning, agriculture water-saving research, crop yield simulation and environment impact assessment. In the past 3 decades, the methods of monitoring and estimating evapotranspiration have made some essential progress, which are analyzed and evaluated. The main monitoring methods mainly include gradient method, soil water balance method, lysimeter method, Bowen ratio method, eddy covariance method and scintillometer method. The main methods of estimating evaotranspiration include regional water balance method, Penman-Monteinth method and complementary method. The adaptability of different methods for different scales evapotranspiration is analyzed. The existing problems and development prospects are pointed out.

2.3 ESTIMATION OF EVAPOTRANSPIRATION

A large number of studies have been conducted for many years, which show the close relationship between the net radiant energy received by an irrigated crop of wet soil and the rate of evapotranspiration. Basically there are two approaches, which have been used for estimation of evapotranspiration:

1. Aerodynamic approach
2. Energy balance approach

However, the energy approach for estimating ET is most reliable & conservative method, in a situation where the sensible heat storage capacity is relatively small or only a small percentage of net heat energy input is stored. However, a thorough understanding of the factors controlling the energy balance of a cropped soil is essential for accurate prediction of irrigation water requirement & management.

Penman (1948) was the first scientist who combined these two approaches and developed equation for estimation of evapotranspiration. Therefore, the equation for estimation of evapotranspiration is called combination equation. This was based on the assumption that there is an unlimited supply of water at the evaporating surface. Therefore, Penman evolved the concept of potential evapotranspiration but he has not specified a particular reference for evaporating surface.

Penman (1956) observed that the energy balance method approaches the ideal in the theory, but in practice, there are great difficulties in ensuring some of the terms other than evaporation and for the sensible heat transfer to the air it is necessary to fall back on aerodynamic ideas.

Blaney and Criddle (1962) developed a simplified empirical formula to compute evapotranspiration using a correlation which utilized mean monthly air temperature, amount of daylight and a crop factor showing seasonal variation. They noted that the efficient design and operation of water supply project depend on an awareness of the quantity of water that is lost through the process of evapotranspiration.

Jensen and Haise (1963) estimated evapotranspiration from solar radiation using energy balance approach based on long-term data and indicated that reliable estimates of evapotranspiration can be made using solar radiation as the main parameter.

Maity *et al.* (1979) compared measured and estimated evapotranspiration based on their study of different models. Evapotranspiration rates measured by the water balance method from the wheat crop in lysimeter under the different soil moisture tension and nitrogen levels were compared with the estimated evapotranspiration rates by the Penman, Thorthwaite, Blaney Criddle and Christiansen models. They developed regression equations and found that when the soil moisture tension is 0.75 atm. there exists a close agreement between estimated and measured evapotranspiration.

Allen *et al.* (1983) studied consumptive use estimates with reference to weather station siting and documented the effect of weather station aridity on consumptive use estimates.

Chin and Zhao (1995) presented a methodology to assess the relative merits of using evaporation –pan network and semi empirical function to estimate reference crop evapotranspiration (ET_C) .Estimation error variance was proposed as a basis of comparison. In the case of pan network, ordinary kriging and universal kriging are viable option for determination of estimation error variance. It was concluded that pan-based estimates of reference crop evapotranspiration are preferable to semi empirical evapotranspiration function in south Florida.

Chandra *et al. (*1996) described that the reference evapotranspiration by Doorenbos and Pruitt's method, which is based on Penman's equation, which is quite rational and accurate, but the computations are quite elaborate and time consuming.

Mishra *et al.* (2000) estimated the actual crop evapotranspiration (ET_a) using continuous crop coefficient (Kc) functions. Kc on daily basis was found by fitting a continuous functions and used for computation of actual crop evapotranspiration (ET_a) for daily crop root zone water balance and daily water use by various crops with computerized simulation model for irrigation scheduling and water management (WATERMAN). The best out of twenty-five different types of functions were fitted in the data. Polynomials degree perfectly fitted in the data of most crops. The predicted values of Kc on daily basis have been used for estimation of ETa for six crops viz. wheat, rice, mustard, potato, jute and tea for lower Assam region. The computed ETa values are obtained from using standard discreet values of Kc using the long time climate data for Dohubri in the study reason. The result of fitting as well as ETa was good agreement and hence it was recommended that by using the continuous for K_C and ETa could be usually computed use of modern WATERMAN.

Samani (2000) introduced a procedure to estimate solar radiation and subsequently reference crop evapotranspiration using minimum climatological data. A modification was made to the original equation that uses minimum and maximum temperature to estimate solar radiation reference crop evapotranspiration. The proposed modification allowed for the correction of the errors associated with indirect climatological parameters affecting the local temperature range.

Shaozhong *et al.* (2000) conducted a field study to investigate the response of leaf water potential and stomata conductance of maize crop to soil water availability, and to test and compare the soil water adjustment coefficient function for estimation of actual evapotranspiration under water deficit .The result showed that correlation coefficient of soil water adjustment of coefficient,stomatel conductance and leaf water potential peaks at 9:30 hours, and than decreased, indicating that correlation coefficient of soil water adjustment coefficient and stomatal conductance at 9:30 hours were better prediction of plant water .

Kashyap and Panda (2001) evaluated the crop evapotranspiration estimation methods and developed a crop coefficient for potato in the sub-humid region. The study was carried out the experimental farm of Agricultural and Food Engineering Department of Indian Institute of Technology, Kharagpur, India having a sub-humid climate. Daily reference crop evapotranspiration (ET_0) was measured with an electronic data logger connected to the lysimeter. Grass was used as the reference crop observing actual evapotranspiration. Ten climatological methods, Penman, FAO-Penman, FAO-Corrected Penman 1982 – Kimberley – Penman, Penman – Monteith, Turc- Radiation, Prestly – Taylor, FAO-Radiation, Hargreaves and FAO – Blaney Criddle were used to estimate the reference evapotranspiration. Performance of climatological method in estimating the ET_0 values as compared to the lysimeter – measured value was evaluated on the basis of (RMSE). The Penman – Monteith equation gave the best result followed by the 1982 – Kimberly – Penman, FAO – Penman, Truc – Radiation and FAO Blaney Criddle. The RMSE in all the cases varied between 0.08 and 0.756. The crop coefficients were estimated on the basis of lysimeter measured actual ET. The crop coefficients for potato crop at four stages of growth were 0.42, 0.58, 1.27 and 0.57 respectively.

Bhakar and Singh (2001) application of computer in estimation of reference evapotranspiration is highlighted by using climatic data of Udaipur weather station. A comparison of estimated ET with measured ET of wheat and green gram crops is also made under climatic conditions of Udaipur. The values of crop ET were found to be different for wheat and green gram. Total measured wheat ET was 277 mm for the whole season, while the estimated value for it was 201 mm. The seasonal measured green gram ET was 515mm, while the estimated ET was 456 mm.

Bhakar and Singh (2003) estimated reference crop evapotranspiration under subhumid climatic conditions of Rajasthan. Ten most commonly used reference crop evapotranspiration models were selected for testing their validity under the climatic conditions of Udaipur region. The important reference evapotranspiration model are: (i) Penman FAO-24 model, (ii) Penman- Montieth FAO-56 model, (iii) Kimberley-Penman model, (iv) Priestely-Taylor model, (v) Jensen- Haise Alfalfa Reference model, (vi) Hargreaves Grass Related model, (vii) SCS Blaney Criddle model, (viii) FAO-24 Blaney Criddle model, (ix) FAO-24 Pan Evaporation model, (x) Christiansen Pan Evaporation model. Testing of these models was made on the basis of actual measurements of agricultural crops based reference evapotranspiration (ET_{OA}). Out of 10 modes only 3 models viz. Penman-Montieth FAO-56, Jensen-Haise Alfalfa Reference, FAO-24 Blaney Criddle models were found to predict ET_{OA} accurately under the climatic conditions of Udaipur region.

Hargreaves and Allen (2003) described a brief history of development of the 1985 Hargreaves equation and its comparison to evapotranspiration predicted by FAO Penman-Monteith method. They also described background and information helpful in selecting an appropriate reference crop evapotranspiration equation under various data situations. Early efforts in irrigation water requirement computation in California and other arid and semi-arid regions required the development of simplified evapotranspiration equations for use with limited weather data. Several initial efforts were directed towards improving the usefulness of pan evaporation for estimating irrigation water requirements. Similarly with climates of other countries allowed developments in California to be extended overseas. Criticism of empirical methods encouraged the search for a robust and practical method that was based on readily available climatic data for computing potential evapotranspiration or reference crop evapotranspiration (ET_0). One of these efforts ultimately culminated in the 1985 Hargreaves reference crop evapotranspiration method. The 1985 Hargreaves ET_O method requires only measured temperature data, is simple and appears to be less impacted than Penman type methods when data are collected from arid and semi-arid, and no-irrigated sites. For irrigated sites, the Hargreaves 1985 ET_0 method produces values for periods of five or more days that compare favorably with those of the FAO Penman-Monteith and California Irrigation Management Information Services (CIMIS) Penman methods. Monthly ET_0 by the 1985 Hargreaves equation compares closely with ET_0 calculated using a simplified "reduced-set" Penman-Monteith that requires air temperature data only.

Tyner *et al.* (2003) presented a method whereby measured soil water chloride concentrations and long term precipitation and air temperature profiles are interpreted to provide temporal estimates of evapotranspiration, recharge and runoff. Applying the chloride mass balance technique to soil water chloride profiles improves the boundary conditions associated with the long-term recharge rate. Temporal estimates of evapotranspiration and runoff are calculated from precipitation and air temperature data. Next, these estimates and measured precipitation are used as inputs in an unsaturated groundwater model to estimate temporal recharge, which is subsequently compared with long-term mean recharge rate calculated from the chloride profiles. Finally the evapotranspiration and runoff components of the model are scaled to the long-term mean recharge rate. This method improves the chloride mass balance method, which up to now only provides long-term mean recharge. Additionally, the method allows initial estimates of evapotranspiration and runoff to be scaled such that the resulting estimates of evapotranspiration and runoff are consistent with both chloride mass balance and water mass balance. Although direct methods to measure evapotranspiration, recharge and runoff are attractive, they are not always reasonable due to the expense of collecting data over long time periods. In contrast this method obtains its required input from basic meteorological data and soil cores collected at a single point in time.

Goyal *et al*. (2004) estimated the sensitivity of evapotranspiration to global warming for arid region of Rajasthan (India).The Penman Monteith equation was used to estimate reference evapotranspiration and sensitivity of evapotranspiration in terms of change in temperature, solar radiation, wind speed and vapour pressure within a possible range of ± 20% from the long term metrological parameters of 32 year (1971-2002). The changes in precipitation and stomatal resistance to increase CO_2 concentration were not considered. The study indicated as increase of evapotranspiration demand with increase in temperature, solar radiation and wind speed.

Garcia *et al*. (2004) computed evapotranspiration (ETo) by means of the Thonthwaite, Hargreaves-Samni and FAO Penman-Monteith equation and compared with the grass evapotranspiration measured with Lysimeter. They were able to demonstrate the suitability of the application of FAO Penman-Monteith equation in the Altiplano.

Lopez *et al*. (2006) used the FAO-56 and ASCE Penman Monteith equations for estimation of hourly evapotranspiration (ETo) under semiarid condition of the province of Albacete. These two equations were compared against measured lysimeter evapotranspiration (ETo). They analyzed that FAO-56 equation for calculating evapotranspiration (ETo) values are more accurate than ASCE Penman Monteith method under semi-arid weather conditions in Albacete.

Calil *et al.* (2006) worked on the Estimation of the monthly evapotranspiration in Parana state at Brazil. A set of measurements of daily average temperature were taken from Agronomic Institute of Parana - IAPAR and calculated the evapotranspiration by deCamargo method, from which values of monthly evapotranspiration were obtained. He used Gamma and log normal distribution for determination of monthly reference crop evapotranspiration with 75% probability of occurrence as the model range, log-normal used to estimate the potential evapotranspiration, if adjusted satisfactorily. With the values of each month, considering probability of 75% of occurrence in each of the stations which represents the variability of potential evapotranspiration, according to the model range, based on the mapping of state of Parana.

Jiabing *et al.* (2007) predicted daily evapotranspiration (ET_0) using the public weather forecast messages available in China by using FAO-56 method. Daily weather data for the period 1984 to 1998 at eight meteorological stations representing a wide range of climatic conditions of China were used to compute the FAO Penman Monteith reference evapotranspiration and to serve as reference data sets for comparison with the variables obtained from daily weather forecast messages at the same locations and period. Several statistical indicators were used for the respective comparisons. They used estimated weather parameter to compute the daily ET_o with the FAO Penman Monteith equation for the eight locations.

Ayman *et al.* (2007) made the study in Georgia and other southeastern states of the United States. The Priestley-Taylor (PT) equation has been used operationally in Georgia to compute evapotranspiration for irrigation scheduling because of its simplicity, its general acceptable performance in humid regions and its limited input requirements. The study based at a site in the humid southeastern United States found that Priestley-Taylor overestimated evapotranspiration and was less accurate than the FAO-56 Penman-Monteith (PM). The objective of this study was to assess the potential improvement that can be achieved by replacing Priestley-Taylor with FAO-56 Penman Monteith in Georgia and southeastern areas. Each site had at least 10 years of daily records that included minimum and maximum air temperature, solar radiation, wind speed and vapour pressure deficit. Priestley-Taylor underestimated the daily and monthly evapotranspiration during the winter months in the central and southeastern areas and overestimated the daily and monthly evapotranspiration during the summer months in the coastal and mountainous areas. For the warm season, i.e., April to September, Priestley-Taylor slightly overestimated the cumulative evapotranspiration in the central and southeastern areas, moderately for the mountainous area and severely for the coastal area. Based on these results, it was anticipated that the use of FAO-56 Penman Monteith for estimating evapotranspiration will standardize the evapotranspiration calculations and improve irrigation efficiency in Georgia, especially for the mountainous and coastal areas.

Jabloun and Sahli (2008) used the Penman Monteith method (FAO-56 PM) which has recently been proposed as the standard for estimating reference crop evapotranspiration (ET_o). Unfortunately, some weather variables, especially solar radiation, relative humidity and wind speed, are often missing which could impede the estimation of ET_o with the FAO-56 Penman Monteith method. To overcome the problem of the availability of climatic parameters, procedures to estimate ET_o with missing climate data are proposed as part of the FAO methodology. The comparison of ET_o estimates using limited data to those computed with full data set revealed that the difference between ET_o obtained from full and limited data set is small considering the 8 locations studied.

Ustun *et al.* (2009) estimated the evapotranspiration of cauliflower and red cabbage crops grown under cool season semiarid climatic conditions from Class A pan evaporation. Actual evapotranspiration (ET_c) of cauliflower and red cabbage crops was calculated according to the water balance approach. Reference evapotranspiration (ET_o) was calculated with FAO Penman-Monteith equation. Pan evaporation (E_{pan}) was measured by using Class A pan. Seasonal ET_c was determined as 475 mm for cauliflower and 556 mm for red cabbage. Seasonal pan coefficient ($k_p = ET_o/E_{pan}$) was determined as 0.82, and the seasonal crop coefficient ($k_c = ET_c/ET_o$) was determined as 0.84 for cauliflower and 0.83 for red cabbage. So the evapotranspiration of cauliflower and red cabbage crops was estimated as 70% Class A pan evaporation.

Jhajria *et al.* (2009) stated that reference crop evapotranspiration (RET) is major component of hydrologic cycle and its accurate estimation is essential for hydrological studies. The three temperature based RET methods. Blaney Criddle, Hargreaves and thornthwaite were used to estimate RET for humid locations of Assam using monthly meteorological data.

Zhao-Liang *et al*. (2009) overviewed the commonly applied evapotranspiration (ET) models using remotely sensed data was given to provide insight into the estimation of ET on a regional scale from satellite data. Generally, these models vary greatly in inputs, main assumptions and accuracy of results, etc. Besides the generally used remotely sensed multi-spectral data from visible to thermal infrared bands, most remotely sensed ET models, from simplified equations models to the more complex physically based two-source energy balance models, must rely to a certain degree on ground-based auxiliary measurements in order to derive the turbulent heat fluxes on a regional scale. We discuss the main inputs, assumptions, theories, advantages and drawbacks of each model. Moreover, approaches to the extrapolation of instantaneous ET to the daily values are also briefly presented. In the final part, both associated problems and future trends regarding these remotely sensed ET models were analyzed to objectively show the limitations and promising aspects of the estimation of regional ET based on remotely sensed data and ground-based measurements.

Fang and Ren *et al.* (2011) estimated and validated basin-scale actual evapotranspiration using MODIS images and hydrologic models. An algorithm for estimating daily spatial actual evapotranspiration (ET) from remotely sensed MODIS data is presented. It is based on the surface energy balance scheme and the modified Priestley–Taylor equation, and has been applied to the MODIS data acquired during growing seasons over the Laohahe River basin, northeastern China. Spatial distributed mapping of daily ET for 22 clear sky days in the year of 2000 from MODIS images over the study area were obtained. In order to validate ET values estimated from MODIS data, regional daily ET values were calculated using the lumped modified Xinanjiang hydrologic model and distributed SWAT model based on the water balance scheme, respectively. The results suggested that the algorithm is applicable and operational for estimating and mapping basin-scale distributed daily actual ET over the study area.

2.4 DEVELOPMENT OF CROP COEFFICIENTS

Crop coefficients (Kc) are used with ETo to estimate specific crop evapotranspiration rates. The crop coefficient is a dimensionless number that is multiplied by the ETo value to arrive at a crop ET (ETc) estimate. The resulting ETc can be used to help an irrigation manager plan when an irrigation should occur and how much water is to be replaced back into the root zone.

The reference evapotranspiration serves as a measurement for the water use of reference crop. In the case of ET_0 grass is used as a reference. However, other crops may not use the same amount of water as grass due to changes in rooting depth, crop growth stages and plant physiology. The crop coefficient (K_C) takes into account the crop type and crop development to adjust the ET_0 for specific crop. Crop coefficient may also vary depending on how the evapotranspiration data has been calculated or obtained.

Although crop coefficients vary from day to day, depending on many factors, they are mainly a function of crop growth and development. The rate of crop growth and development will change from year to year, but the crop coefficient corresponding to a particular growth and development stage is fixed from year to year.

A number of approaches for determining crop coefficient are available in literature. The Penman-Monteith as presented by Allen *et al*. (1998) could be used to estimate the reference crop evapotranspiration. It may be pointed out that the lysimeter has been vital in the measurement of crop evapotranspiration and subsequently in the development of crop coefficient. Due to lack of locally determined crop water use data, project designer has to estimate crop coefficients determined elsewhere in world. The reviews of work done on crop coefficient are given as under :

Wright (1982) developed improved crop coefficients for Pacific Northwest irrigated crops for estimating crop evapotranspiration from estimates or measurements of reference evapotranspiration. Reference evapotranspiration was based on for well watered, actively growing alfalfa with sufficient growth for near maximum evapotranspiration values in arid irrigated regions. Evapotranspiration values for the alfalfa reference crop and other crop were measured with sensitive weighing lysimeters at a field site near Kimberly, Idaho. The new crop coefficients are based on minimal coefficient for conditions when soil evaporation is minimal but root zone soil moisture is adequate. When combined with improved estimates of evaporation from wet soils, they should permit more accurate estimates of daily crop evapotranspiration, more accurate irrigation scheduling, and more reliable estimate of crop water requirements. Curves were developed for alfalfa, potatoes, snap beans, sugar beets, peas, sweet and field corn and winter and spring cereals.

Suryawanshi *et al*. (1990) worked out the crop coefficient from lysimetric and climatological data for crops such as sorgam, maize, wheat, gram, safflower and groundnut. The maximum crop coefficient values were 1.07,0.99,0.88,1.20,1.04,0.91,1.03 and 0.99for rainy cropping season and summer cropping season sorgam, maize, wheat, chickpea, safflower, rainy cropping season and summer season groundnut, respectively.

Pruitt (1992) conducted the lysimeter based crop coefficient studies and developed the seasonal curves for the both crop coefficient Kc and basal coefficient Kcb. Smooth curves for Kc for most of the crops studied are than presented. Weekly Kc data for corn is presented for showing 10% error in July 1970 due to 40-50 cm height difference between lysimeter and field plants.

Tarantio (1992) studied the comparison between the measured grass ET and evapotranspiration calculated by the FAO method and in some cases by Penman-Monteith and Thornthwaite methods. Comparisons were made on a daily basis with weighing lysimeter and ten days basis with drainage lysimeters.

Steele *et al*. (1996) conducted the study to compare the accuracy of four methods for calculating corn water use. The comparisons were based on differences between estimated and measured soil moisture content (SMC) for the 1990, 1991, 1992 and 1994 seasons using non weighing lysimeters near Oakes. All four of the methods are based on the Jensen-Haise reference evapotranspiration methods. The methods calculate crop evapotranspiration, which differ only in their method of determining K_C and crop coefficient curve. The SMC data were compared to estimate using mean bias errors and mean absolute errors. The SMC estimates were corrected to measured values at three frequencies: start of season only, approximately monthly, and approximately semi-monthly. All of the methods tended to overestimate evapotranspiration. Most of the gains in accuracies were obtained between the initial and the monthly, with little additional gain in semi-monthly.

Dabral and Rao (1997) carried out investigations to find out crop coefficient values under 12 irrigation levels for tea crops using weighing type lysimeter at Mohurgong and Gulma estates, Darjiling. The highest crop coefficient and irrigation was observed for tea plants when 0.9 IW/CPE ratio was maintained from the last week of October to April end.

Hunsaker (1999) conducted field studies in central Arizona to develop basal crop coefficient K_{cb} values for an early maturing, upland cotton. Cotton evapotranspiration rate were determined from soil water depletion measurements made during the season in both small and large level basins in 1993 and 1994. Values for K_{cb} were developed from the crop evapotranspiration data and an estimated grass reference ET data. The “basal crop coefficient” procedure presented in the recently published Food and Agricultural Organization (FAO).Irrigation and Drainage Paper Number 56 was used to estimate the soil water evaporation coefficient (K_e) following periods of irrigation and rain, thus, quantify the amount of soil evaporation. A separate analysis was conducted to evaluate the water stress coefficient (K_s) for condition of low soil water. The developed K_{cb} data were used to derive two K_{cb} polynomial curves as function of the FAO “straight- line” method. When used in irrigation management procedure, any of three K_{cb} curves were presented should results in good estimation of daily evapotranspiration for early maturity cotton, grown under climatic conditions similar to those for these studies.

Shah and Edling, (2000) calculated daily evapotranspiration from a flooded rice field by water balance equation using measured values of water level, precipitation, irrigation, seepage and tail water runoff. Stage wise ET was 6.3, 8.1 and 6.8 mm/day for the vegetative, flowering and yield formation stages respectively. Average daily ET was 6.8 mm/day. Grass reference evapotranspiration (ET_r) combination models Penmen -Monteith, FAO-Penman and 1963 Penman were evaluated for their capabilities to predict rice ET using daily weather data.

The Penman-Monteith method had a coefficient of determination (R^2) of 63.7% as compared with 60.0% and 61.7% for FAO-Penman and 1963 Penman method respectively. Crop coefficient (Kc) using the Penman-Monteith (daily) model was 1.39, 1.51 and 1.43 for the vegetative, flowering and yield formation stages respectively. Developed Kc values were verified by using limitation rice ET data in 1996.

Tyagi *et al*. (2000a) conducted lysimeter experiments on rice during rainy season (July-October) and sunflower during summer (March-June) in a set of two electronic weighing lysimeter of 2mx2mx2m size to measure the hourly ET for these crops from 1994 to 1995 at Karnal. The estimated values of sunflower ET were 11.6-74.2 % higher than suggested values by Allen *et al*. (1998).

Tyagi *et al.* (2000b) conducted study to measure the daily, weekly and seasonal crop evapotranspiration of wheat and sorghum directly from sensitive weighing-type lysimeter. The estimated values of crop coefficient for wheat by Penman-Montieth at the crop growth stages (initial, crop development, reproductive and maturity) were 0.5, 1.36, 1.24 and 0.2 respectively, and for sorghum the crop coefficient values at the four stages were 0.532, 0.82, 1.24 and 0.85 respectively. In the case of these two crops actual crop coefficient were found significantly different from those suggested by Allen et. al.(1998). It is therefore necessary that the crop coefficient values should be developed in a particular region for accurate estimation of evapotranspiration crops.

Medeiros *et al*. (2001) conducted experiments to investigate the effect of crop development on ET and yield of beans in Brazil. A complete randomized design was carried out with three-population density and four replications. A simulation study was carried out and showed that Kcb based on leaf area index (LAI) would allow good estimates of water use for different plant density populations in the field.

Sepaskhah and Andam (2001) conducted an experiment to determine the crop coefficient (Kc) of sesame in a semi-arid climate. The relationships between Kc and ETp/Ep (pan evaporation) and leaf area index (LAI), growing degree-day (GDD) and days after sowing (DAS) were also investigated. The seasonal ETp for sesame in the study area with a 5-month growth period was 91 m. The mid-season and late-season Kc values for sesame were 1.08 and 0.64, respectively. These values are somewhat lower and higher than those for other oil seed crops. The Kc value for the initial stage was close to that obtained by the procedure proposed by(Allen et al. 1998 The ratio of ETp/Ep varied between 0.49-1.0 from the beginning to the middle of the growing season which is a sign of mild local advection in the region. The maximum ratios of ETp/ET0 and ETp/Ep occurred at a LAI of 3.0. Furthermore, third-order polynomials were presented to predict the Kc values from days after sowing (DAS), percent days after sowing (%DAS) and growing degree-day (GDD).

Singh and Bhakar (2002) developed improved crop coefficients for precise estimates of wheat evapotranspiration. The crop coefficient curves can be developed by plotting the ratios of crop evapotranspiration and reference evapotranspiration with respect to time. The evapotranspiration values of wheat crop were measured with the help of electronic weighing Iysimeter at Udaipur. The crop coefficient curves were developed for wheat by FAO-56 curve method and modified FA0-56 method. The FAO-56 method underestimates wheat evapotranspiration by 28.17 per cent. Therefore, FAO-56 curve method does not appear to predict wheat evapotranspiration accurately. The modified FAO-56 curve method underestimates wheat evapotranspiration only by 5.55 per cent. Therefore, the performance of modified FAO-56 curve method was found better than FAO-56 curve method for estimation of wheat evapotranspiration.

Yu-Lin Li *et al.* (2003) calculated crop coefficients (K_c) for spring wheat and maize from the measured crop evapotranspiration (ET_c) data and the predicted Et_0 data by the FAO-56 Penman-Monteith method, and their values were 0.55, 1.03, 1.19 and 0.65 during the initial, crop development , mid season and late-season of spring wheat, respectively, and the corresponding values for maize were 0.50, 1.02, 1.26 and 0.68.

Chuanyan and Zhongren, (2007) estimated water needs of maize (*Zea mays* L.) using the dual crop coefficient method in the arid region of northwestern China. This study was performed using the dual crop coefficient method to predict seasonal changes in evapotranspiration (ETc) for maize fields in northwestern China in 2004. The reference crop evapotranspiration ET0, an important parameter in simulating the actual crop evapotranspiration (ETc), was estimated using FAO Penman–Monteith equation. The values suggested by FAO-56 were used for the basal crop coefficients (Kcb) after adjustment for the specific climatic condition in the study area. The soil evaporation coefficients (Ke) were determined for the climate, the soil, the maize growing stages, and the irrigation method. Some missing climatic parameters were calculated. The results showed that the ETc values were very low (average value of 1.09 mm day-1) except during irrigation events in the initial stage of crop growth. The ETc value increased during the crop development stage (average value of 3.67 mm day-1) and reached its peak during the mid-season stage (average value of 5.49 mm day-1), then the ETc value declined rapidly during the last crop growth stage (average value of 3.33 mm day-1).

Rank (2008) conducted a field experiment adopting 2-factorial spilt plot design. Total 16 treatments with different combinations of 3 water application levels (irrigation at 80 %,60 % and 40 % depletion of ASM) and five growth periods (vegetative, flowering, boll development, boll maturity stages and whole season) and 1 control (stress free conditions throughout season) replicating four times. The relationship between the leaf area index and crop coefficient was developed. The water balance approach was adopted to find actual evapotranspiration (ET_0) was computed using the FAO recommended Penman-monteith approach. The highest leaf area index was found as 4.430 at 160 days after sowing (DAS). The average K_C value was found as 0.52, 1.03, 1.56, 1.45 and 0.82 respectively during the eastablishment, vegetative development, flowering, ball development and ball maturity. The crop coefficient (K_C) under water stressed condition was reduced.

Allen (2009) estimated daily crop coefficients (Kc) for irrigated cotton (Gossypium hirsutum L.) at the Louisiana State University (LSU) Agriculture Center Northeast Research Station near St. Joseph, Louisiana. Kc values were calculated using daily crop evapotranspiration (ETc), which was measured using paired weighing lysimeters, and daily reference evapotranspiration (ET_0), which was calculated using the Standardized Reference Evapotranspiration Equation (SREE) for a short crop. Meteorological data for input into the SREE were obtained from a nearby Louisiana Agriclimatic Information System (LAIS) Weather station and an on-site portable weather station. Averaged Kc values were 0.15, 0.64, and 1.39 for the initial (day 22 to 29), development (day 30 to 69), and mid-season (day 70 to 136) stages. The beginning of the mid-season stage corresponded closely with first flower (FF), maximum internodes length, and 80 percent crop canopy cover. Also, the relationship between Kc and day after planting was determined for each stage. Kc values from this study can be used to estimate ETc for irrigated cotton in a clay soil in northeastern Louisiana.

Bryla *et al.* (2010) worked on weighing lysimeter for developing crop coefficients and efficient irrigation practices for vegetable crops. Crop coefficients are used by both growers and researchers to estimate crop water use and accurately schedule irrigations. Two lysimeters of this type were installed in 2002 in central California to determine dailyrates of crop and potential (grass) evapotranspiration and develop crop coefficients for better irrigation management of vegetable crops. From 2002 to 2006, the crop lysimeter was planted with broccoli, iceberg lettuce, bell pepper, and garlic. At midseason, when groundcover was greater than 70% to 90%, Kcb was ’1.0 in broccoli, 0.95 in lettuce, and 1.1 in pepper, and Kcb of each remained the same until harvest. Garlic Kcb, in comparison, increased to 1.0 by the time the crop reached 80% ground cover, but with only 7% of additional coverage, Kcb continued to increase to 1.3, until irrigation was stopped to dry the crop for harvest. Three weeks after irrigation was cutoff, garlic Kcb declined rapidly to a value of 0.16 by harvest. The new crop coeficients will facilitate irrigation scheduling in the crops and help to achieve full yield potential without over irrigation.

Liu *et al.* (2010) studied a consolidated evaluation of the FAO-56 dual crop coefficient approach using the lysimeter data in the North China Plain to evaluate whether not the dual crop coefficient (DCC) method proposed in FAO-56 was suitable for calculating the actual daily evapotranspiration of the main crops (winter wheat and summer maize) in the North China Plain (NCP). The results were evaluated with the data measured by the large-scale weighing lysimeter at the Yucheng Comprehensive Experimental Station (YCES) of the Chinese Academy of Sciences (CAS) from 1998 to 2005 using the Nash-Sutcliffe efficiency (NSE), the root mean square error (RMSE) and the root mean square error to observations' standard deviation ratio (RSR). The evaluation results showed that the DCC method performed effective in simulating the quantity of seasonal evapotranspiration for winter wheat but was inaccurate in calculating the peak values. The Kc (compositive crop coefficient, Kc = ETc/ ET0, ETc here is the observed values by lysimeter, ET0 is the reference evapotranspiration) values were estimated using observed weighing lysimeter data during the corresponding stages for winter wheat and summer maize were 0.80, 1.15, 1.25, 0.95; 0.90, 0.95, 1.25, 1.00, respectively.

Ahmed and Mahmoud (2010) studied effect of irrigation on consumptive use, water use efficiency and crop coefficient of sesame (*Sesamumindicum L.*). Sesame was grown for two successive seasons (2001/2002 - 2002/2003) at Shambat, Sudan. The aim of the study was to investigate five irrigation water quantities on actual evapotranspiration as compared with estimated evapotranspiration using Penman-Monteith method, modified Penman formula and pan evaporation. Water use efficiency and crop factors were calculated and the best water use efficiency was obtained under 650mm irrigation water application. Under all irrigation treatments, there was a large deviation of pan evaporation, modified Penman and Penman-monteith estimate from actually measured evapotranspiration. Crop coefficients were decreased with decreased water quantities in all treatments. Crop coefficients computed by pan evaporation were under all circumstances, lower than these obtained by modified Penman and Penman- Monteiths methods.

Suleiman *et al.* (2011**)** determined FAO-56 crop coefficients for peanut under different water stress levels. The objective of this study was to evaluate the FAO-56 crop coefficients for peanut grown under various levels of water stress in a humid climate. Two experiments were conducted in three automated rainout shelters located at the University of Georgia Griffin Campus in Griffin, Georgia, USA in 2006 and 2007. The irrigation treatments corresponded to irrigation thresholds (IT) of 40, 60 and 90% of AWC. The length of the four developmental stages was different than the values listed in FAO-56. The 2-year average absolute relative error of K cini was 8, 19 and 6% for 40, 60 and 90% IT, respectively. For the 90% IT, the FAO-56 K cmid and K cend were almost identical to the 2-year averages of the observed K cmid and K cend, respectively. The findings of this study confirmed that the FAO-56 procedure was reasonably accurate for estimating peanut ET under water stress in a humid climate.

2.5 ESTIMATION OF LEAF AREA INDEX

Many properties of crop and plant canopies affect water use. The plant species and in many cases plant variety affect physiological development, rooting depth, leaf density and orientation, plant height and plant morphology.

When the soil surface is wet ET of non-stressed plant at the potential rate irrespective to leaf canopy development. After the surface layers dries, vapor diffusion rate through the dry layer limit soil evaporation and ET is largely influenced by vegetative canopy. Under plant water stress, evaporation from dry soil is low and stomata aperture largely controls the transpiration rate. Since overlapping of leaves normally occurs on a plant canopy develops, the ET rate does not reach the potential rate until leaf area index increases about 3.0.

Plant cover greatly affects water use rates Ritchie and Burnett (1968) found that a leaf area index of about 2.7 was required for water use equal to potential rate for row crops.Due to strong relationship between evapotranspiration and leaf area index it is important to develop relationship between growth parameters and evapotranspiration is necessary for different crops. Related review of literature are as follow:

Soegaard and Boegh (1995) , measured millet crop evapotranspiration during a 2-month period from the middle of the rainy season to the beginning of the dry season. The measurements comprise continuous recording of sap flow from a number of millet plants and of evapotranspiration using the eddy correlation technique. It is shown how the leaf area index may be used for transferring the sap flow rates into real estimates of transpiration. The diurnal and seasonal variations are analyzed in relation to leaf area, leaf temperature and stomatal resistance.

Kucharik *et al.* (1998) Estimates of leaf area index obtained with indirect measurement techniques. Usually, branches are assumed to be positioned randomly with respect to leaves or shoots in the canopy. A new instrument called a Multiband Vegetation Imager (MVI) is used to capture two-band (Visible, 400-620 nm and Near-Infrared, 720-950 nm) image pairs of contrasting Canadian boreal forest canopies. The spatial relationship of branches and photo synthetically active foliage is studied to estimate the fraction of the effective branch hemi-surface area index (Be) that is masked by leaves and shoots. They suggested an approach that corrects indirect LAI measurements using the LAI-2000 or a similar instrument by correcting for the following biases: (1) the effective canopy branch hemi-surface area that is not masked by leaves or shoots in the canopy, (2) the amount of stem hemi-surface area beneath crowns, (3) leaf (or shoot) and branch non-random spatial distributions in the canopy, and (4) the fraction of maximum LAI resulting from defoliation in the canopy. In boreal aspen, MVI image analysis shows that 95% of the effective branch hemi-surface area is masked by other foliage in the canopy. These estimates suggest the fraction of indirect LAI that consists of branches intercepting light is less than 10. and do not significantly bias indirect LAI measurements. However, stems which comprise 30-50% of the total woody area in this study may not be preferentially shaded by leafy foliage. Therefore, stem contribution to indirect LAI estimates measured with the LAI-2000 or a similar instrument cannot be overlooked. MVI estimates of the total branch hemi-surface area index agree to within 10-40% of direct measurements.

Ross *et al.* (2000) proposed a statistical interpolation method which allows calculation of the leaf area index LAI (t), the downward cumulative leaf area index $L(z, t)$ and the canopy leaf area density $u(z, t)$ as the functions of height and time for any day of the growth period. The method was based on three functions: probability density of stem height, interrelationship between stem height and stem foliage area, and the shape function of stem foliage vertical distribution. The estimated values of $u(z, t)$ and those calculated by the method differ by about 10-15%.The interpolation model can be used when phytometrical data are available for certain days throughout the growing season.

Shaozhong *et al.* (2000) conducted a field study to investigate the response of leaf water potential and stomatal conductance (Cs) of maize crop to soil water adjustment coefficient (Ks) functions for estimation of actual ET under water deficit conditions. The result showed that correlation coefficients of Ks to Cs and leaf water potentials peak at 09:30 hrs and then decreased, indicating that leaf water potentials and stomatal conductance at 09:30hrs were better predictors of plant water.

Sone et al. (2009) obtained nondestructive estimates of leaf area index (LAI) using two canopy analyzers (LAI-2000 and SunScan) was compared with destructively measured LAI for four upland rice (*Oryza* spp.) cultivars with various types of canopy development during the period from 21 to 56 days after sowing (DAS). For the LAI-2000, LAI was estimated with or without the wide angle reading (Ring 5). When data from 50 and 56 DAS, which included LAI measured destructively of >4 m^2 m^{-2}, were omitted, the relationship of LAI measured destructively with LAI estimated by the SunScan was highly significant (R^2 = 0.96) and had lower root mean square error than that with LAI estimated by the LAI-2000 without Ring 5. They concluded that by restricting the range of LAI to <4 m^2 m^{-2}, the SanScan can provide reasonable estimates of LAI.

Zheng and Moskal (2009) stated that the ability to accurately and rapidly acquire leaf area index (LAI) is an indispensable component of process-based ecological research facilitating the understanding of gas-vegetation exchange phenomenon at an array of spatial scales from the leaf to the landscape. However, LAI is difficult to directly acquire for large spatial extents due to its time consuming and work intensive nature. Such efforts have been significantly improved by the emergence of optical and active remote sensing techniques. This paper reviews the definitions and theories of LAI measurement with respect to direct and indirect methods. Then, the methodologies for LAI retrieval with regard to the characteristics of a range of remotely sensed datasets are discussed. Remote sensing indirect methods are subdivided into two categories of passive and active remote sensing, which are further categorized as terrestrial, aerial and satellite-born platforms. Due to a wide variety in spatial resolution of remotely sensed data and the requirements of ecological modeling, the scaling issue of LAI is discussed and special consideration is given to extrapolation of measurement to landscape and regional levels.

Yang *et al.* (2011) studied on hyper spectral estimating models of tobacco leaf area index. Based on the pot experiment data, an evaluation of tobacco LAI retrieval methods was conducted using four vegetation indices, principal component analysis (PCA), and neural network (NN) methods. The estimated effects of the three methods were then compared. Results indicated that all three methods have ideal effects on LAI estimation. The Determination coefficients (R^2) of the validated models of vegetation indices, PCA, and NN were (0.768 ~ 0.852), 0.938, 0.889, respectively. The PCA and NN methods show higher precision. The suitability of the PCA validated model is the best because its root mean square error (RMSE) of 0.172 is smaller than those of the vegetation indices (0.237 ~ 0.322) and NN (0.195). As a Whole, the PCA and NN methods could improve the retrieval precision and were prior selection for LAI Estimation.

Cerekovic *et al.* (2010) studied the relationship between leaf area index and crop coefficient for tomato crop grown in southern Italy. A study on tomato crop evapotranspiration was conducted during 2002 in Southern Italy to investigate the influence of weather and management on crop growth and development parameters (e.g. leaf area index) and to evaluate Kc values for this climatic region. The measurements of the main weather parameters and tomato crop data were collected near Policoro (Southern Italy), at experimental station "E. Pantenelli" of Bari University and CNR-Bari. The objective of this research was to make better estimates of crop evapotranspiration (ETc) by improving seasonal crop coefficient (Kc) curves. The relationship between Kc values and leaf area index LAI was investigated using lysimeter-measured ETc data and electronic leaf area meter - leaf area index data from the Bari University and CNR-Bari experimental station located in Policoro (Southern Italy). The results indicated that the seasonal Kc can be modelled satisfactorily for either crop a logarithmic relationship between Kc and LAI.

2.6 STOCHASTIC MODELLING OF EVAPOTRANSPIRATION

Stochastic processes treat sequences that are governed by law of chance. Time series are considered as part of stochastic processes. The word 'stochastic' means, according to its Greek origin, skillful in aiming. If an individual were shooting at a target, it is likely that the density of hits near the center would be greatest and least near the edge. The location of the hits would be random with respect to the center. Thus, the word 'stochastic' has come to refer to the random nature of the variable.

The purpose of a stochastic model is to represent important statistical properties of one or more time series. Indeed, different types of stochastic models are often studied in terms of statistical time series they generate. Examples of these properties include: trend, seasonality, mean, variance, skewness, serial correlation, covariance, cross-correlation and long term properties such as the rescaled range and the variance function. Since the various statistical models are described in terms of these properties, the appropriate stochastic model and numerical value of the model parameters may be inferred from statistics of the observed time series. Models formulated on stochastic concept explain the extent of dependence of the present observation on the past observations.

The first step in stochastic model construction is to select suitable classes or families or models from which the most appropriate model to a given time series can be chosen by following the identification, estimation and diagnostic check stages of model development. For example, when modelling a hydrologic time series one may wish to consider the Auto Regressive Moving Average (ARMA) family of models (Box and Jenkins, 1976), the classes of non-Gaussian models suggested by Lewis (1985) and fractional differencing models (Hosking, 1985). Certainly if one is not aware that certain classes of models exist, one may not fit the most appropriate model to a given time series.

Stochastic processes deal with continuous or discrete state and time parameters. Discrete series occur when the random variate in the time series is continuous, but for computation and analysis purposes time is considered discrete. Discrete stochastic models may be classified in many ways. Generally, it has been subjectively decided to classify them as short memory or long memory models. Short memory models and non-stationary series may model a stationary series by long memory models.

Short memory models of hydrologic phenomena include moving average (MA) models; autoregressive (AR) models and autoregressive integrated moving average (ARIMA) models. The use of short memory models in hydrologic analysis was introduced primarily to produce synthetic sequences of flows to route through a water resources system, the idea being to test it under variety of conditions and with longer sequences of flows than historically available. Short memory models maintain the statistical characteristics of the historical series. Short memory models have also extensively been used for forecasting stream flows. The long memory models are specifically designed to reproduce the Horst phenomenon (Mandelbrot 1971).

Autoregressive model (AR) has been used extensively in hydrologic analysis. It is a very useful tool in the simulation of hydrological and climatological data. As with the moving average process, this model also works with the deviation, Zt from the mean μ of the process or sequence of events Zt. However, the autoregressive process expresses the deviation from the mean of the process, a finite weighted sum of previous deviation plus a random variate, a_t.

Thus

$$Zt - \mu = at + \Phi_1 (Z_t-1- \mu) + \Phi_2 (Z_t-2 - \mu) + \ldots\ldots + \Phi p (Z_t-p - \mu) \qquad \ldots (2.2)$$

Where,

Z_t = deviation from mean
μ = sample mean
Φ = autoregressive model parameters
p = order of moving average

is an autoregressive process of order p. It contains P+2 parameters, μ, Φ_1, Φ_2,………….. Φp and at that must be estimated from a given data.

The mathematical models can be suitably used for abstraction of complex physical phenomena. The models should be sufficiently complete in its description so as to produce useful results and sufficiently limited in its complexity as to be manageable.

Box and Jenkins (1976) have systematically discussed the time series models. Most of the recent advances in time series analysis are based on the basic work of Box and Jenkins. A comprehensive discussion on time series modelling of hydrologic variables are presented by Salas et al, (1980). Many aspects of hydrologic modelling in single variate or multi variate scenario are also discussed. Many other applications and recent advances made in the field of time series analysis applied to the field of hydrology are discussed by Hipel and McLeod (1994). Thus stochastic model can be used to predict the frequency of occurrence of certain hydrologic variable including water deficit. A brief review related to stochastic modelling is described as under:

Parlange *et al.* (1992) formulated a first order autoregressive Markovian Model AR (1) on the basis of hydrologic budget and soil water transport equation. Model prediction compared well with neutron probe measurement of soil moisture content. Derived AR (1) model parameter was used to compute the mean diffusivity of soil, which was an agreement with reported laboratory measurement. Field estimates obtained from cumulative evaporation measurements made with two large lysimeters.

Sharma (1998) used stochastic models for forecasting of stream flow data. However, there use for modeling of evapotranspiration appears to be very limited. Models formulated on stochastic concept explain the extent of dependence of the present observation on the past observations. There is a scope of exploring the possibility of stochastic modeling of evapotranspiration.

Gupta and Kumar (1994) developed the stochastic series of the weekly evaporation data of the Palanpur, Himachal Pradesh. It was concluded that there was no trend, periodicity of the periodic component was found to be 52. The stochastic component was selected on the basis of least residual variance and final relationship was developed to predict the evaporation on weekly basis.

Hameed *et al. (*1995) developed a dynamic relationship between reference evapotranspiration and commonly observed climatologically parameters through the utilization of maltiple input transfer-function–noise modeling techniques and subsequent forecasting of evapotranspiration by such relationships.

Mailhol *et al.* (1997) describes the structure and testing of PILOTE 1.3, an operative water balance model that predicts actual ET and yield of crops. The model simulates the LAI using a water stress index and thermal time, which is calculated, from air temperature. When tested against independent data the model generates reliable predictions of actual ET and yields of sorghum and sunflower ($r^2 > 0.93$).

Raghuwanshi and Wallender (1997) determined the spatial variability of evapotranspiration with irrigation intervals and modeled temporal variability of average ET as a stochastic process. Spatial variability of total ET within the chosen time interval reflected the variability in irrigation requirements. They showed that stochastic irrigation scheduling could be performed knowing the spatial variability of ET and temporal correlation structure of ET.

Bhakar (2000) developed a stochastic model for the weekly evaporation values using 20 years data under the climatic conditions of Udaipur. Validation of the developed model was done by comparison of estimated values with measured values. The stochastic model was found to predict evaporation very accurately. Stochastic model was also developed for estimation of daily wheat evapotranspiration and daily green gram evapotranspiration using 20 years data. The developed stochastic model for wheat evapotranspiration and green gram evapotranspiration were found to predict the daily crop evapotranspiration very accurately.

Raghuwanshi and Wallender (2000) stressed the importance of accurate irrigation scheduling, better farm water management and operation of water delivery systems for forecasting grass reference crop evapotranspiration (ET0). Daily ET0 values were forecasted using a time domain methodology and historical ET0 values for Davis, California. The underlying stochastic process of daily ET0 was characterized by both the first order auto regressive [AR (1)] and auto regressive moving average [ARMA (1,1)] models. Performance of these models was evaluated. The forecasted ET0 values wee compared with the historical mean ET0 series. For each parameter estimation methods, the ARMA (1,1) models outperformed the AR (1) model and the least square method produced the best estimates of parameters. Because forecasted error was only 0.11 mm/day, the model could be used to forecast the daily ET0 values accurately.

Kumar (2001) developed a stochastic model for estimation of daily maize evapotranspiration using 23 years data. Validation of the developed model was done by comparison of estimated values with measured values. The developed stochastic model for maize evapotranspiration was found to predict the daily crop evapotranspiration very accurately.

Pandey (2002) developed a stochastic model for the estimation of daily blackgram evapotranspiration using 24 years data. Validation of the developed model was done by the serial correlation analysis and sum of squares test, which confirmed the appropriateness of the model. Hence the model may be employed to generate black gram evapotranspiration data for planning and designing of irrigation schemes in Udaipur region.

Kumar (2002) developed a stochastic model for the estimation of daily okra evapotranspiration. Validation of the developed model was done by the serial correlation analysis and sum of squares test, which confirmed the appropriateness of the model. Hence the model may be employed to generate black gram evapotranspiration data for planning and designing of irrigation schemes in Udaipur region.

Bhakar and Singh (2008) worked on stochastic modelling for mean monthly wind speed of Udaipur using 26 years (1978-2003) data. The performed statistical tests indicated that the series of the monthly wind speed data is trend free. The periodic component can be represented by third harmonic expression. The coefficient between generated and measured mean monthly wind speed series was 0.9995 and found to be highly significant at 1 per cent level.

Bhakar *et al.* (2008) conducted a study to develop stochastic model for monthly minimum and maximum relative humidity using 12 years (1992-2003) data of Banswara. The performed statistical test indicates that the series of monthly minimum and maximum relative humidity data are trend free. Their periodic components can be presented satisfactorily by the second harmonics. The stochastic components of both monthly minimum and maximum relative humidity follow second order Markov model. Validation of generated series was made with measured series. High correlation coefficients of 0.9980 and 0.9976 for mean monthly minimum and maximum relative humidity respectively were observed.

Machiwal and Jha (2008) evaluated the twenty-nine statistical tests for detecting time series characteristics by applying them to analyze 46 years of annual rainfall, 47 years of 1-day maximum rainfall and consecutive 2-, 3-, 4-, 5- and 6-day maximum rainfalls at Kharagpur, West Bengal, India. The performance of all the tests was evaluated. No severe outliers were found, and both the annual and maximum rainfall series were found to be normally distributed. Based on the known physical parameters affecting the homogeneity, the cumulative deviations and the Bayesian tests were found to be superior to the classical von Neumann test. Similarly, the Tukey test proved excellent among all the multiple comparison tests. These tests indicated that all the seven rainfall series are homogeneous. Two parametric t tests and the non-parametric Mann-Whitney test indicated stationarity in all the rainfall series. Of 12 trend detection tests, nine tests indicated no trends in the rainfall series. The Kendall's Rank Correlation test and the Mann-Kendall test were found equally powerful. Moreover, the Fourier series analysis revealed no apparent periodicities in all the seven rainfall series. The annual rainfall series was found persistent with a time lag of nine years. All the rainfall series were subjected to stochastic analysis by fitting 35 autoregressive moving-average (ARMA) models of different orders. The best-fit models for the original annual rainfall and 1-, 2- and 3-day maximum rainfall series were found to be ARMA(0,4), ARMA(0,2), ARMA(0,2) and ARMA(3,0), respectively. The best-fit model for the logarithmically transformed 4-day maximum rainfall was found to be ARMA(0,2). However, for the inversely transformed 4-, 5- and 6-day maximum rainfall series, ARMA(0,1) was obtained as the best-fitmodel. It is concluded that proper selection of time series tests and use of several tests is indispensable for making useful and reliable decisions.

Asokan *et al.* (2010) developed and evaluated evapotranspiration (ET) models for zaid and kharif groundnut under climatic conditions of Udaipur. Pan evaporation data for the duration of thirty two years (1978-2009) and measured zaid and kharif groundnut evapotranspiration data by soil moisture depletion method were analysed. The crop coefficient curves were developed for zaid and kharif groundnut by FAO-56 curve method, modified FAO-56 curve method and quadratic curve method. The performance of modified FAO-56 curve method was found to be better than FAO-56 curve method and quadratic curve method. Modelling of zaid and kharif groundnut evapotranspiration was made with the help of pan evaporation method. The performance of the methods based on crop coefficient for estimation of zaid and kharif groundnut was found to be better than pan evaporation method. The reference evapotranspiration (ET_0) was estimated by Penman–Monteith FAO-56 method. The climatological data was taken from the Meteorological Observatory established at the instructional farm of College of Technology and Engineering, Udaipur. Models of zaid and kharif groundnut evapotranspiration rate and cumulative zaid and kharif groundnut evapotranspiration were developed on the basis of time and plant growth parameters, like leaf area index and plant height. The performance of all these models developed was found quite satisfactory under climatic conditions of Udaipur. Stochastic model was developed for the estimation of daily zaid and kharif groundnut evapotranspiration using thirty two years data (1978-2009). The developed stochastic model for zaid and kharif groundnut evapotranspiration was found to predict the daily zaid and kharif groundnut evapotranspiration very accurately.

Pandey *et al.* (2011) studied stochastic modelling of actual black gram. The study was undertaken to develop and evaluate evapotranspiration model for black gram (Vigna Mungo L.) crop under climatic conditions of Udaipur, India. Pan evaporation data for the duration of twenty three years (1978-2001) and measured black gram evapotranspiration data by electronic lysimeter for duration of kharif season of 2001 were used for analysis. Black gram is an important crop of Udaipur region. No sys-tematic study on modelling of black gram evapotranspiration was conducted in past under above said cli-matic conditions. Therefore, stochastic model was developed for the estimation of daily black gram evapotranspiration using 24 years data. Validation of the developed models was done by the comparison of the estimated values with the measured values. The developed stochastic model for black gram evapotran-spiration was found to predict the daily black gram evapotranspiration very accurately.

The review of different models of evapotranspiration indicates that different workers have developed many models of evapotranspiration under different climatic conditions during last many years. It is important to adopt the relationships that are based on sound physical laws and principles. It may be pointed out that a single model does not necessarily predict the accurate results in all type of climatic conditions. It is desirable to develop appropriate models for dependable estimation of evapotranspiration of crops in a specific climatic condition. Present study was, therefore, undertaken tos develop models for spring mint evapotranspiration under climatic condition of Udaipur.

III - MATERIALS AND METHODS

This chapter includes the methodology adopted in achieving the sets of objectives in the light of basic background data, the location of the study area and its characteristics features and other relevant components of the study.

3.1 LOCATION OF THE STUDY AREA

The Instructional Farm, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture & Technology, Udaipur (Raj.) was used for collecting ET data of Mint (*Mentha arvensis* L). Udaipur is situated on latitude of 24°-35’ north and longitude of 37°-42’ east and at an elevation of 582.17 meters above mean sea level.

3.2 COLLECTION OF EVAPORATION AND METEOROLOGICAL DATA

The data of pan evaporation, air temperature, relative humidity, wind speed and sun shine hours, were collected from Meteorological Observatory of the College of Agriculture, Maharana Pratap University of Agriculture & Technology, Udaipur, Rajasthan. Meteorological data for a period of twelve years were used in the study.

Pan evaporation observations were taken with the standard U.S. Weather Bureau Class ‘A’ pan covered with wire mesh. The U.S. Weather Bureau Class ‘A’ pan was adopted by the World Meteorological Organization and the International Association of Scientific Hydrology as a reference instrument for evaporation measurement.

The USWB Class ‘A’ pan evaporimeter is 122 cm in diameter and 25 cm deep. The bottom, supported on a wooden frame, is raised 15 cm above the ground surface to allow free circulation of air beneath it. The pan evaporimeter is placed on level ground inside the Meteorological Observatory. The water surface in the pan is kept 5 to 7.5 cm below the rim of the pan. The evaporation is measured each morning by means of hook gauge in stilling well which provides an undisturbed water surface around the hook gauge and the support of the gauge.

Air temperature data were obtained from maximum and minimum thermometers housed in a Stevenson screen. Thermo- hydrograph and dry and wet bulb thermometers located in Stevenson screen are used to provide relative humidity values. Anemometer was used to measure the wind speed. An Anemometer is installed at a height of 3 m above the ground. Bright sunshine hours were measured with the help of Campbell Stokes Sunshine recorder. The recorder is positioned over a concrete pillar at a height of 3 m from the ground and at a place where there is no obstacle to obstruct the sunrays at any time of the day during the whole year.

3.3 MEASUREMENT OF MINT EVAPOTRANSPIRATION

The estimation of mint evapotranspiration was carried out by using Soil Moisture Depletion Method. This method involves measurement of soil moisture various depths at a no. of times throughout the growth period. The soil moisture measurement was done using gravimetric method. In this method soil moisture sample was taken with the help of soil auger at different places and at the depths of 15 cm, 30 cm and afterwards soil moisture was calculated as per proposed method. Consumptive use (Cu) or evapotranspiration is calculated from the change in the soil water content in successive samples from following equation.

$$\mathrm{C}u = \sum_{i=1}^{n} \frac{M_{1i} - M_{2i}}{100} Ai\ Di \qquad \ldots (3.1)$$

Where,

Cu = water use from the root zone for successive sampling periods or within one irrigation cycle, mm

n = number of soil layers sampled in the root zone depth D

M_{1i} = soil moisture percentage at the time of first sampling in the i^{th} layer

M_{2i} = soil moisture percentage at the time of second sampling in the i^{th} layer

A_i = apparent specific gravity of the i^{th} layer of the soil

D_i = depth of the i^{th} layer of the soil, mm.

The apparent specific gravity of the soil at the depth of 15 cm and 30 cm is taken as 1.57. The grass based reference evapotranspiration, ET_0 is calculated by ET_0 calculator (Version 3.1, 2009).

3.4 ESTIMATION OF REFERENCE EVAPOTRANSPIRATION BY FAO-PENMAN-MONTEITH METHOD

Many equations have been developed for estimating reference evapotranspiration **(**ET_0). The most common Penman- Monteith FAO-56 equation was used for the estimating reference evapotranspiration for the present study. The equation represents a basic general description of reference evapotranspiration process as follows (Allen *et al.*, 1998):

The reference evapotranspiration (ET_0) will be calculated by the following FAO-Penman-Monteith Equation:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34U_2)} \qquad \ldots (3.2)$$

where,

ET_0 **=** reference evapotranspiration (mm day^{-1})

G = soil heat flux density (MJ M^{-2} day^{-1})

R_n = net radiation (MJ M^{-2} day^{-1})

T = mean daily air temperature (^{0}C)

γ = Psychrometric constant (kPa ^{0}C^{-1})

Δ = Slope of saturation vapour pressure function (kPa ^{0}C^{-1})

e_s = saturation vapour pressure at air temperature T (kPa)

e_a = actual vapour pressure at dew point temperature (kPa)

U_2 = average daily wind speed at 2 m height (m sec^{-1}**)**

3.5 DEVELOPMENT OF CROP COEFFICIENT CURVES FOR MINT

Crop evapotranspiration was determined by the crop coefficient approach where by the effect of various weather conditions were incorporate into reference evapotranspiration and the crop characteristics into the crop coefficient (K_C)

$$ET_C = K_C * ET_O \qquad \ldots (3.3)$$

where,

ET_C = crop evapotranspiration, mm day^{-1}

ET_0 = grass based reference evapotranspiration, mm day^{-1}

The effect of crop transpiration and soil evaporation were integrated into single crop coefficient. The crop coefficient (K_C) incorporates crop characteristics and averaged effect of evaporation from the soil. The calculation procedure for crop evapotranspiration, (ET_C), consists of:

1. Identifying the crop growth stage, determining their length, and selecting the corresponding crop coefficients (K_C);
2. Adjusting the selected crop coefficient (K_C) for frequency of wetting or climatic conditions during the stage;
3. Constructing the crop coefficient curves (allowing one to determine K_C values for any period during the growth period); and
4. Calculating ET_C from Equation (3.3).

The crop coefficient curves for mint crop was developed by the following methods:

(i) FAO – 56 curve method.
(ii) Modified FAO – 56 curve method.
(iii) Quadratic curve method.

The best method was decided by using the criterion of correlation coefficient at one percent level of significance, standard error and nearness to 1:1 line between measured and predicted crop evapotranspiration.

3.6 FORMULATION OF STOCHASTIC MODEL FOR MINT EVAPOTRANSPIRATION

The mathematical procedure adopted for formulation of a predictive model based on stochastic component has been discussed in the following subsection:

3.6.1 Stochastic Behavior of Time Series

First step in the analysis of data is to determine its various statistical parameters. Mean, variance, coefficient of variation, skewness coefficient and kurtosis of data were estimated using the following equations:

Mean of the data is given by:

$$\overline{X} = \frac{1}{N}\sum_{i=1}^{N} X_i \qquad \dots\ (3.4)$$

where,

X_i = data sequence

$\overline{X}$ = arithmetic mean

N = number of data point

Variance of the data (σ^2) can be expressed as

$$\sigma^2 = \frac{1}{N-1}\sum\left(X_i - \overline{X}\right)^2 \qquad \text{... (3.5)}$$

Coefficient of variation CV is calculated as

$$C_V = \frac{\sigma}{\overline{X}} \times 100 \qquad \text{… (3.6)}$$

Skewness characterized the degree of symmetry of a distribution around its mean. Positively skewed distribution will have greater variation towards the higher values of variables and a negatively skewed distribution will have greater variation towards the lower values of variables. The equation of skewness is defined as:

$$Skewness = \frac{N(N-2)}{N-1}\sum_{i=1}^{N}\left(\frac{X_i - \overline{X}}{\sigma}\right)^3 \qquad \text{... (3.7)}$$

Kurtosis characterized the relative peaked or flatness of a distribution compared with the normal distribution. Positive kurtosis indicates a relatively peaked distribution, whereas negative kurtosis indicates a relatively flat distribution. Kurtosis can be expressed as:

$$Kurtosis = \left\{\frac{N(N+1)}{(N-1)(N-2)(N-3)}\sum_{i=1}^{N}\left(\frac{X_i - \overline{X}}{S}\right)^4\right\} - \frac{3(N-1)^2}{(N-2)(N-3)} \qquad \text{... (3.8)}$$

where,

S = sample standard deviation

The stochastic behavior of soil moisture series was identified by the estimation of certain standard statistical parameters. The method involves analysis of serial correlation coefficient at lag one and estimation of coefficient of variation of the historical time series.

3.6.2 Serial Correlation Coefficient

For a time series noted by X (t) t=1,2,3…N the serial correlation coefficient (γ_K) at lag K is estimated by the following equation:

$$\gamma_K = \frac{\sum_{i=1}^{N-K} X_i X_{j+k} - \frac{1}{N-K}\left(\sum_{i=1}^{N-K} X_i\right)\left(\sum_{i=1}^{N-K} X_{j+k}\right)}{\left[\sum_{i=1}^{N-K} X_i^2 - \frac{1}{N-K}\left(\sum_{i=1}^{N-K}(X_i)^2\right)\right]^{1/2}\left[\sum_{i=1}^{N-K} X_{i+K}^2 - \frac{1}{N-K}\left(\sum_{i=1}^{N-K}(X_{j+K})^2\right)\right]^{1/2}} \quad \text{... (3.9)}$$

Numerator in the equation 3.9 is called the auto covariance and the denominator is called the variance of the time series.

For a time series with stochastic behavior, the value of lag-one serial correlation coefficient should lie outside the range given by following equations:

$$U.L = \{[-1/(N-1)] + [1.95(N-2)/(N-1)^{3/2}]\} \quad \text{… (3.10)}$$

$$L.L = \{[-1/(N-1)] - [1.95(N-2)/(N-1)^{3/2}]\} \quad \text{… (3.11)}$$

3.6.3 Stochastic Model

The principle aim of the analysis was to obtain a reasonable model for estimating the generation process and its parameters by decomposing the original data series into its various components. Generally a time series can be decomposed into a deterministic component, which could be formulated in a manner that allow exact prediction of its value, and a stochastic component, which is always present in the data and cannot strictly be accounted for as it is made by random effect. The time series X(t) was represented by a decomposition model of the additive type as follow:

$$X(t) = T(t)+P(t)+S(t) \quad \text{... (3.12)}$$

where,

T (t) = trend component, t = 1, 2, 3… N
P (t) = periodic component
S (t) = stochastic component, including dependent and independent part

To obtain the representative stochastic model of time series, identification and selection of each component of Equation (3.12) was necessary. A systematic identification and detection of each component of X(t) was done, procedure of which was describes below:

3.6.3.1 Trend component

The trend component describes the long smooth movement of the variables lasting over the span of observations ignoring the short-term fluctuation. The basic idea here was to study only T (t) while eliminating the effect of other components. It leads to use the total seasonal data Zi, for identification of T(t) so that other components were suppressed. For detecting the trend, a hypothesis of no trend was made and following statistical tests, as suggested by Kottegoda (1980), were performed;

(i) Turning point test
(ii) Kendall's rank correlation test

(i) Turning point test:

In an observed sequence Zi, i = 1, 2, 3……… N a turning point, p , occur at time I if Z_i is either greater than Z_{i-1} and Z_{i+1} or less than the two adjacent values.
The expected number of p in a random series is

$$E(p) = 2*(N-2)/3. \quad \ldots (3.13)$$

Variance (p) can be shown as

$$\mathrm{Var}(p) = (16N-29)/90 \quad \ldots (3.14)$$

Consequently, Z can be expressed as a standard measure,

$$Z_{cal} = (P - E(p))/(\mathrm{var}(p))^{1/2} \quad \ldots (3.15)$$

which is treated approximately as standard normal deviate. This was compared with its table value, at 5% level of significance to test the trend. If the calculated value of Z is within the limit, then hypothesis of no trend is accepted.

The turning point test also indicates the randomness or non- randomness of time series. If there are too few or too many turning points then series indicates non- randomness otherwise the series is random.

(ii) **Kendall's rank correlation test**

If the series is thought to have a trend component, Kendall's rank correlation test can be used to test the significance. This measures the 'disarray' in the data. It is particularly effective if the underlying trend is of a linear type. This test, which is also referred to as the τ

test, is based on the proportionate number of subsequent observations which exceed a particular value. For a sequence X_l, X_2,…, X_N, the standard procedure is to determine the number of times, say p in all pairs of observations (X_j, X_i; j > i) that X_j is greater than X_i. The ordered (i, j) subsets are (i = 1, j = 2, 3, 4 … N), (i = 2, j = 3, 4, 5,….. , N), ……..., (i = N-1, i = N). The test is based on the static

$$\tau = \frac{4p}{N(N-1)} - 1 \qquad \text{… (3.16)}$$

$$\mathrm{Var}(\tau) = \frac{2(2N+5)}{9N(N-1)} \qquad \text{… (3.17)}$$

And a standard measure is given by

$$Z = \frac{\tau}{(Var(\tau))^{1/2}} \qquad \text{… (3.18)}$$

The standard measure Z was again compared with its table value at 5 per cent level of significance and hypothesis of no trend was tested. If the calculated value of Z is within its table value, then it can be concluded that the trend is not present in the data, and the sequence is random. If trend is present the same may be removed by regression, square root transform, log transform or any other methods. After removing the trend a trend free series can be obtained.

3.6.3.2 Periodic component

The periodic component concerns an oscillating movement, which is repetitive over a fixed interval of time (Kottegoda 1980). The existence of P(t) was identified by the correlograms, a plot of auto correlation coefficient, r, verses lag 1. The oscillating shape of the correlogram verifies the presence of P(t) , with the seasonal period P, at the multiple of which peak of estimation can be made by Fourier analysis followed by the tests for significant harmonics. The correlogram of the time series clearly shows the presence of periodic variation indicating its detection. The time series X(t) was expressed in the Fourier form as follows:

$$X(t) = A_O + \sum_{K=1}^{\infty}\left[A_K Cos\left(\frac{2Kt\pi}{p}\right) + B_K Sin\left(\frac{2Kt\pi}{p}\right)\right] \qquad \text{… (3.19)}$$

where,

$$A_O = \frac{1}{N}\sum_{t=1}^{N} X(t) \qquad \ldots (3.20)$$

$$A_K = \frac{2}{N}\sum_{t=1}^{N} X(t) Cos\left(\frac{2Kt\pi}{p}\right) \qquad \ldots (3.21)$$

and

$$B_K = \frac{2}{N}\sum_{t=1}^{N} X(t) Sin\left(\frac{2Kt\pi}{p}\right) \qquad \ldots (3.22)$$

where,

K = number of significant harmonics

P = Base period

N = number of observation points

A_K and B_K = Fourier coefficient

These coefficients were obtained by a least square fit of the data to the Kth harmonics components, than a least square approximation can be given by the finite series

$$P(t) = A_O + \sum_{K=1}^{M}\left[A_K Cos\left(\frac{2Kt\pi}{p}\right) + B_K Sin\left(\frac{2Kt\pi}{p}\right)\right] \qquad ... (3.23)$$

where, M is the number of significant harmonics (maximum,p/2). For later use, it was more convenient to use the alternate form for P(t) given as under:

$$P(t) = A_O + \sum_{t=1}^{M} D_K Cos\left(\frac{2Kt\pi}{p} - \theta_K\right) \qquad \ldots (3.24)$$

where

$$D_K = \sqrt{A_K^2 + B_K^2} \qquad \ldots (3.25)$$

and

$$\theta_K = Arc\tan\left(\frac{A_K}{B_K}\right) \qquad ... (3.26)$$

A Fbench was used for computation of the Fourier coefficients, Periodic components, and amplitude and phase angle.

In Equation (3.20) if M→ ∞, P(t) →X(t) then X (t) can be represented satisfactory by Equation(3.13) only. However it may not be practical or desirable to allow the condition

$M \rightarrow \infty$. Thus the appropriate approach would be the selection of M, which contains only those harmonics, which are significantly contributing towards X(t). With this as the objective, following tests were conducted to select an appropriate value of M.

(i) Test of analysis of Variance

(ii) Fourier decomposition of mean square.

Test of analysis of Variance: If the points r = 1,2,3,…. P indicates the time span of periodicity, than periodic function of the periodic mean, m(r) of time series can be written by replacing P(t) and A_0 by m(r) and m_o, respectively in Equation (3.29). The Fourier coefficient, αK and βK (K = 1,2, ….p/2) can be estimated as follow:

$$m_O = \sum_{r=1}^{p} \frac{m(r)}{p} \quad \text{… (3.27)}$$

$$\alpha_K = \frac{2}{p} \sum_{r=1}^{p} m(r) Sin\left(\frac{2Kt\pi}{p}\right) \quad \text{… (3.28)}$$

$$\beta_K = \frac{2}{p} \sum_{r=1}^{p} m(r) Cos\left(\frac{2Kt\pi}{p}\right) \quad \text{… (3.29)}$$

and

$$\beta_{p/2} = \frac{1}{p} \sum_{r=1}^{p} m(r)(-1)^r \quad \text{… (3.30)}$$

$$Amplitude, R_K = \sqrt{\alpha_K^2 + \beta_K^2} \quad \text{... (3.31)}$$

After determination of the Fourier coefficients, variance test was conducted for selecting the number of significant harmonics. In this test, the null hypothesis was that the variance planned by a harmonic K, which was $(N/2)(\alpha_K^2 + \beta_K^2)$ is zero. Steps were taken to test the $(\alpha_{K,}\beta_K)$ values for K = 8,7…1, in order to obtain F rations. If this values of F ratio is less than its table value at 1 and 5 per cent level of significance, the corresponding harmonics will be selected, otherwise test is to be repeated for higher harmonics until the obtained value of F ratio comes less than its table value.

Fourier decomposition of mean square: The contribution of the individual harmonics towards the mean square was calculated and the number of harmonics, which were dominantly contributing to mean square, were selected as the significant harmonics. For the zeroth and the Kth harmonics, contribution is R_K^2 and for other harmonics, the average power is $2R_K^2$. The plot of the average power verses corresponding frequency indicates the number of significant harmonics.

Cumulative periodigram test: A graphical method was employed for selecting the significant harmonics in Fourier series fit of a periodic estimate. The mean squared deviation, MSD, of periodic estimate around the mean of the periodic estimate was determined:

$$\text{MSD(u)} = \frac{1}{P}\sum_{\tau=1}^{p}(u_\tau - \bar{u})^2 \qquad \ldots (3.32)$$

Where,

MSD(u) = Mean squared deviation

u_τ = Periodic estimate

ū = Mean of periodic estimate

$= \frac{1}{P}\sum_{\tau=1}^{p} u_\tau$

Mean square deviation MSD (j) of each harmonics j was calculated by the following expression:

$$\text{MSD(j)} = \frac{1}{2}(A_j^2 + B_j^2) \qquad \text{j = 1, 2, …, p} \qquad \ldots (3.33)$$

The cumulative periodigram, P_t was determined by the following equation:

$$P_t = \frac{\sum_{j=1}^{i} MSD(j)}{MSD(u)} \qquad \text{i = 1,2 , …, p} \qquad \ldots (3.34)$$

A graph was drawn between P_t and the number of harmonics for selecting the significant harmonics. The significant harmonics were selected up to the fast increase in P_t and the rest of harmonics were rejected. The periodic component was then removed from the time series using the harmonic constants. The remaining component was the stochastic component, which was used for time series modelling.

3.6.3.3 Stochastic component

The stochastic component is constituted by various random effects, which can not be estimated exactly. In the case of evapotranspiration time series various climatic and soil parameters response to value of component without changing the cyclicity itself and thus add randomness to the time series. A stochastic model of the form of autoregressive model, AR, was used for the presentation of time series. In this model, the current value of the process is expressed as a finite. Linear aggregate of value of the process and the variate that is completely random. This model was applied to the S(t) which was treated as random variable i.e. deterministic components were removed and the residual was stationary in nature. Mathematically, an autoregressive model of order p, AR (p) can be written as

$$S(t) = \sum_{K=1}^{p} \phi_{p,K} S_{(t-K)} + a(t) \qquad \ldots (3.35)$$

$$= \phi_{p,1} S_{(t-1)} + \phi_{p,2} S_{(t-2)+\ldots\ldots\ldots} + \phi_{p,p} S_{t-p} + a(t)$$

where

a (t) = independent random number

$\Phi_{p,K}$ = Autoregressive model parameter = 1,2…p

The fitting procedure of the AR (p) model to the crop evapotranspiration series involved selection of order (p) of the model.

Selection of order of the AR (p) model: Residual variance method should be used for selection of model order.

In this method, residual variance $S_Z^2(p)$ was calculated using following equation for different orders.

$$S_Z^2(p) = \frac{1}{n-2p-1} S(\mu, \alpha_1, \alpha_2, \ldots, \alpha_p) \qquad \ldots (3.36)$$

where

S (μ, α_1, α_2………α_p) is known as residual sum of squares and was calculated as follows:

$$S(\mu,\alpha_1,\alpha_2\ldots\ldots\ldots\alpha_p) = (N-P)*(C_O-\alpha_1*C_1 - \alpha_1*C_2 \ldots\ldots\ \alpha_1*C_p) \qquad \ldots (3.37)$$

Where,

N = number of observation points

α_1, α_2………α_p parameter of the corresponding model

$C_{O,}$ $C_{1,}$, C_2…. C_p auto covariance function at lag P,

P = 0,1,2…p.

The minimum value of $S^2_z(p)$ suggest an approximate order of the autoregressive model to be used further.

Based on the above procedure, and order of the AR model was selected and the model was tried with time series data.

Estimation of the autoregressive parameters: The parameter estimation deals with the estimation of autoregressive parameters of Equation (3.4). These parameters can be expressed in terms of serial correlation coefficient, as Yule – Walker equations. The general recursive formula for estimating these parameters ($\Phi_{p,K}$), where suffix p and k indicate the order in AR (p) model, respectively may be written as:

$$\phi_{p,p} = \left[\frac{r_p - \sum_{K=1}^{p-1} (\phi_{p-1,K})(r_{p-K})}{1 - \sum_{K=1}^{p-1} (\phi_{p-1,K})(r_K)} \right] \qquad \text{... (3.38)}$$

and

$$\phi_{p,K} = \phi_{p-1,K} - \phi_{p.p} . \phi_{p-1,p-K} \qquad \text{... (3.39)}$$

in Equation 3.9, r_K is the autocorrelation coefficient, auto correlation regression of the series for K and was computed, for any series Y(t) at any lag , 1, as follows:

$$r_1 = \frac{\sum_{t=1}^{N-1} [Y(t) - \overline{Y(t)}][Y(t+1) - \overline{Y(t)}]}{\sum_{t=1}^{N} \left[Y(t) - \overline{Y(t)} \right]^2} = \frac{C_1}{C_2} \qquad \text{… (3.40)}$$

where

Y (t) = mean of the series Y(t)

N = total number of discrete values of X(t)

C_l = auto covariance function at lag l , l = 0,1,2,3….p

After estimating the AR parameters $\Phi_{p,K}$S(t) was calculated using Equation (3.37) computer was used for computation of model parameters and stochastic components.

The sum of the periodic and stochastic component forms the generated value of the observed data. The difference was termed as residuals, which were tested to check the adequacy of the formulated model.

3.6.4 Diagnostic Checking of the Model

Diagnostic Checking concerns the verification for the adequacy of the fitted model. The examination of the auto correlation structure of the residuals provides the powerful way of diagnostic checking. The residual were examined for any lack of randomness. If the residual were not random or were auto correlated, the model has to be modified until the residual becomes uncorrelated. The residual, a(t), record defined by the difference estimated by Equation (3.41) was used in analyzing the closeness of fit of the formulated model.

$$a(t) = S(t) - \sum_{K=1}^{p} \phi_{p,K} . S_{(t-K)} \quad \text{... (3.41)}$$

Following tests were conducted to check the adequacy of the model.

3.6.4.1 Randomness in residual component

The autocorrelation coefficient of the a(t) were estimated for different lag l, and a correlogram was obtained.

The confidence limits at 95% tolerance limit were drawn on the plotted correlogram to test independent normal distribution. If the correlogram is well within the tolerance limits, then it can be derived from correlogram that residuals were normally distributed with zero mean and Var (1/e). The confidence limit t_1 for lag l were estimated by the following Equation suggested by Kottegoda(1980)

$$t_1 = \frac{\left[-1 \pm 1.645\sqrt{N-l-1}\right]}{N-1} \quad \text{... (3.42)}$$

3.6.4.2 Sum of square of analysis

This is the most commonly used method for appraisal of the formulated model, and is described below by Clarke (1973). It involves computation of statistical measures, R^2, in the following way:

The sum of square of residuals is given as:

$$A = \sum \left(Y_t - \hat{Y}_t\right)^2 \quad \text{... (3.43)}$$

And the sum of squares of deviation of observed value from their mean is

$$B = \sum \left(Y_t - \overline{Y}_t\right)^2 \quad \text{... (3.44)}$$

Then R^2 is the measure required and is given as

$$R^2 = \frac{(B-A)}{B} \quad \text{... (3.45)}$$

If all the residuals are Zero i.e. $R^2 = 1$ (or 100 if R^2 is expressed as a percent),it indicates perfect fitting of the formulated model. The goodness is better if the value of R^2 is closer to unity.

3.6.5 Validation of Stochastic Model

Validation of developed model was made by comparison of the generated series with the measured historical series. The variation of the generated and the measured series was presented graphically with respect to time. Linear regression was fitted between generated and measured series. The relationship between generated and measured series was presented graphically. Correlation coefficient, standard error and nearness to correlation line with 1:1 line tested the correlation. Percentage deviation of mean generated series with mean measured value of the series was also determined.

IV- RESULTS AND DISCUSSION

The experiment was conducted at instructional farm of the Rajasthan College of Agriculture, Udaipur to measure the evapotranspiration of mint crop by soil moisture depletion method. For this study pan evaporation data were collected from Meteorological observatory of the Rajasthan College of Agriculture, Udaipur, for the duration of 12 years (2000-2011). The data of other climatic parameters such as air temperature, relative humidity, wind speed and bright sunshine hours were also collected for the duration of crop period.

Evapotranspiration can be seen as an integrated effect of various climatic parameters as major contributor to irrigation requirement. The relationship of evaspotranspiration with various climatic factors helps in identification of specific parameters to be used for modeling of spring mint evapotranspiration. The evapotranspiration data are stochastic in nature. Therefore, stochastic analysis of evapotranspiration data was also made. Validation of developed model was made with measured values of spring mint evapotranspiration. The results and discussion under the different titles are as under:

4.1 VARIATION OF SPRING MINT EVAPOTRANSPIRATION WITH TIME

Spring mint was grown from 28th February 2011 to 11th June 2011 for measurement of evapotranspiration using soil moisture depletion method. The row-to-row spacing was kept 45 cm and the depth of sowing was kept 5cm and the seed rate was taken as 4.00 – 5.00 qtl (stolen) /ha for mint. All the agronomical practices were done in accordance with the standard recommendation. The koshi variety of mint was taken for the present study.

The measured values of evapotranspiration of crop (ET_{SM}) are plotted with respect to time (Figure 4.1). The measured values of mint evapotranspiration (ET_{SM}) are shown in Appendix D-1. The initial value of mint evapotranspiration was found to be about 0.5 mm day^{-1}. Mint evapotranspiration increases with growing season. It achieves its maximum value at mid season stage. It starts falling during late season stage and evapotranspiration reaches its lowest value just before harvesting the crop. The total growing season of mint crop lasted for 109 days. By visual observation the crop growth stages could be identified as initial stage, 20 days (28th February to 13th March), crop development stage, 28 days (14th March to 11th April), mid season stage, 36 days (12th April to 16th May) and late season stage 24 days

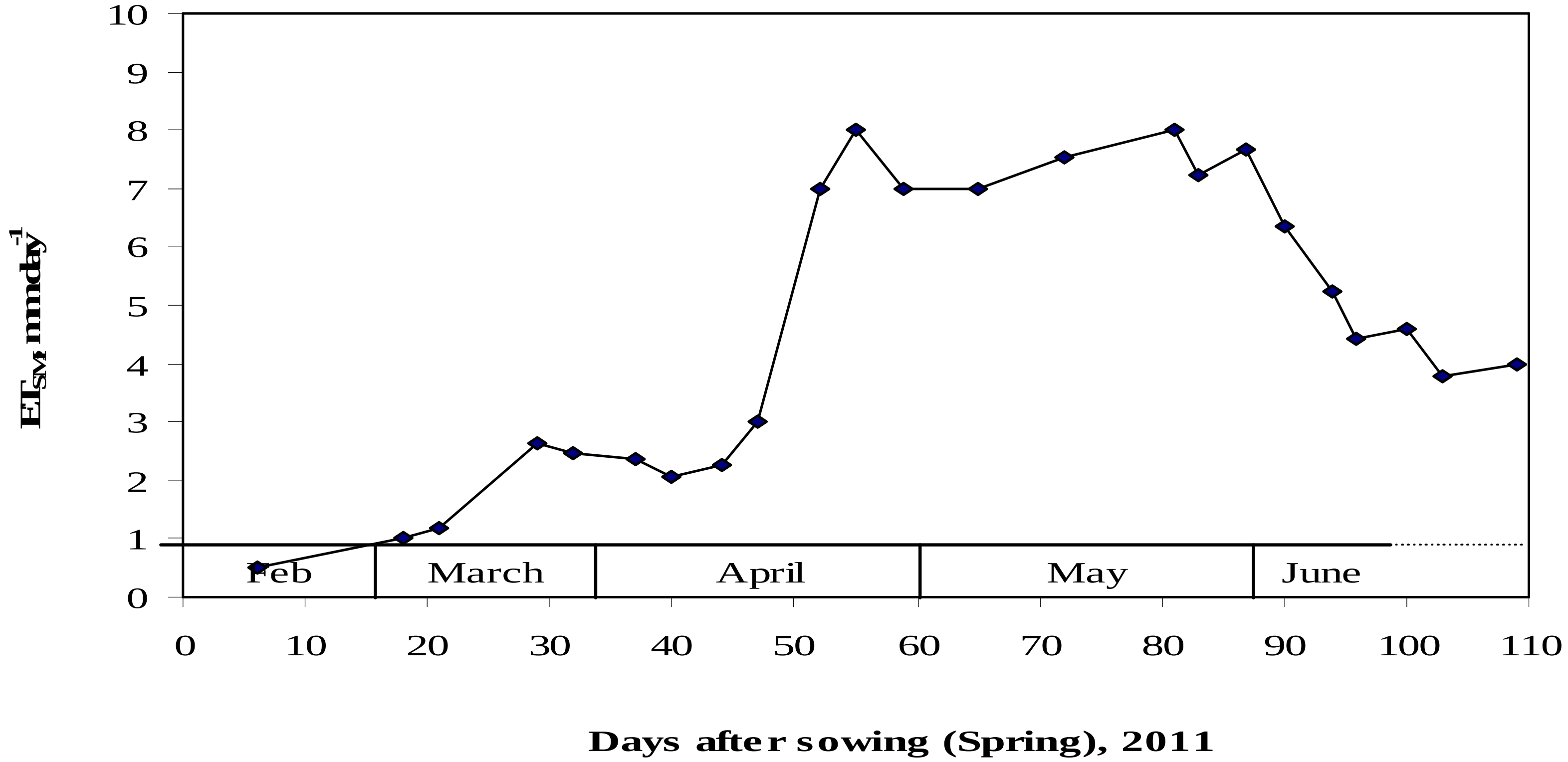

Figure 4.1 Variation of spring mint evapotranspiration rate (ET_{SM}) with respect to growing season during 2011.

(17th May to 11th June). Values of total, average, maximum, minimum mint evapotranspiration was found to be 474.39 mm, 4.58 mm day^{-1}, 8.00 mm day^{-1}, and 0.50 mm day^{-1} respectively.

4.2 DEVELOPMENT OF CROP COEFFICIENT CURVE FOR SPRING MINT

The crop coefficient curves for groundnut (K_{CSM}) were developed by:

(i) FAO-56 curve method,

(ii) Modified FAO-56 curve method and

(iii) Quadratic curve method.

4.2.1 FAO-56 Curve Method

The K_{CSM} curve for the spring mint crop was developed using the FAO-56 method (Allen *et al.,* 1998) proposed three values of crop coefficient for three important stages for development of crop coefficient curve. The crop coefficient for initial stage is referred as K_{cini} Similarly, crop coefficient for mid stage and late stages are designated as K_{cmid} and K_{cend} respectively. Allen *et al.,* (1998) tabulated the values of K_{cini}, K_{cmid} and K_{cend} for different crops under standard growing conditions.

Evapotranspiration during initial stage is predominantly in the form of evaporation. Therefore the frequency with which the soil surface is wetted during initial stage is taken into account. The value of K_{cini} is affected by the evaporating power of atmosphere, magnitude of wetting event and time interval between wetting event. The K_{cini} value for mint crop was found to be 0.5 (Allen *et al.,* 1998).

The value of K_{cmid} varies with the climatic condition and crop height. Under more arid climatic condition with greater wind speed will have higher values of K_{cmid}. More humid climatic conditions with lower wind speed will have lower values of K_{cmid}. For specific adjustment in climates where value of minimum relative humidity differ from 45 per cent or where U_2 is larger or smaller than 2.0 m s^{-1}, K_{cmid} value is determined from the following expression:

$$K_{cmid} = K_{cmid\,(TAB)} + [0.04(U_2 - 2) - 0.004\,(RH_{min} - 45)]\,(h/3)^{0.3} \qquad \ldots(4.1)$$

where,

$K_{cmid\,(TAB)}$ = Tabulated value of $K_{C\,mid}$

U_2 = Mean value of daily wind speed at 2m height during mid season growth stage for $1 \text{ m s}^{-1} \leq U_2 \leq 6 \text{ m s}^{-1}$, m s^{-1}

RH_{min} = Mean value of daily minimum relative humidity during the mid season growth stage for $20\% \leq RH_{min} \leq 80\%$, percent

h = Mean plant height during mid season stage for $0.1 \text{ m} \leq h \leq 10\text{m}$, m

The value of K_{cmid} is less effected by wetting frequency than K_{cini}, the vegetation during this stage is generally near full groundcover so that the effect of surface evaporation on K_{cmid} is smaller. During the mid season stage, mean wind speed was 2.28 m sec^{-1}. Mean value of minimum relative humidity was 25.62 per cent and height of the crop was 21.19 cm. The K_{cmid} value for mint crop was worked out to be 1.06.

The value of K_{cend} reflects crop and water management practices. The K_C value is determined from the following expression:

$$K_{cend} = K_{cend(Tab)} + 0.04(U_2 - 2) - 0.004(RH_{min} - 45)](h/3)^{0.3} \quad ...(4.2)$$

where,

$K_{cend\,(TAB)}$ = Tabulated value of K_{Cend}

U_2 = Mean value of daily wind speed at 2m height during end season growth stage for $1 \text{ m s}^{-1} \leq U_2 \leq 6 \text{ ms}^{-1}$, ms $^{-1}$

RH_{min} = Mean value of daily minimum relative humidity during the end season growth stage for $20\% \leq RH_{min} \leq 80\%$, percent

h = Mean plant height during end season stage for $0.1 \text{ m} \leq h \leq 10$ m, m

The equation 4.2 is only applied when the tabulated value of K_{Cend} exceeds 0.5. The tabulated value of K_{Cend} for mint crop was taken as 0.54.

Using values of K_{cini}, K_{cmid} and K_{cend} the crop coefficient curve for the mint crop was developed, and is presented in Figure 4.2. A comparison was made between the crop evapotranspiration estimated by FAO–56-curve method and the measured crop evapotranspiration by soil moisture depletion method for mint. The relationship was plotted in Figure 4.3 show that there exist a linear relationship between crop evapotranspiration

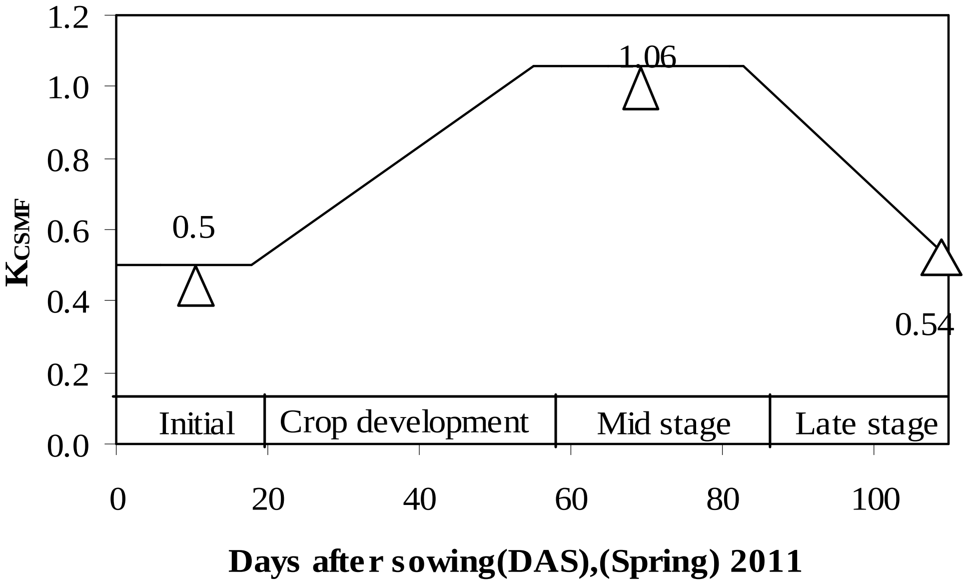

Figure 4.2 Development of crop coefficient curve for spring mint by FAO-56 (K_{CSMF}) curve method.s

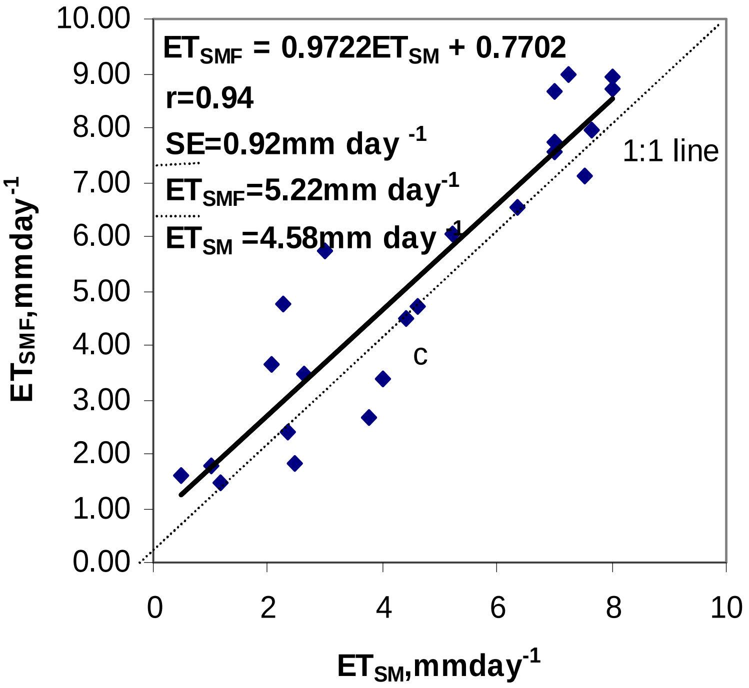

Figure 4.3 Relationship between estimated spring mint evapotranspiration by FAO - 56 curve method (ET_{SMF}) and measured spring mint evapotranspiration (ET_{SM})

estimated from FAO-56 curve method and a measured crop evapotranspiration by soil moisture depletion method. The correlation coefficients were found to be 0.94, which are significant at 1 percent level. The standard error was found to be 0.92 mm day^{-1}.

The FAO –56 curve methods overestimates the ET_{SM} values by 3.05 percent. Therefore, this method does not appear to predict mint evapotranspiration very accurately under climatic conditions of Udaipur.

4.2.2 Modified FAO –56 Curve Method

The FAO-56 curve method was modified by using actual values of the crop coefficient of mint (K_{CSM}). This method is therefore, designated as modified FAO–56 curve method. Crop coefficient values were calculated as ratio of the measured crop evapotranspiration (ET_{SM}) by soil moisture depletion method to estimate reference evapotranspiration (ET_0) using Penman-Monteith method. Figure 4.4 shows the daily K_{CSM} values during growing season of mint crop. The growing season of the mint crop may be divided into four stages:

(i) Initial stage, 20 days (28th February to 13th March),
(ii) Crop development stage, 28 days (14th March to 11th April),
(iii) Mid season stage, 36 days (12th April to 16th May), and
(iv) Late season stage 24 days (17th May to 11th June).

During the initial stage, the leaf is small and evapotranspiration is the predominantly in the form of soil evaporation. The crop coefficient for the initial stage was determined by taking the mean of K_{CSM} values for 20 days. The K_{CSM} for initial stage were found to be 0.5, which is shown by a horizontal line in Figure 4.4. As the crop develops and shades more and more of the ground, evaporation becomes restricted and transpiration gradually becomes the major process. Figure 4.4 shows that the K_{CSM} value increases during the crop development stage to the beginning of the mid season.

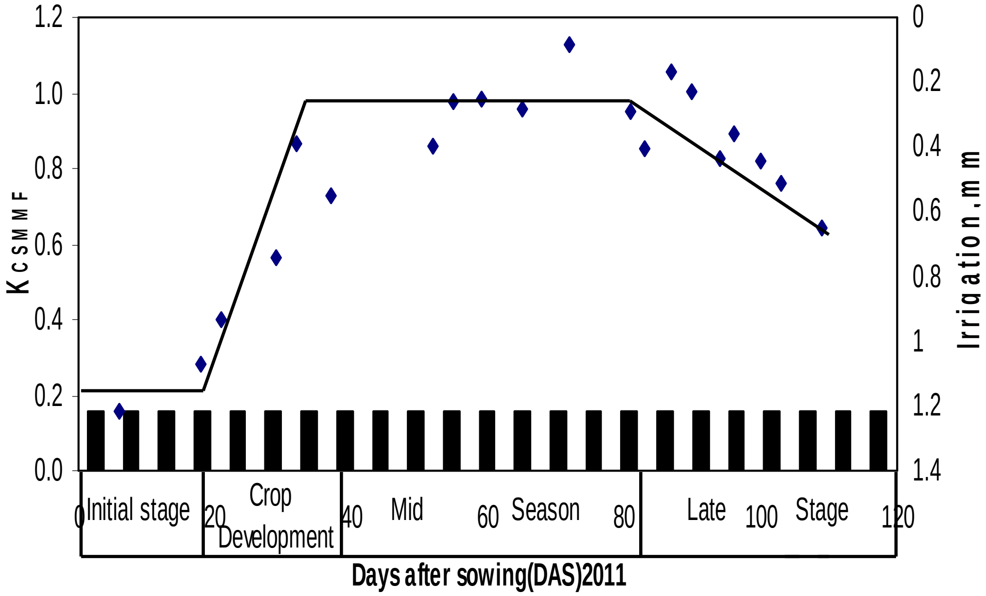

Figure 4.4 Daily K_{CSM} values, modified FAO - 56 curve (K_{CSMMF}), amount of irrigation during growing season of spring mint crop

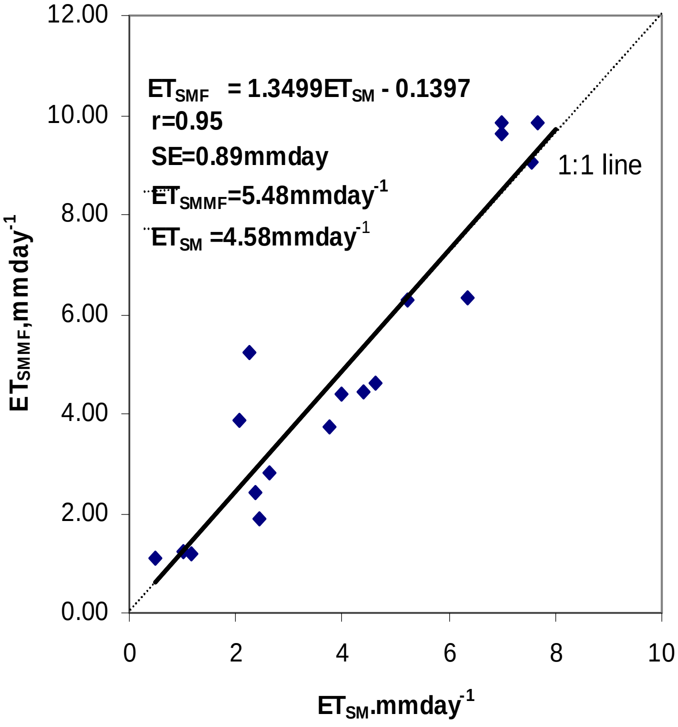

Figure 4.5 Relationship between estimated spring mint evapotranspiration by modified FAO - 56 curve method (ET_{SMMF}) and measured spring mint evapotranspiration (ET_{SM})

The midseason stage runs from full effective cover to the last of start of the maturity. The start of maturity is indicated by senesce of mint leaves. It is evident from Figure 4.4 that at mid season stage the value of K_{CSM} is higher than that at other stages of mint crop. Allen *et al.,* (1998.) indicated that some crop coefficient values might be higher following wetting of soil by irrigation. These higher values may be neglected while constructing crop coefficient curves. The K_{CSM} value for mid season stage were found to be 1.0.

The K_{CSM} values were reduced during the late season stage. The reduction is linear from the end of mid season stage to the end of maturity. The K_{CSM} values at the end of late season were found to be 0.54. By joining all stages the modified K_{CSM} curve was constructed which are shown in Figure 4.4. Dates and amount of irrigation are also indicated in Figure 4.4.

The comparison was made between crop evapotranspiration estimated by the modified FAO-56 curve method (ET_{SMMF}) and measured evapotranspiration ET_{SM} by soil moisture depletion for spring mint respectively. The relationship depicted in Figure 4.5. shows that there exists a linear relationship between crop evapotranspiration estimated from modified FAO–56 curve method (ET_{SMMF}) and measured crop evapotranspiration (ET_{SM}) by soil moisture depletion. The correlation coefficient was found to be 0.92, which are significant at 1 percent level. The standard error was found to be 0.89 mm day^{-1}. The modified FAO–56 curve method overestimates the mint evapotranspiration values by 1.33 per cent.

4.2.3 Quadratic Curve Method

The quadratic crop coefficient curve for mint was developed by fitting quadratic equation by least square method. The quadratic crop coefficient curve for mint is presented in Figure 4.6 Which shows that K_{CSMQ} values increase during initial stage and crop development stage. The K_{CSM} attains its maximum value at the mid season stage. The K_{CSMQ} value starts decreasing during the late season stage till harvesting. The fitted quadratic equation is given as follows:

$$K_{CSMQ} = -0.0002\ DAS^2 + 0.0291\ DAS + 0.1243 \qquad \ldots(4.3)$$

where,

K_{CSMQ} = quadratic crop coefficient for spring mint

DAS = days after sowing

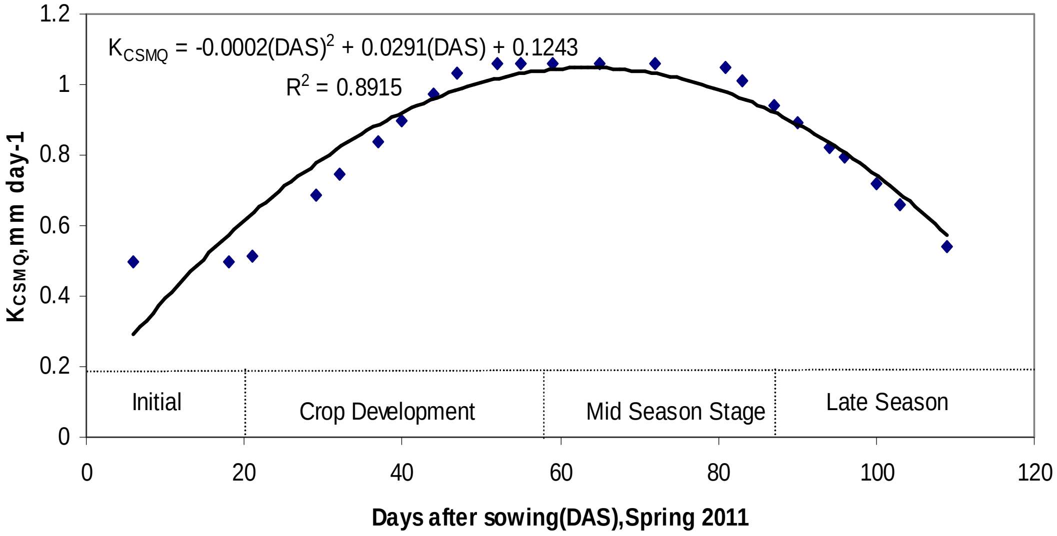

Figure 4.6 Development of crop coefficient curve for spring mint by quadratic curve (K_{CSMQ}) method

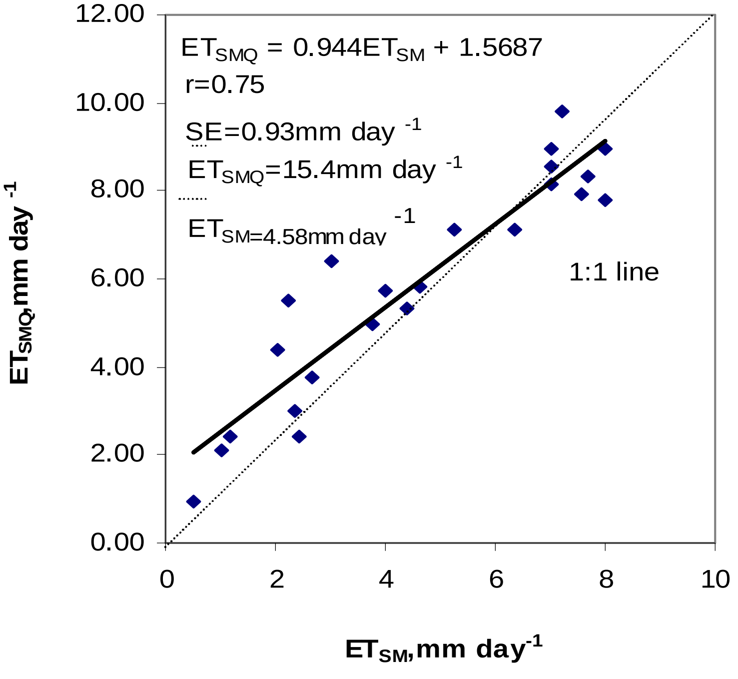

Figure 4.7 Relationship between estimated spring mint evapotranspiration by quadratic curve method (ET_{SMQ}) and measured spring m evapotranspiration

The coefficient of determination (R^2) of Equation 4.3 was found to be 0.8915. The comparison was made between crop evapotranspiration estimated by quadratic curve method (ET_{SMQ}) and measured evapotranspiration (ET_{SM}) by soil moisture depletion method for mint. The relationship is depicted in Figure 4.7 Which shows that there exists a linear relationship between crop evapotranspiration estimated from quadratic curve method (ET_{SMQ}) and a linear relationship between crop evapotranspiration estimated from quadratic curve method (ET_{SMQ}) and a measured crop evapotranspiration (ET_{SM}) by soil moisture depletion method. The correlation coefficient was found to be 0.75, which is significant at 1 per cent level. The standard error was found to be 0.93 mm day^{-1}. The quadratic curve method overestimates the mint evapotranspiration values by 28.38 percent.

Table 4.1 shows the detailed comparison of FAO-56 curve method, modified FAO-56 curve method and Quadratic curve method. It is evident from Table 4.1 that FAO-56 curve method and modified FAO-56 curve method may be used for prediction of mint evapotranspiration under climatic conditions of Udaipur.

Table 4.1 Correlation coefficient, standard error and per cent deviation of linear regression equations showing relationship between measured spring mint evapotranspiration and sestimated spring smint evapotranspiration by various methods

S.No.	Prediction Equation	Correlation Coefficient	Standard Error mm day^{-1}	% Deviation
1	FAO-56 Kc curve $ET_{SMF} = 0.9722\ ET_{SM} + 0.7702$	0.94**	0.92	3.05
2	Modified FAO-56 Kc curve $ET_{SMMF} = 0.3499\ ET_{SM} - 0.1397$	0.95**	0.89	1.33
3	Quadratic Kc curve $ET_{SMQ} = 0.944 ET_{SM} + 1.5687$	0.75**	0.93	28.38

** Significant at 1% level

4.3 RELATIONSHIP BETWEEN SPRING MINT EVAPOTRANSPIRATION AND PAN EVAPORATION

Evaporation from open water surface provides an index of the integrated effect of solar radiation, air temperature, relative humidity and wind speed on crop evapotranspiration. However, difference in water and cropped surface produces significant difference in the water loss from an open water surface and the crop. Results of a number of studies suggested the use of evaporation pan as a fairly reliable indicator of crop evapotranspiration.

The relationship between pan evaporation and crop evapotranspiration depends on the type of evaporation pan, geographical location, pan exposure and growing season of crop. Many types of evaporation pan have been employed though the U.S. weather Bureau. Class ‘A’ pan is most widely used through out the world. Since evaporation integrates many of the weather factors, the ratio of crop evapotranspiration to pan evaporation is quite significant parameter to establish the relationship between crop evapotranspiration and pan evaporation.

Daily ratios of spring mint evapotranspiration (ET_{SM}) to pan evaporation E_P are plotted with respect to time (days after sowing) in Figure 4.8. It is clear from Figure 4.8 that in the initial stage the ratio of ET_{SM}/ E_p has a smaller value 0.10. It increases with a growing season and tends to reach a maximum value 1.19 at about 59 days after sowing of mint crop. The ET_{SM}/ E_p ratio again diminishes toward maturity of mint crop.

Following relationships were developed between ET_{SM}/E_p and days after sowing of mint crop:

$$ET_{SM}/E_P = -0.0002DAS2 + 0.0304DAS - 0.234 \qquad \ldots(4.4)$$

Where,

ET_{SM} = spring mint evapotranspiration, mm day $^{-1}$,

E_p = pan evaporation, mm day $^{-1}$

The value of coefficient of determination R^2 for Equation (4.4) is 0.7019. This gives a clear indication that equation 4.4 can be used for estimation of mint evapotranspiration under climatic conditions of Udaipur.

A linear regression analysis was made for daily mint evapotranspiration (ET_{SMP}) and measured evapotranspiration ET_{SM} by soil moisture depletion method for mint. The relationship is depicted in Figure 4.9. Figure 4.9 shows that there exists a linear relationship between crop evapotranspiration estimated from pan evaporation (ET_{SMP}) and a measured crop evapotranspiration (ET_{SM}) by soil moisture depletion method. The correlation coefficient was found to be 0.92, which is significant at 1 percent level. The standard error was found to be 0.68 mm day^{-1}.

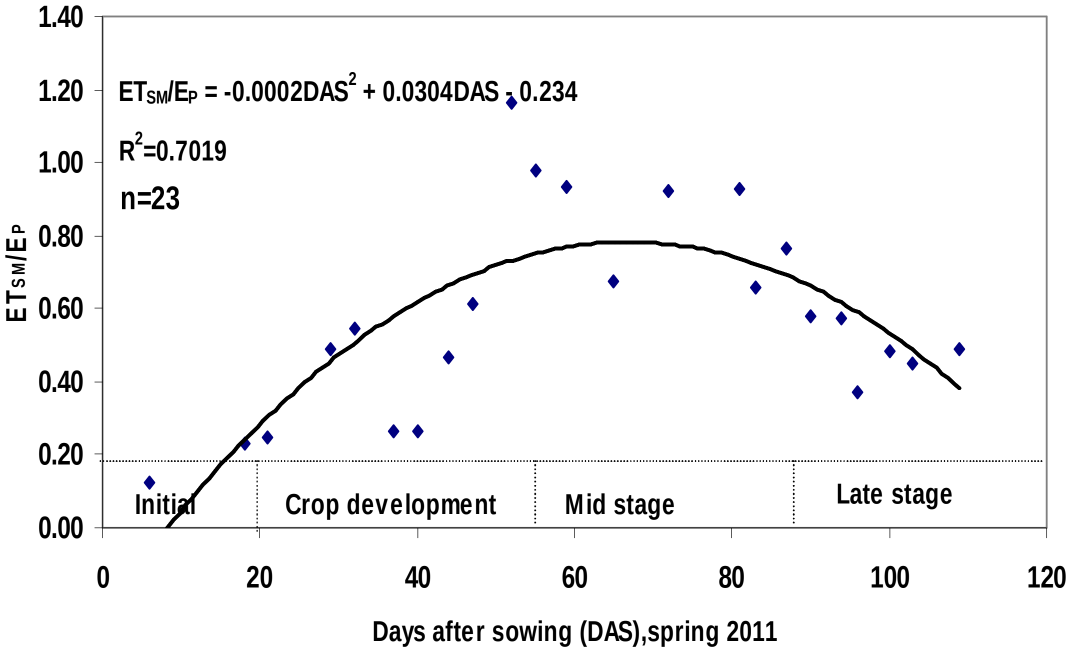

Figure 4.8 Relationship between ratio of spring mint evapotranspiration (ET_{SM}) and pan evaporation (E_P) and Days after sowing (DAS)

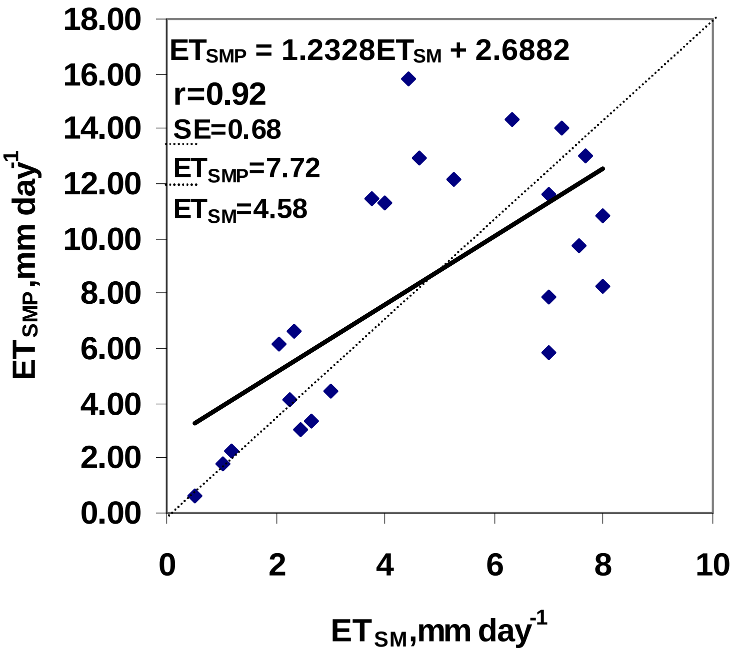

Figure 4.9 Relationship between estimated spring mint evapotranspiration by Pan evaporation method (ET_{SMP}) and measured spring mint Evapotranspiration (ET_{SM})

It may be observed from Figure 4.9, a reasonably adequate estimate of mint evapotranspiration in Udaipur region.

4.4 MODELLING OF SPRING MINT EVAPOTRANSPIRATION BASED ON TIME

Mint evapotranspiration were measured from 28th February, 2011 to 11th June, 2011 respectively by soil moisture depletion method. Modelling of mint evapotranspiration may be undertaken on the basis of rate of ET_{SM} and cumulative ET_{SMCM} and respectively with respect to time. The results of modelling of mint evapotranspiration rates and cumulative mint evapotranspiration are discussed as under:

4.4.1 Modelling of spring mint Evapotranspiration Rate

Figure 4.10 presents the rate of ET_{SM} with respect to growing season. Following quadratic curves was fitted to represent the mint evapotranspiration rate during growing season.

$$ET_{SM=} -0.0018(DAS)^2 + 0.2617(DAS) - 3.3223 \qquad ..(4.5)$$

where,

ET_{SMQE} = Spring mint evapotranspiration rate, mm day $^{-1}$

DAS = days after sowing of spring mint crop.

The values of coefficients of determination (R^2) are 0.6805. This indicates that about 69.76 percent variability of mint evapotranspiration is explained by Equation 4.5.

The comparison was made between estimated mint evapotranspiration rate (ET_{SMQE}) by equation (4.5) and measured mint evapotranspiration rate (ET_{SM}). The relationships are presented in Figure 4.11 that a good correlation (r=0.8238) exist between ET_{SMQE} and ET_{SM}. The correlation coefficient was found to be significant at 1 percent level. The standard error 0.82 of ET_{SMQE} is also quite low. Regression Equation overestimates the measured evapotranspiration by about 13.95 percent. Therefore, Equation (4.9) can be used to estimate ET_{SM} rate during growing season in this region.

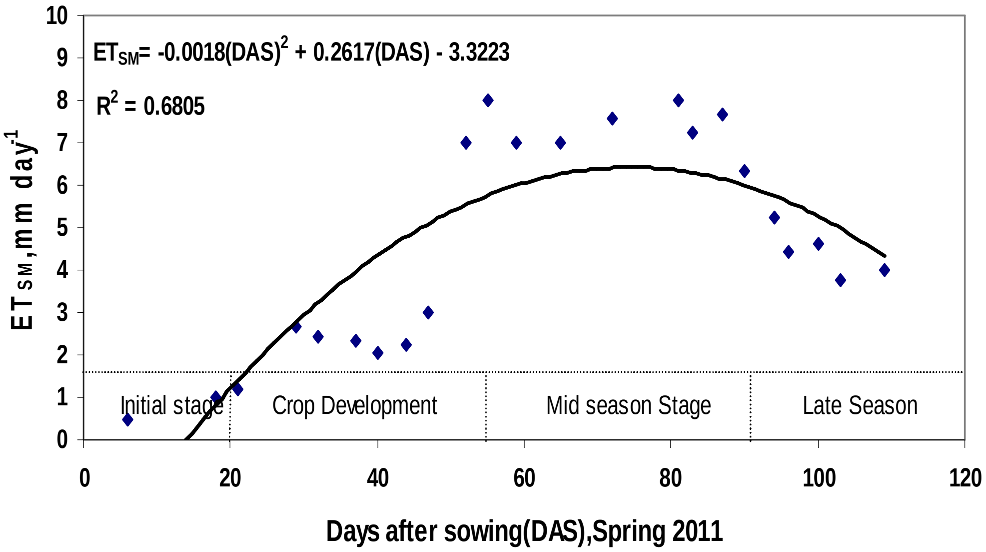

Figure 4. 10 Variation of spring mint evapotranspiration rate (ET_{SM}) with respect to growing season

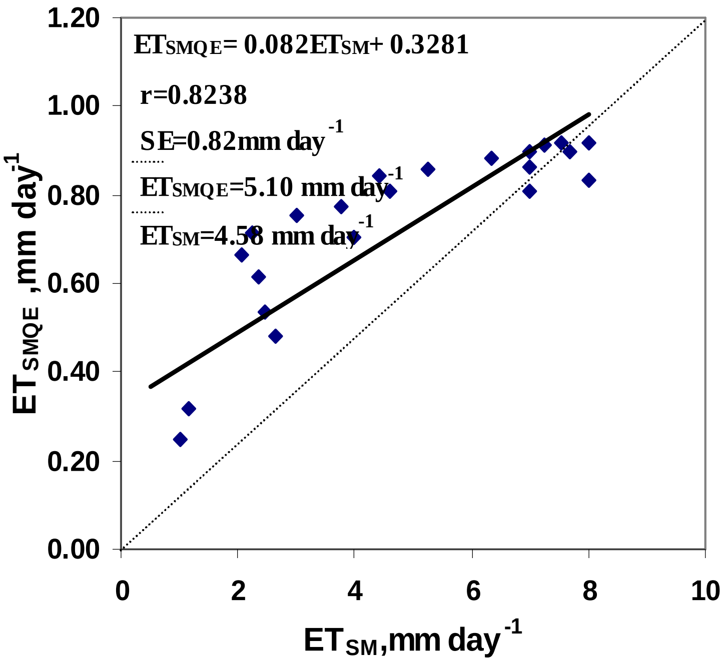

Figure 4.11 Relationship between spring mint evapotranspiration estimated by quadratic model (ET_{SMQE}) and measured spring mint evapotranspiration (ET_{SM})

4.4.2 Modelling of Cumulative Spring mint Evapotranspiration

Variations of cumulative mint evapotranspiration (ET_{SMCM}) during growing season are given in Figure 4.12. Following equations were fitted to represent cumulative mint evapotranspiration:

$$ET_{SMCM} = -0.0009(DAS)^3 + 0.2021(DAS)^2 - 6.6064(DAS) + 61.586 \qquad \ldots(4.6)$$

where,

ET_{SMCM} = cumulative mint evapotranspiration, mm

DAS = days after sowing of mint crop.

A very high value of $R^2 = 0.9992$ was obtained for Equation (4.8). This shows that 99.92 per cent of cumulative Spring mint evapotranspiration is represented by Equation (4.6). Therefore, Equation (4.6) can be used to predict cumulative mint evapotranspiration under climatic conditions of Udaipur region.

Figure 4.17 shows the relationship between estimated cumulative mint evapotranspiration ET_{SMCE} from Equation (4.6) and measured cumulative mint evapotranspiration ET_{SMCM} by soil moisture depletion method. It is evident from Figure 4.13 that a very high correlation exists between estimated cumulative mint evapotranspiration (ET_{SMCE}) and measured cumulative mint evapotranspiration (ET_{SMCM}). The correlation coefficient was found to be 0.99, which is significant at 1 percent level. The value of standard error is 10.36 mm. The estimated cumulative mint evapotranspiration overestimates the measured cumulative mint evapotranspiration only by 5.4 per cent. The regression line is very near to 1:1 line. Therefore, Equation (4.6) can be used to predict cumulative mint evapotranspiration under climatic conditions of Udaipur region.

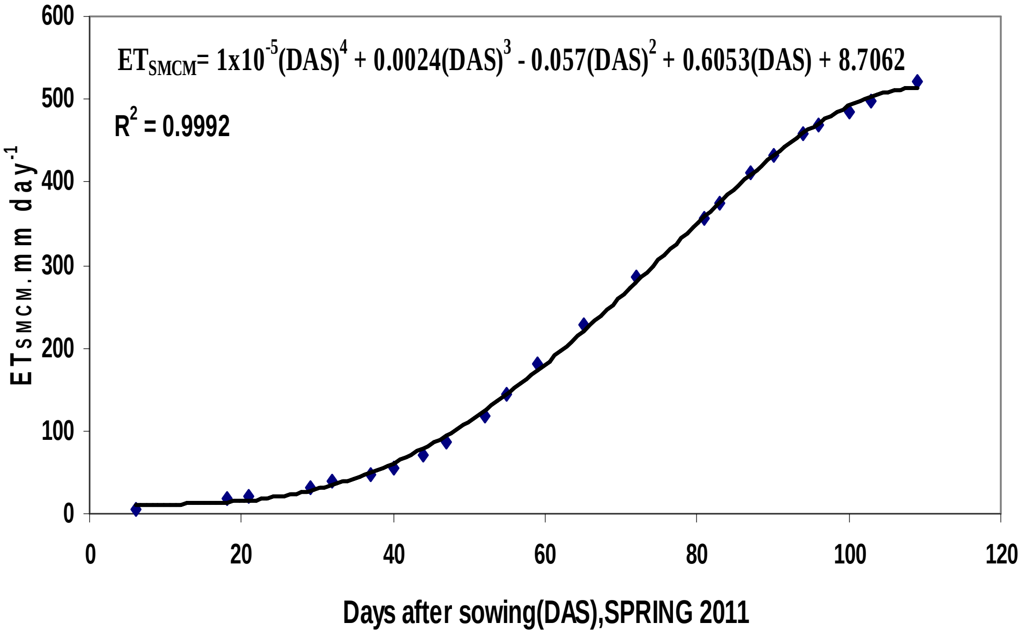

Figure 4.12 Variation of cumulative spring mint evapotranspiration (ET_{SMCM}) during growing season

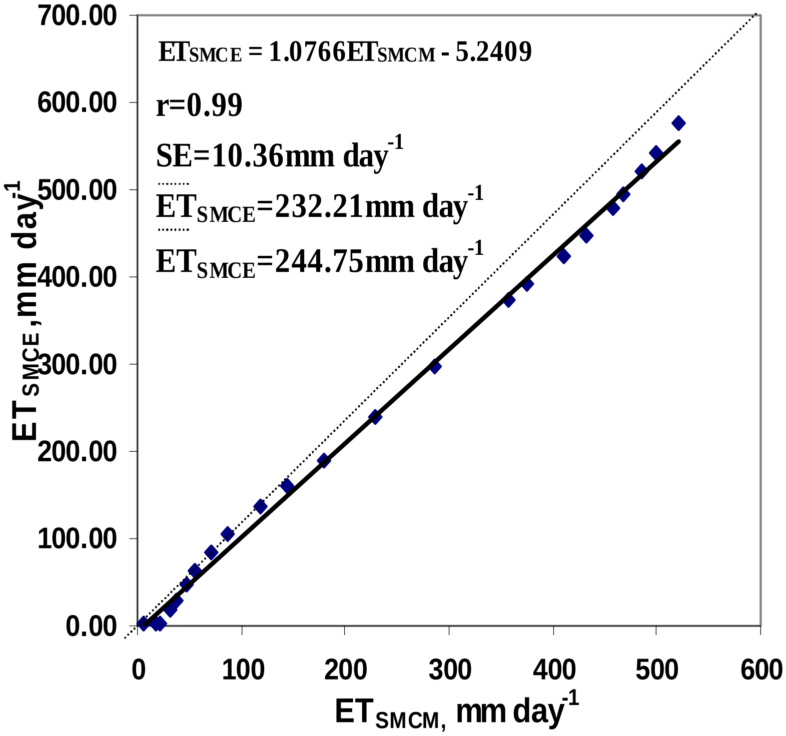

Figure 4.13 Relationship between estimated cumulative spring mint evapotranspiration(ET_{SMCE}) and measured cumulative spring mint evapotranspiration(ET_{SMCM})

4.5 MODELLING OF SPRING MINT EVAPOTRANSPIRATION BASED ON GROWTH PARAMETERS

Leaf area index (LAI) and plant height are the basic growth parameters of plant. The Leaf area index (LAI), a dimensionless quantity, is the leaf area (Upper side only) per unit area of soil below it. It is expressed as m^2 leaf area per m^2 of ground area.

Leaf area index (LAI) is the index of leaf area that actively contributes to the surface heat and vapor transfer. It is generally the upper sunlight portion of dense canopy. As the Leaf area index (LAI) and plant height increases the crop evapotranspiration also increase. But after a stage of plant it begins to decrease because of leaf senesce. The Leaf area index was measured with the help of an electronic laser leaf area meter. Plant growth parameters and corresponding values of measured mint evapotranspiration are given in Table 4.2.

Plant height increases with days after sowing but after the midseason it become almost constant. A relationship was developed between cumulative mint evapotranspiration (ET_{SMCM}) and plant height (Ht, cm) as shown in Figure (4.14). Different models were fitted and it was observed that the exponential form of model shows the good result. The coefficients of determination were found to be (0.9917). The correlation coefficient is very close to one. So the following power relationship may be used to predict the cumulative mint evapotranspiration under climatic conditions of Udaipur.

$$ET_{SMCM} = 0.093Ht_{SM}^{\ 2.5426} \qquad ...(4.7)$$

Where,

ET_{SMCM} = cumulative mint evapotranspiration, mm

Ht_{SM} = plant height, cm

Table 4.2 Plant growth parameters and corresponding values of spring mint evapotranspiration

Date	Days after sowing (DAS)	Daily mint ET_{SM}, mm day $^{-1}$	Plant height ht. Cm	Leaf area index (LAI)
28-Feb-11	6	0.5	3.6	0.554
11-Mar-11	18	1.01	8.5	0.56
14-Mar-11	21	1.17	10.80	0.59
22-Mar-11	29	2.65	12	0.6
25-Mar-11	32	2.45	14	0.62
30-Mar-11	37	2.35	15.60	0.648
3-Apr-11	40	2.05	18	0.789

Date	Days after sowing (DAS)	Daily mint ET_{SM}, mm day $^{-1}$	Plant height ht. Cm	Leaf area index (LAI)
7-Apr-11	44	2.25	22.80	0.845
10-Apr-11	47	3.00	25	0.946
15-Apr-11	52	7.00	32.60	0.95
18-Apr-11	55	8.00	34	0.97
22-Apr-11	59	7.00	38.80	0.99
28-Apr-11	65	7.01	40	1.789
4-May-11	72	7.55	42	2.198
13-May-11	81	8.00	43	2.874
15-May-11	83	7.23	43.40	3.146
19-May-11	87	7.61	44	3.961
22-May-11	90	6.34	45.50	4.589
26-May-11	94	5.24	48	4.987
28-May-11	96	4.41	50	5.279
2-Jun-11	100	4.61	52	5.769
5-Jun-11	103	3.77	53	6.349
11-Jun-11	109	4.00	54.25	6.988

A relationship was also developed between cumulative mint evapotranspiration (ET_{SMCM}) and Plant height (Ht_{SM}). Variation of cumulative mint evapotranspiration with Plant height (Ht_{SM}) is shown in Figure (4.14). The different models were fitted for obtaining the best model. It was observed that the Power model gives the best results. The coefficient of determination was found to be (0.9653) reveals that (96.53%) percent cumulative mint evapotranspiration represented by following model

$$ET_{SMCM} = 0.3968Ht_{SM}^{1.762} \quad \text{... (4.8)}$$

Where,

ET_{SMCM} = cumulative mint evapotranspiration, mm

Ht_{SM}= height of the plant for spring mint crop, m

Table 4.3 Different fitted models and coefficient of determination between cumulative spring mint evapotranspiration and plant height

S.No	Type of model	Model	Coefficient of determination (R^2)
1	Logarithmic	$ET_{SMCM} = 218.62Ln(Ht_{SM}) – 488.61$	0.6906
2	Exponential	$ET_{SMCM} = 10.417\ e^{0.07791Ht}{}_{SM}$	0.9614
3	Linear	$ET_{SMCM} = 10.999Ht_{SM} – 126.87$	0.8916
4	Power	$ET_{SMCM} = 0.3968Ht_{SM}^{1.762}$	0.9653

Table (4.3) shows that power model of cumulative mint evapotranspiration and plant height may be used for prediction of mint evapotranspiration.

The different models and the values of coefficient of determination corresponding to each model are shown in Table 4.3.

A relationship was also developed between cumulative mint evapotranspiration (ET_{SMCM}) and Leaf area index (LAI). Variation of cumulative mint evapotranspiration with Leaf area index (LAI) is shown in Figure (4.15). The different models were fitted for obtaining the best model. It was observed that the Logarithmic model gives the best results. The coefficient of determination was found to be (0.9917) reveals that (99.17%) percent cumulative mint evapotranspiration represented by following model

$$ET_{SMCM} = 202.72 \ln (LAI_{SM}) - 129.86 \qquad ...(4.9)$$

Where,

ET_{SMCM} = cumulative mint evapotranspiration, mm

LAI_{SM} = Leaf area index for spring mint

The different fitted models and their values of coefficient of determination is shown in Table 4.4

Table 4.4 Different fitted models and coefficient of determination developed between cumulative spring mint evapotranspiration and Leaf area index

S.No	**Model Type**	**Model**	**Coefficient of determination (R^2)**
1	Logarithmic	$ET_{SMCM} = 202.72 \ln (LAI_{SM}) - 129.86$	0.9917
2	Exponential	$ET_{SMCM} = 40.633e.4785^{LAI_{SM}}$	0.6429
3	Linear	$ET_{SMCM} = 83.6 LAI_{SM} - 25.066$	0.9195
4	Power	$ET_{SMCM} = 70.089 LAI_{SM}^{1.2507}$	0.8228

Table (4.4) shows that Logarithmic model of cumulative mint evapotranspiration and Leaf area index may be used for prediction of mint evapotranspiration.

The relationship was also developed between Leaf area index (LAI) and plant height for mint crop. The relationships are shown in Figure (4.16). The coefficient of determination

(R^2) was found to be 0.8759. It reveals that the model may represent 87.59 per cent values of Leaf area index. The model is represented as follow:

$$LAI_{SM}=0.2884e^{0.0538Ht}{}_{SM} \qquad ...(4.10)$$

Where,

LAI = Leaf area index

Ht_{SM}= height of the plant for spring mint crop, m

The different fitted models and their values of coefficient of determination is shown in Table 4.5

Table 4.5 Different fitted models and coefficient of determination developed between leaf area index and plant height

S.No	Model Type	Model	Coefficient of determination (R^2)
1	Logarithmic	$LAI_{SM} = 2.143Ln\ (Ht_{SM})-4.5879$	0.5043
2	Exponential	$LAI_{SM} = 0.2884e0.0538^{Ht}{}_{SM}$	0.8759
3	Linear	$LAI_{SM} = 0.1139Ht_{SM}-1.2412$	0.7269
4	Power	$LAI_{SM} = 0.0493Ht_{SM}{}^{1.088}$	0.6804

Table (4.4) shows that Exponential model of Leaf area index and plant heightmay be used for prediction of mint evapotranspiration

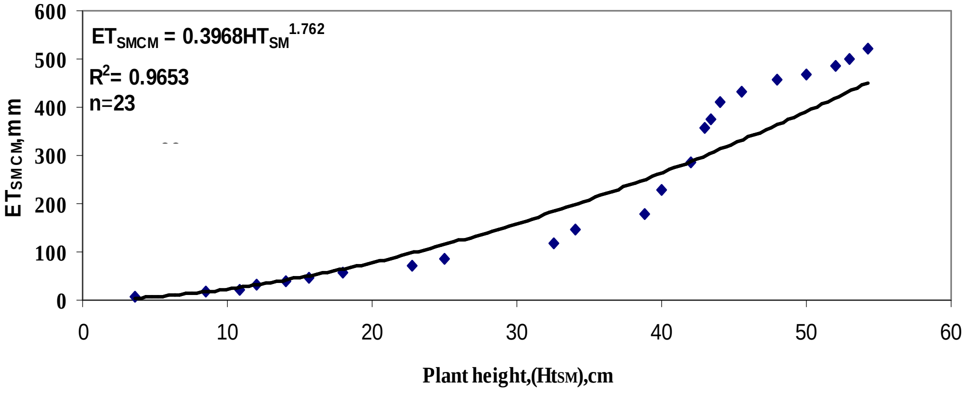

Figure 4.14 Relationship between cumulative spring mint evapotranspiration (ET_{SMCM}) and plant height (Ht_{SM}) for spring mint

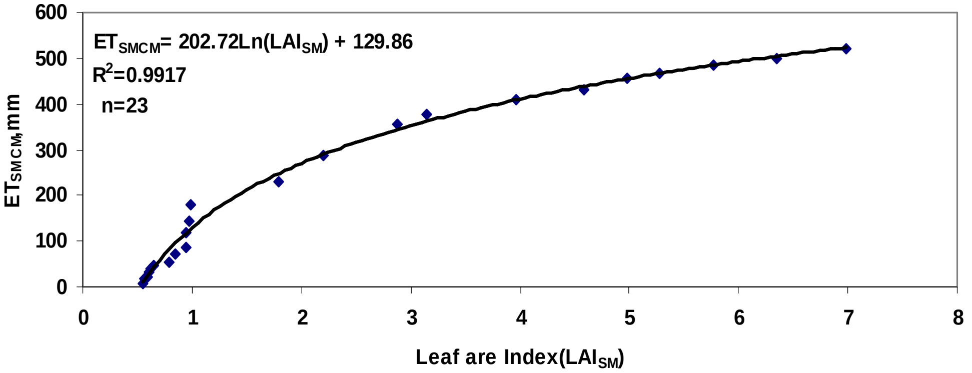

Figure 4.15 Relationship between cumulative spring mint evapotranspiration (ET_{SMCM}) and leaf area index (LAI_{SM}) for mint

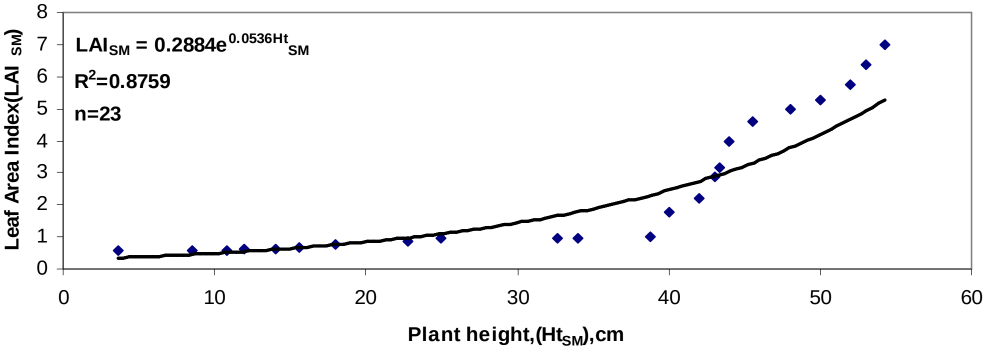

Figure 4.16 Relationship between leaf area index (LAI_{SM}) and plant height (Ht_{SM}) for Spring mint

It is very clear from the above discussion that the Equation (4.8) , (4.9) and (4.10) may be used for the modeling of mint evapotranspiration based on plant growth parameters.

4.6 STOCHASTIC MODELLING OF SPRING MINT EVAPOTRANSPIRATION

Evapotranspiration is an important weather parameter for estimation of crop water requirement. Frequently, it is required to estimate evapotranspiration of places where measured evapotranspiration data are not available. Evapotranspiration is governed by various climatic parameters. Combined effect of weather parameters adds randomness to evapotranspiration without changing the cyclicity itself. This type of series could be estimated by sum of periodic series and stochastic series. Periodic component takes into account the portion which repeats after certain duration. The stochastic component constituted by various random effects cannot be estimated exactly.

The mathematical procedure of analysis as described in Section 3.7 has been used to investigate the structure of time series of daily mint evapotranspiration. The daily mint evapotranspiration values for twelve years (2000-2011) were generated using pan evaporation values with help of Equation (4.4). The daily mint evapotranspiration series was tested for stochastic behavior. The trend series was identified for its trend component. Fourier series modeled the periodic component in the series and the residual from the Fourier series were modeled by using an autoregressive model. The results are presented as under:

4.6.1 Behavior of Daily Spring mint Evapotranspiration Time Series

For testing statistical characteristics of the daily spring mint evapotranspiration series, twelve years (2000-2011) daily mint evapotranspiration was taken and the mean daily Spring mint evapotranspiration values were generated. The mean daily series of spring mint evapotranspiration is shown in Figure 4.17. The nature of curve of Figure 4.18 confirms the presence of dependent cyclic component and independent part in the series of ET_{SM} .

The statistical characteristics of mean daily mint evapotranspiration series were estimated and presented in Table 4.5. Mean daily values vary from 1.0250 to 11.4250 mm day^{-1}. No large variability among the daily values of mint evapotranspiration of different years was observed. This was further confirmed by the estimated deviations. The standard deviation of daily mint evapotranspiration values ranged from 0.5152 to 4.4472 mm day^{-1} during the entire year. The variation may be attributed towards the natural changes in seasonal climate.

4.6.1.1 Coefficient of variation

The estimated values of coefficient of variance of mint evapotranspiration are given in Table 4.5 Which shows that the value of coefficient of variance ranges from 0.0665 to 1.3277. This signifies that importance of variability of daily mint evapotranspiration series. Since the values of coefficient of variation are significantly different from zero, it confirms that mint evapotranspiration are mutually dependent.

4.6.1.2 Serial correlation coefficient

The lag one serial correlation coefficient of observed series was calculated by using Equation (3.9) and was found to be 0.154. The respective confidence limits were estimated as 0.05 and – 0.05 by using relationship present in Subsection 3.6.4.1. Correlogram up to lag 218 of daily groundnut evapotranspiration is shown in Figure 4.18. Figure 4.18 shows that the value of lag one serial correlation coefficient lies outside the range of confidence limit and are significantly different from zero. This again confirms that groundnut evapotranspiration is mutually dependent.

From the analysis of coefficient of variance and serial correlation coefficient, it is confirmed that mint evapotranspiration process is a time variant and not an independent one. Thus, the mint evapotranspiration time series may be modeled for stochastic

Table 4.6 Statistical characteristics of mean daily spring mint evapotranspiration series for Eleven years (2000-2011)

Days after sowing	Mean ET_{SM}, mm day^{-1}	Standard Deviation	Coefficient of Variation	Skewness	Kurtosis
1	0.3805	3.2343	0.4648	-0.8439	0.0378
2	0.5731	3.3242	0.5263	-1.0963	-0.3449
3	0.7175	3.6147	0.5870	-1.0837	-0.5681
4	0.8492	4.1636	0.7358	-0.4230	-1.7742
5	1.0913	4.2645	0.8601	-0.0030	-2.0059
6	1.2841	4.4472	1.0146	0.4018	-1.7800
7	1.4655	3.6814	1.1564	1.0899	-0.3401
8	1.6544	3.5214	1.2005	1.0959	-0.4729
9	1.8912	2.6489	1.1905	1.4156	0.7242
10	2.0495	2.6775	1.3277	1.9177	2.6603
11	2.2984	1.8362	1.2810	2.7909	8.4562
12	2.4437	0.7124	0.6950	0.9807	0.7544
13	2.6122	0.6184	0.5798	0.6712	-0.0996
14	2.8349	0.5152	0.4684	0.2393	-0.7372
15	3.2618	0.6890	0.5011	0.2557	-1.2481
16	3.4275	0.8507	0.5317	0.5699	-0.4424

Days after sowing	Mean ET_{SM}, mm day^{-1}	Standard Deviation	Coefficient of Variation	Skewness	Kurtosis
17	3.5164	0.8192	0.4615	0.5867	-1.0108
18	3.6148	0.8469	0.4324	-0.0693	-1.4278
19	3.8779	1.0722	0.5273	0.5309	-0.8703
20	4.2227	1.0466	0.4652	0.5352	-0.6051
21	4.3525	0.9995	0.3932	0.0556	-1.3250
22	4.7334	0.9147	0.3357	-0.0219	-1.3225
23	5.0675	1.1506	0.3682	0.1751	-0.5680
24	5.4356	1.2063	0.3693	0.0034	-1.8785
25	5.4139	1.0527	0.3182	-0.2164	-0.8529
26	5.6292	1.1810	0.3128	0.1340	-1.3788
27	5.7872	0.9545	0.2529	0.5794	-1.5055
28	6.2837	1.1488	0.2958	0.0206	-1.4500
29	6.6693	1.0472	0.2539	-0.4681	-0.6307
30	6.6078	1.0439	0.2632	-0.5500	-1.1053
31	6.7883	1.3102	0.2961	0.5481	-0.1708
32	6.2100	0.9050	0.2084	0.2261	0.1006
33	6.5800	1.4444	0.3175	-0.2541	-1.2499
34	6.5800	1.3056	0.2783	0.4103	-0.5355
35	6.8940	1.5465	0.3052	0.5334	1.2394
36	6.5840	1.4594	0.2542	0.2823	-0.9833
37	6.2590	1.2434	0.2317	-0.5928	2.3252
38	6.5800	1.4759	0.2578	-0.2571	-0.1268
39	6.2917	1.2724	0.2022	1.1378	1.6845
40	6.2917	1.1689	0.1858	0.7162	-0.0271
41	6.8583	1.4687	0.2142	-0.2461	-1.4999
42	6.2250	1.6815	0.2701	0.2932	-0.5166
43	6.3500	1.7635	0.2777	-0.2399	-0.9320
44	6.5917	1.6014	0.2429	0.7643	1.1261
45	6.7667	1.2759	0.1886	-1.0447	0.6954
46	6.4500	1.4387	0.2231	-0.5032	0.3222
47	6.7500	1.4068	0.2084	-0.6368	-0.1792
48	7.1083	1.6763	0.2358	-0.0150	0.1886
49	7.7667	2.3581	0.3036	0.0436	-0.5514
50	8.0167	2.4412	0.3045	0.2110	-0.0079
51	8.5917	2.4055	0.2800	0.0192	1.6111
52	8.6667	1.8946	0.2186	1.1555	2.1318
53	8.3917	1.7495	0.2085	-0.1604	-0.7223
54	8.5667	1.6143	0.1884	-1.0102	1.9011
55	8.8917	2.4359	0.2740	0.5306	-0.1418
56	9.7333	2.3650	0.2430	0.2041	-0.9198
57	9.4167	2.1825	0.2318	0.0337	-1.1427
58	11.3500	2.0983	0.1849	-0.0679	-0.8445
59	10.3417	2.7813	0.2689	-0.9353	0.6730
60	10.0583	1.6373	0.1628	-0.5217	0.4375
61	10.2333	1.7768	0.1736	-0.5829	0.8628
62	9.8583	2.0354	0.2065	0.1929	-0.3485
63	10.6917	2.2056	0.2063	-0.6690	-0.5412
64	10.1083	2.8315	0.2801	0.6926	0.6930
65	9.5583	1.5442	0.1616	-1.3470	3.1207
66	9.0583	3.1295	0.3455	-2.5662	7.2136

Days after sowing	Mean ET_{SM}, mm day^{-1}	Standard Deviation	Coefficient of Variation	Skewness	Kurtosis
67	8.1667	4.3943	0.5381	-0.9440	0.6985
68	9.9750	2.3511	0.2357	0.0316	-0.6954
69	10.4500	1.6698	0.1598	-2.1179	5.7878
70	10.5083	2.0773	0.1977	-0.0300	-0.8621
71	11.4250	2.2519	0.1971	0.8702	0.9264
72	10.0833	3.4226	0.3394	-1.0786	0.5088
73	10.2333	2.9056	0.2839	-0.3311	-0.8092
74	10.7250	2.5309	0.2360	0.7316	-0.4157
75	10.0583	1.5600	0.1551	0.2943	-1.0626
76	11.3167	2.4271	0.2145	0.8244	0.2930
77	11.1500	2.4025	0.2155	-0.4411	-1.0119
78	11.2083	2.3838	0.2127	-0.2250	-1.0703
79	10.7333	2.8147	0.2622	0.0409	-0.1109
80	11.0000	1.5457	0.1405	-0.8444	0.2862
81	10.5583	1.9524	0.1849	0.0440	-0.7022
82	11.1417	2.1492	0.1929	-0.1897	-0.4275
83	11.4083	1.6670	0.1461	0.4086	0.3804
84	10.9000	0.7249	0.0665	1.0259	0.3766
85	10.4917	1.3256	0.1263	-1.2681	1.9977
86	10.9333	1.8951	0.1733	0.2361	0.3198
87	9.6167	1.8712	0.1946	-2.1049	5.8701
88	10.2083	0.9681	0.0948	0.5766	-0.7332
89	10.0833	1.1769	0.1167	0.2167	-0.2058
90	9.4417	1.7181	0.1820	-0.6998	-0.5147
91	9.6417	1.8725	0.1942	0.2500	-1.2556
92	9.2167	1.8886	0.2049	0.5869	-0.3397
93	9.9750	3.1755	0.3183	0.3943	0.5720
94	8.9000	2.3772	0.2671	-0.2277	-1.1425
95	9.1250	2.3046	0.2526	-0.8335	-0.0731
96	9.1167	2.1438	0.2352	-0.0571	-1.2294
97	9.4417	2.0097	0.2129	-0.8747	0.4148
98	8.5167	2.5623	0.3009	-0.9406	0.5286
99	9.0833	2.3272	0.2562	-0.3763	-0.3409
100	8.0667	2.4066	0.2983	-0.2789	-1.2477

Process. The mutual dependence of the observed mint evapotranspiration series was confirmed by the correlogram (Figure 4.22).

4.6.2 Trend Component

For identification of trend component annual spring mint evapotranspiration series was used (Kottegoda, 1980). The annual spring mint evapotranspiration series was obtained by transforming the twelve years seasonal daily spring mint evapotranspiration data Table (4.6).

Table 4.7 Annual series of spring mint evapotranspiration of twelve years (2000-2011)

Sr. No	Year	Annual Spring mint evapotranspiration, mm
1	2000	818.70
2	2001	779.67
3	2002	839.70
4	2003	901.28
5	2004	876.01
6	2005	783.70
7	2006	807.00
8	2007	785.94
9	2008	665.40
10	2009	845.77
11	2010	885.40
12	2011	971.70

The calculated values of test statistics (z_{cal}) are presented in Table (4. 7)

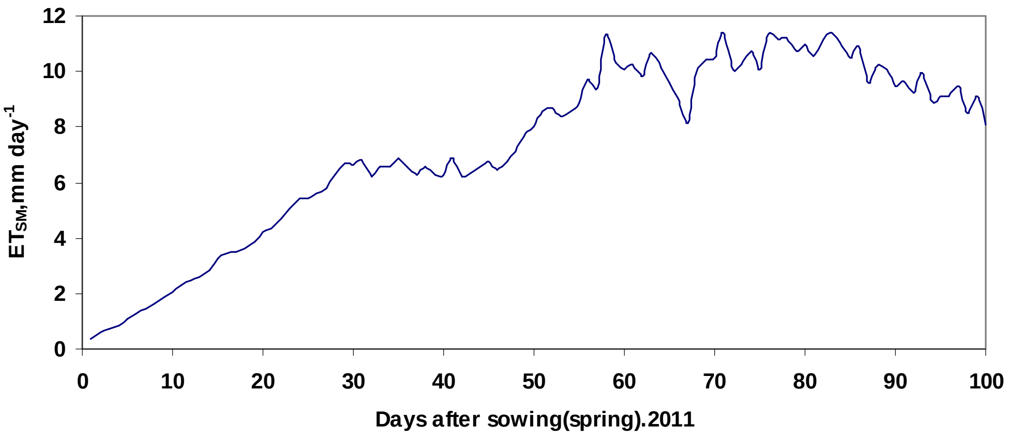

Figure 4.17 Mean daily spring mint evapotranspiration series for twelve years (2000-2011)

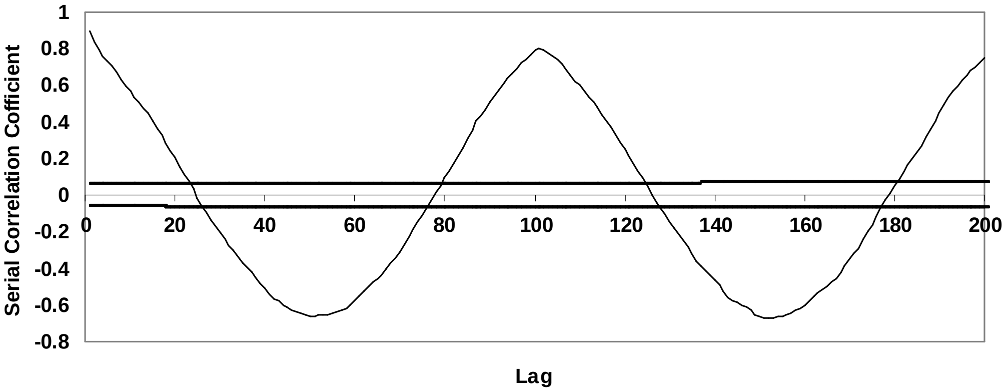

Figure 4.18 Correlogram of observed series of spring mint evapotranspiration for Twelve years (2000-2011)

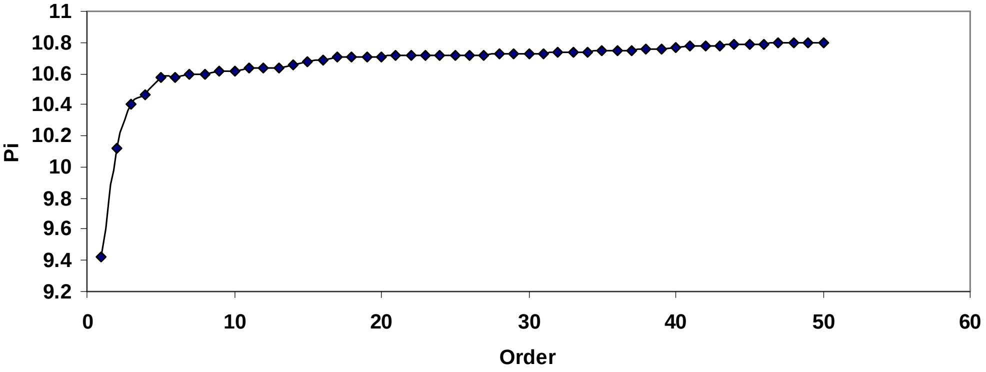

Figure 4.19 Periodogram of observed series of spring mint evapotranspiration for Twelve years (2000-2011)

Table 4.8 Test statistic (Z_{cal}) values for trend identification of spring mint evapotranspiration

Sr. No.	Test	Values of test statistic (z)
1	Turning Point Test	0.55
2	Kendall's Rank Correlation Test	0.63

The estimated values of test statistics (z_{cal}) obtained for turning point test, and Kendall's rank correlation test were within the 1 per cent levels of significance. Hence the hypothesis of no trend was accepted.

Further from the turning point test total tuning point were found to be 19. This indicates that the spring mint evapotranspiration series are random. From the above analysis it is confirmed that the trend components in spring mint evapotranspiration time series are absent and the observed series may be treated as trend free series.

4.6.3 Periodic Component

To confirm the presence of periodic component in daily spring mint evapotranspiration series, a correlograms were drawn. The correlograms of the observed series are shown in Figure 4.18. The resulting oscillating shape of the correlograms confirms the presence of periodic component in the daily mint evapotranspiration series.

Further, the correlograms have peaks at lags equal to 109 and at other multiples of it. The time span of periodicity was taken as 109 for use in harmonic analysis of periodic component.

4.6.3.1 Determination of significant harmonics

For representing the periodic component of the spring mint evapotranspiration series the number of significant harmonics were determined by analyzing the periodic mean daily mint evapotranspiration series. Equation (3.21) and (3.22) were used to estimate the Fourier coefficient α_K and β_K for the mean daily mint evapotranspiration series. To further confirm this, an analysis of variance was performed. The results are shown in Table 4.10.

Values of F ratio for different harmonics are given in Table 4.9. The calculated values are given for first two harmonics only. The values of estimated F-ratio for variation explained by 3,4,5,…53 harmonics are lower than the tabulated values of F- distribution at 1 percent and 5 percent level of significance. This mean that only first two harmonics are highly significant and other harmonics are not significant and therefore can be ignored.

4.6.3.2 Parameters of periodic component

Using Equation (3.28) and (3.29) the Fourier coefficients A_K and B_K were estimated. The results are presented in Table 4.10.

The amplitude, phase angle and Explained Variance for different harmonics were calculated by using Equation (3.24), (3.25) and (3.26) respectively. Fourier decomposition for daily mint evapotranspiration series is also presented in Table 4.11. Study of Table 4.8 reveals that the first two harmonics explain more than 83.12 per cent of the variance.

Table 4.9 Fourier decomposition of periodic components of mean daily spring mint evapotranspiration for twelve years (2000-2011)

Order	Alpha	Beta	Amplitude	Theta	Explained Variance	Cumulative Variance
1	9103.755	483.021	9540.276	0.724	955187.9	80.685
2	9509.756	593.575	9528.264	0.987	952782.9	83.120
3	9301.789	6070.80	9518.637	1.412	950858.4	84.482
4	1189.955	4560.23	9502.647	1.265	947668.2	85.222
5	5570.265	7678.01	9485.769	1.214	944303.8	85.485
6	5460.263	6654.01	9466.394	1.353	940450.2	85.767
7	7994.245	5535.01	9446.923	-1.542	936585.5	86.431
8	6879.165	9118.62	9428.175	1.147	932872.4	86.899
9	5864.236	8115.25	9410.64	0.914	929404.4	86.977
10	8902.946	3000.30	9394.903	-1.379	926299.5	87.165
11	7658.25	3875.92	9381.715	0.785	923700.33	87.292
12	3598.201	2156.23	9370.841	-1.567	921560.04	87.465
13	3268.066	8773.50	9362.409	0.625	919901.90	87.551
14	2365.077	7568.23	9356.357	1.377	918713.03	87.596
15	8969.731	6589.13	9352.265	-1.508	917898.11	87.672
16	7865.631	8051.84	9350.051	0.994	917476.23	87.745
17	6523.245	1235.12	9349.659	0.322	917397.85	87.764
18	7702.228	5302.72	9351.103	1.451	917682.82	87.785
19	6702.15	1375.78	9354.448	1.468	918338.71	87.833
20	5831.324	1256.68	9359.721	1.236	919374.58	87.863
21	730.174	9338.72	9367.232	0.476	920851.11	87.876
22	615.324	1547.23	9377.331	1.312	922837.37	87.901
23	9389.469	-82.89	9389.833	-1.222	925299.46	87.931
24	8324.156	6478.60	9404.799	0.568	928252.33	87.954
25	560.219	1256.34	9421.865	1.249	931623.22	88.011
26	6025.77	7267.44	9440.636	0.418	935339.57	88.014
27	5246.235	1254.25	9460.221	0.525	939223.17	88.042
28	7680.774	8546.13	9479.611	-1.348	943078.10	88.050
29	6529.665	9324.37	9497.99	-0.172	946738.42	88.057
30	5598.254	8456.32	9514.126	1.366	949957.66	88.132
31	9218.979	2402.76	9526.957	0.754	952521.74	88.146
32	8456.325	4564.86	9535.855	0.946	954302.37	88.173
33	2976.521	7568.15	9540.039	-0.069	955138.92	88.189
34	4037.494	8642.77	9539.338	0.814	954998.97	88.210
35	3256.125	7856.15	9533.636	0.527	953858.97	88.214
36	8863.101	6589.15	9523.405	-0.388	951810.95	88.221
37	7835.235	8593.54	9509.428	1.467	949020.56	88.224
38	6589.256	7856.45	9492.557	-1.258	945655.88	88.230
39	8281.996	4600.06	9473.754	-1.135	941913.36	88.231
40	7523.235	2297.43	9454.125	0.797	938013.43	88.249
41	5117.434	1254.26	9434.813	1.228	934185.38	88.255
42	1670.449	9267.26	9416.611	0.214	930584.13	88.257
43	2364.264	8564.25	9400.191	1.028	927342.05	88.262
44	9329.345	7856.15	9385.929	-1.232	924529.85	88.262
45	8563.158	7108.40	9374.291	1.127	922238.76	88.270
46	-380.036	6523.12	9365.052	-1.568	920422.25	88.275
47	6655.435	6578.65	9358.081	0.682	919051.17	88.303
48	5648.256	-271.47	9353.475	-0.885	918147.68	88.310
49	7020.449	0.059	9350.737	-0.408	917610.82	88.313
50	6523.256	0.075	0.075	-0.514	0.0004576	88.320

Table 4.10 Analysis of variance of Fourier coefficient of daily spring mint evapotranspiration series for twelve years (2000-2011)

Sr. No	Harmonics	Sum of square	Degree of freedom	F_{cal}	F_{tab} 5%	Ftab 1%
1	3,4,5,…..53	226.4	104	1.08	1.25	1.37
2	2	68.9	2	7.51	3	3.61
3	1	200.4	2	21.83	3	3.61
4	Residual	6805.6	3379			
	Total	7301.3	3487			

This further confirms that only first two harmonics are significant and may be used to express the periodic component of the daily mint evapotranspiration series. For the first two harmonics the values of the Fourier coefficients (A1, A2, B1, B2) were found to be 9103.755, 483.021, 9509.756, and 593.575 respectively. With these coefficients and using Equation (3.23) the periodic component (P_t) from periodic deterministic process may be mathematically expressed as:

$$P_{(t)=}4.3-9103.755Cos(2\pi t/P)-483.021Sin(2\pi t/P)-9509.756Cos(4\pi t/P)- 593.575Sin (4\pi t/P) \quad ....(4.10)$$

The deterministic cycle component (P_t) was computed by using Equation (4.10) for all the values of t (t_{MAX}=3488). After estimating the periodic component it was removed from the historical series by subtracting the periodic component from historical time series. By this process a new stastionary series $S_{(t)}$ resulting from deterministic stochastic process was obtained.

Table 4. 11 Results of Fourier analysis of mean daily spring mint evapotranspiration series for twelve years (2000-2011)

Order	Ak	Bk	Amplitude	Theta	Explained Variance	Cumulative Variance
1	-1.181	-4.177	4.341	1.295	5.325	65.325
2	0.211	-1.167	1.186	-1.392	4.877	70.203
3	0.219	-0.711	0.744	-1.273	1.921	72.122
4	0.347	0.014	0.347	0.041	0.418	72.548
5	0.455	-0.154	0.479	-0.319	0.797	73.337
6	0.043	0.059	0.074	0.943	0.019	73.356
7	0.165	0.008	0.165	0.049	0.095	73.454

Order	**Ak**	**Bk**	**Amplitude**	**Theta**	**Explained Variance**	**Cumulative Variance**
8	0.093	-0.081	0.124	-0.716	0.053	73.503
9	-0.154	0.061	0.162	-0.388	0.091	73.594
10	0.062	0.003	0.062	0.046	0.013	73.608
11	-0.131	-0.147	0.197	0.845	0.135	73.743
12	-0.078	0.048	0.091	-0.553	0.029	73.771
13	0.021	0.028	0.035	0.958	0.004	73.776
14	0.061	-0.171	0.184	-1.223	0.113	73.888
15	-0.198	-0.045	0.203	0.222	0.143	74.032
16	0.085	0.137	0.161	1.017	0.091	74.121
17	0.087	-0.18	0.212	-1.119	0.139	74.263
18	-0.078	0.006	0.079	-0.081	0.021	74.281
19	0.023	0.003	0.003	1.479	0.002	74.281
20	0.014	-0.039	0.04	-1.313	0.006	74.287
21	-0.098	0.029	0.095	-0.314	0.031	74.318
22	0.009	-0.038	0.039	-1.328	0.005	74.323
23	-0.011	-0.008	0.014	0.582	0.001	74.324
24	-0.043	-0.016	0.046	0.355	0.007	74.331
25	0.034	-0.019	0.039	-0.512	0.005	74.337
26	0.025	0.021	0.032	0.673	0.004	74.345
27	0.004	-0.059	0.062	-1.497	0.012	74.353
28	0.037	-0.025	0.045	-0.596	0.007	74.364
29	-0.019	-0.091	0.093	1.365	0.031	74.391
30	-0.057	0.002	0.057	-0.033	0.011	74.401
31	0.053	-0.062	0.082	-0.867	0.023	74.424
32	-0.085	-0.052	0.099	0.546	0.034	74.459
33	-0.046	0.044	0.064	-0.759	0.014	74.473
34	0.088	0.004	0.088	0.045	0.027	74.534
35	0.029	-0.067	0.073	-1.165	0.018	74.518
36	-0.056	-0.053	0.077	0.758	0.021	74.539
37	-0.015	0.075	0.077	-1.372	0.021	74.559
38	0.069	-0.071	0.099	-0.792	0.034	74.593
39	-0.075	-0.045	0.084	0.573	0.024	74.617
40	0.016	0.149	0.155	1.467	0.078	74.695
41	0.032	-0.101	0.106	-1.265	0.039	74.733
42	-0.059	0.006	0.059	-0.106	0.012	74.746
43	0.029	0.027	0.044	0.756	0.006	74.751
44	-0.077	-0.057	0.096	0.642	0.032	74.783
45	0.006	-0.027	0.028	-1.354	0.003	74.786
46	-0.114	-0.055	0.126	0.453	0.055	74.841
47	-0.062	0.028	0.068	-0.425	0.016	74.857
48	-0.071	0.017	0.073	-0.235	0.019	74.876
49	0.036	0.032	0.047	0.697	0.008	74.883
50	-0.023	0.015	0.023	0.589	0.002	74.885

Table 4.12 Serial Correlation Coefficient and Auto Covariance for different lags of autoregressive model of spring mint evapotranspiration (2000- 2011)

Lag	Serial Correlation Coefficient	Auto Covariance	Lag	Serial Correlation Coefficient	Auto Covariance
1	0.898	12933.43	101	0.805	11589.49
2	0.834	12013.53	102	0.795	11448.55
3	0.792	11414.93	103	0.775	11168.51
4	0.776	10945.33	104	0.758	10917.26
5	0.732	10537.18	105	0.743	10695.32
6	0.703	10128.00	106	0.717	1.96
7	0.671	9665.07	107	0.686	0.06
8	0.663	9078.66	108	0.654	-0.07
9	0.596	8589.00	109	0.624	8990.42
10	0.567	8173.72	110	0.603	8681.78
11	0.533	7681.11	111	0.571	8229.31
12	0.551	7349.09	112	0.534	7697.81
13	0.475	6845.68	113	0.512	7348.03
14	0.445	6414.56	114	0.483	6951.27
15	0.405	5827.84	115	0.442	6361.05
16	0.361	5203.62	116	0.404	5822.51
17	0.325	4686.16	117	0.373	5366.93
18	0.283	4082.53	118	0.331	4765.49
19	0.244	3512.03	119	0.285	4101.48
20	0.204	2941.63	120	0.25	3594.63
21	0.156	2249.10	121	0.212	3055.84
22	0.113	1626.35	122	0.173	2499.02
23	0.078	1119.79	123	0.134	1933.89
24	0.035	509.10	124	0.096	1387.70
25	-0.017	-248.32	125	0.052	741.97
26	-0.061	-878.29	126	0.053	-7.00
27	-0.098	-1414.51	127	-0.039	-555.05
28	-0.138	-1981.50	128	-0.069	-987.49
29	-0.175	-2515.51	129	-0.104	-1499.39
30	-0.205	-2953.07	130	-0.143	-2059.24
31	-0.242	-3491.07	131	-0.183	-2635.63
32	-0.276	-3980.83	132	-0.215	-3096.28
33	-0.304	-4377.70	133	-0.251	-3602.86
34	-0.335	-4832.39	134	-0.286	-4117.36
35	-0.366	-5276.15	135	-0.322	-4632.20
36	-0.397	-5714.00	136	-0.362	-5185.93
37	-0.422	-6085.09	137	-0.383	-5515.23
38	-0.449	-6468.63	138	-0.412	-5901.56
39	-0.479	-6893.22	139	-0.436	-6285.22
40	-0.511	-7356.76	140	-0.464	-6676.62
41	-0.538	-7752.24	141	-0.492	-7090.19
42	-0.564	-8120.73	142	-0.524	-7541.83
43	-0.558	-8351.82	143	-0.556	-8011.22
44	-0.616	-8639.36	144	-0.572	-8234.20

Lag	**Serial Correlation Coefficient**	**Auto Covariance**	**Lag**	**Serial Correlation Coefficient**	**Auto Covariance**
45	-0.613	-8823.10	145	-0.586	-8441.36
46	-0.625	-9007.19	146	-0.603	-8683.10
47	-0.638	-9185.30	147	-0.614	-8850.20
48	-0.644	-9270.85	148	-0.631	-9090.37
49	-0.656	-9444.00	149	-0.652	-9394.92
50	-0.661	-9515.43	150	-0.663	-9549.40
51	-0.666	-9592.59	151	-0.668	-9626.23
52	-0.657	-9461.25	152	-0.671	-9651.89
53	-0.651	-9370.82	153	-0.668	-9619.59
54	-0.665	-9357.02	154	-0.662	-9502.72
55	-0.643	-9256.83	155	-0.659	-9494.09
56	-0.664	-9215.24	156	-0.656	-9448.87
57	-0.628	-9047.49	157	-0.649	-9342.52
58	-0.619	-8913.91	158	-0.632	-9101.75
59	-0.601	-8653.56	159	-0.621	-8924.71
60	-0.572	-8238.89	160	-0.604	-8701.74
61	-0.549	-7902.66	161	-0.577	-8307.77
62	-0.526	-7581.40	162	-0.552	-7956.64
63	-0.502	-7225.88	163	-0.534	-7691.36
64	-0.476	-6850.97	164	-0.514	-7405.92
65	-0.453	-6521.34	165	-0.497	-7155.26
66	-0.435	-6259.79	166	-0.476	-6855.55
67	-0.405	-5839.88	167	-0.457	-6582.48
68	-0.373	-5368.36	168	-0.423	-6100.01
69	-0.344	-4948.37	169	-0.391	-5611.03
70	-0.308	-4438.53	170	-0.353	-5090.37
71	-0.262	-3780.90	171	-0.321	-4617.42
72	-0.219	-3151.79	172	-0.288	-4151.42
73	-0.185	-2666.37	173	-0.241	-3466.35
74	-0.149	-2142.96	174	-0.245	-2886.46
75	-0.108	-1557.77	175	-0.161	-2314.26
76	-0.107	-1001.21	176	-0.123	-1735.10
77	-0.026	-380.86	177	-0.072	-1040.89
78	0.015	221.80	178	-0.025	-358.49
79	0.052	742.62	179	0.014	146.44
80	0.092	1332.00	180	0.051	724.42
81	0.132	1905.54	181	0.089	1284.23
82	0.177	2542.55	182	0.132	1867.82
83	0.218	3141.30	183	0.162	2339.59
84	0.262	3768.96	184	0.196	2821.08
85	0.315	4533.57	185	0.237	3419.03
86	0.357	5138.20	186	0.272	3924.49
87	0.404	5817.68	187	0.318	4585.32
88	0.443	6190.41	188	0.366	5275.44
89	0.464	6681.50	189	0.409	5887.09
90	0.511	7366.30	190	0.445	6412.97
91	0.544	7838.81	191	0.491	7076.16
92	0.579	8342.72	192	0.536	7721.24

Lag	Serial Correlation Coefficient	Auto Covariance	Lag	Serial Correlation Coefficient	Auto Covariance
93	0.609	8776.56	193	0.567	8161.34
94	0.639	9197.24	194	0.596	8589.59
95	0.665	9577.21	195	0.628	9044.22
96	0.688	9904.78	196	0.658	9481.50
97	0.721	10390.76	197	0.682	9822.35
98	0.742	10691.06	198	0.699	10063.73
99	0.768	11059.47	199	0.721	10387.57
100	0.789	11358.46	200	0.752	10827.14

Table 4.13 Cumulative periodogram of daily spring mint evapotranspiration for twelve years (2000-2011)

Order	MSD(u)	MSD(j)	Cumu MSD(j)	Pi
1	20296.92	9.419	9.419	0.94
2	20296.92	0.703	10.122	0.96
3	20296.92	0.277	10.399	0.97
4	20296.92	0.006	10.459	0.98
5	20296.92	0.115	10.574	0.98
6	20296.92	0.003	10.577	0.98
7	20296.92	0.014	10.591	0.98
8	20296.92	0.008	10.598	0.98
9	20296.92	0.013	10.611	0.98
10	20296.92	0.002	10.613	0.98
11	20296.92	0.019	10.633	0.99
12	20296.92	0.004	10.637	0.99
13	20296.92	0.001	10.638	0.99
14	20296.92	0.016	10.654	0.99
15	20296.92	0.021	10.675	0.99
16	20296.92	0.013	10.687	0.99
17	20296.92	0.02	10.707	0.99
18	20296.92	0.003	10.711	0.99
19	20296.92	0.004	10.711	0.99
20	20296.92	0.001	10.711	0.99
21	20296.92	0.004	10.716	0.99
22	20296.92	0.001	10.717	0.99
23	20296.92	0.005	10.717	0.99
24	20296.92	0.001	10.718	0.99
25	20296.92	0.001	10.718	0.99
26	20296.92	0.001	10.719	0.99
27	20296.92	0.002	10.721	0.99
28	20296.92	0.001	10.722	0.99
29	20296.92	0.004	10.726	0.99
30	20296.92	0.002	10.728	0.99
31	20296.92	0.003	10.731	0.99
32	20296.92	0.005	10.736	0.99
33	20296.92	0.002	10.738	0.99

Order	MSD(u)	MSD(j)	Cumu MSD(j)	Pi
34	20296.92	0.004	10.742	1.00
35	20296.92	0.003	10.745	1.00
36	20296.92	0.003	10.748	1.00
37	20296.92	0.003	10.751	1.00
38	20296.92	0.005	10.755	1.00
39	20296.92	0.003	10.759	1.00
40	20296.92	0.011	10.77	1.00
41	20296.92	0.006	10.776	1.00
42	20296.92	0.002	10.777	1.00
43	20296.92	0.001	10.778	1.00
44	20296.92	0.005	10.783	1.00
45	20296.92	0.005	10.783	1.00
46	20296.92	0.008	10.791	1.00
47	20296.92	0.002	10.794	1.00
48	20296.92	0.003	10.796	1.00
49	20296.92	0.001	10.797	1.00
50	20296.92	0.001	10.798	0.94

4.6.4 Stochastic Component

The presence of stochastic component was already confirmed by plotting the correlogram (Figure 4.18) and periodogram (Figure 4.19) of observed series and analysis of serial correlation coefficient (SCC) and the coefficient of variance (CV), which has been discussed in Subsection 4.1.6.1.

As discussed in section 3.6 the periodic component was removed from the historical series. The rest of the data were analyzed to obtain non-deterministic stochastic component by fitting the autoregressive process of stochastic modeling.

4.6.4.1 Estimation of autoregressive parameters

The autoregressive parameters were estimated by using Equations (3.38), (3.39) and (3.40). The estimated values of auto covariance function and SCC of different lags (l_{MAX}=218) are presented in Table 4.12. The values of auto covariance function in table 4.12 reveals that the values of SCC are significantly different from zero, which confirms the dependence of present values and past values. In other words, it may be concluded that the past and present values are highly inter correlated.

4.6.4.2 Selection of model order

Residual variance method was used to determine the order of the model, which may be significantly representing the non- deterministic stationary stochastic component.

Residual variance at different lags was computed with the help of Equation (3.36) and (3.37). The minimum residual variance was obtained at last order. But the values of residual variance after 1st order showed no definite trend, so in order to reduce the complexity model of 1st order was selected to represent the stochastic component by the autoregressive model. But the serial correlation coefficients of the residual series of the first order model were extending out of the calculated limit. So, higher order models were checked and the performance of the 2nd order model was found to be satisfactory. Hence the 2nd order model was selected finally.

4.6.4.3 Mathematical representation of stochastic component

The autoregressive coefficients (ϕ_{PP}) were estimated by Equation (3.38) and (3.39) for 2nd order model. The values of $\phi_{(2,1)}$, $\phi_{(2,2)}$ and $\phi_{(2,3)}$ are given in Table 4.14.

Table 4.14 Autoregressive parameters of 2nd order model of spring mint evapotranspiration series for twelve years (2000-2011)

S.No	$\phi_{P,K}$	Values
1	$\phi_{(2,1)}$	0.898
2	$\phi_{(2,2)}$	0.769
3	$\phi_{(2,3)}$	0.144

Using Equation (3.35) and the estimated autoregressive coefficient the stochastic component of daily groundnut evapotranspiration series may be expressed as:

$$S_t = 0.898\ S_{t-1} + 0.769\ S_{t-2} + 0.14\ S_{t-3} + a_t \qquad ...(4.11)$$

The non-deterministic stochastic component was estimated by using Equation (4.11) for all the values (t = 4 to 3488).

4.6.4.4 Residual series of stochastic component

The residual series (a_t), which is random independent part of stochastic component was obtained after removing the periodic and dependent stochastic parts from the historical series.

The statistical analysis of the residual series confirm its normal distribution with mean which is almost equal to zero (0.005) and standard deviation was less than one (0.216). The values of statistics measures are presented in Table 4.15. The mean, standard deviation and coefficient of variation of the historical and generated series are almost same which shows closeness between historical and generated data.

Table 4.15 Statistical parameters of the historical, generated and residual series of daily Spring mint evapotranspiration series

Series	Mean mm day^{-1}	Standard deviation mm day^{-1}	Variance
Historical series	4.305	3.708	13.751
Generated series	4.305	3.688	13.606
Residual series	5 X 10^{-5}	0.216	0.046

4.6.5 Model structure

Since the observed daily mint evapotranspiration series was found to be a trend free, the developed model describes the periodic- stochastic behavior of the series.

The developed model is a superposition of harmonic deterministic process and third order autoregressive model. The mathematical structure of the additive model described by Equation (3.12) can now be represented as follows:

$$X(t)=4.3-9103.755\text{Cos}\ (2\pi t/P)-483.021\text{Sin}\ (2\pi t/P)-9509.756\text{Cos}\ (4\pi t/P)-\ 593.575\text{Sin}\ (4\pi t/P)+\ +0.898\ S_{t-1}+0.769\ S_{t-2}+0.144\ S_{t-3}+a_t$$

The first five terms in the formulated model represented by above Equation 4.10 constitute the deterministic part of daily mint evapotranspiration time series. The sixth, seventh and eigth terms represent the dependent stochastic component of the model where the current value of S_t depends on the weighted sum of observed preceding three values. The last term is the random independent part of the stochastic component. Using the developed model the average daily spring mint evapotranspiration series was generated for all the values (t = 4 to 3488).

4.6.6 Diagnostic Checking of spring mint Evapotranspiration Model

The residual obtained after fitting the formulated models were subjected to various analyses to test their adequacy for representing the time dependent structure of the daily mint evapotranspiration.

4.6.6.1 Sum of squares analysis

The sums of Square of mean residual series were calculated and sum of square of deviation of mean observed values from their mean were computed. The value of measure coefficient of determination (R^2) was found to be 0.986, which is nearly equal to unity.

Thus, this leads to the conclusion that the developed model has a fair goodness of fit to generate the daily mint evapotranspiration series.

4.6.6.2 Serial correlation coefficient

The serial correlation coefficients of the residual series up to lag 200 were calculated. The correlation coefficients were within the prescribed limits. A graph was plotted between serial correlation coefficient and lag, which is shown in Figure 4, for residual series. As the confidence limits for the series is calculated at 99% probability level if 1% data out of the total used for plotting the graph, fall out ht e limits, it is acceptable. Figure 4.22 indicates that the residual series is purely random series. It is having neither any periodicity nor any stochastic component.

4.6.7 Validation of daily spring mint evapotranspiration

Validation of generated mint evapotranspiration (ET_{SMGM}) series developed by stochastic model (Equation 4.16) was done by comparison of ET_{SMGM}. Figure 4.23 depicts the variation of daily measured spring mint evapotranspiration and daily-generated spring mint evapotranspiration series for twelve years (2000-2011) at Udaipur. It is evident from Figure 4.21 that there is a linear correlation between estimated and measured daily spring mint evapotranspiration series.

Validation of generated two years mean daily spring mint evapotranspiration series was made with observed two years mean daily spring mint evapotranspiration series. The relationship of ET_{SMGM} and ET_{SMOM} are shown in Figure 4.21. It is clear from Figure 4.21 that there exists a linear relationship between the two series. The relationship between ET_{SMGM} and ET_{SMOM} is shown in Figure 4.21. The correlation coefficient between ET_{SMGM} and ET_{SMOM} was found to be 0.9967, which is significant at 1 per cent level. The standard error (0.21 mm day-$^{-1}$), which is quite low. It was found that the mean ET_{SMGM} = 9.91 mm day $^{-1}$ and ET_{SMOM} = 8.84 mm day $^{-1}$, which are very close to each other. The regression line almost coincide the 1:1 line.

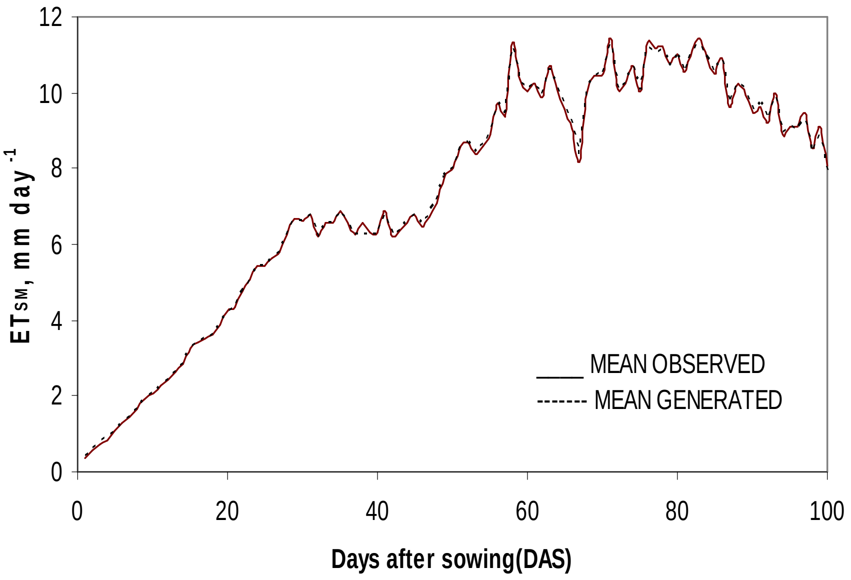

Figure 4.20 Variation of generated (ET_{SMGM}) and observed (ET_{SMOM}) mean daily Spring mint evapotranspiration for twelve years (2000-2011)

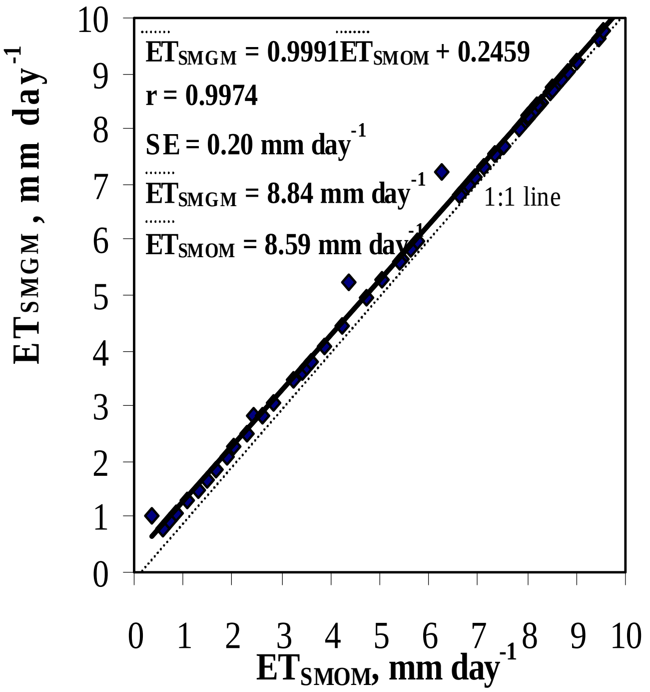

Figure 4.21 Relationship between generated and observed msean daily spring mint evapotranspiration for twelve years (2010-2011)

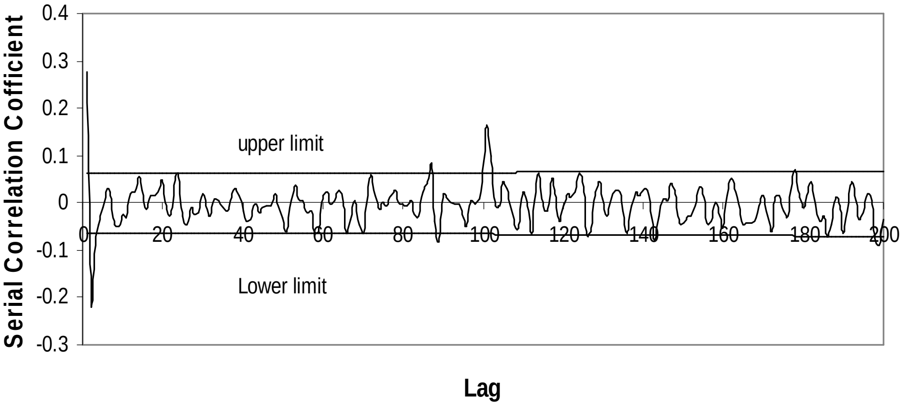

Figure 4.22 Correlogram of residual series of daily spring mint evapotranspiration twelve years (2000-2011)

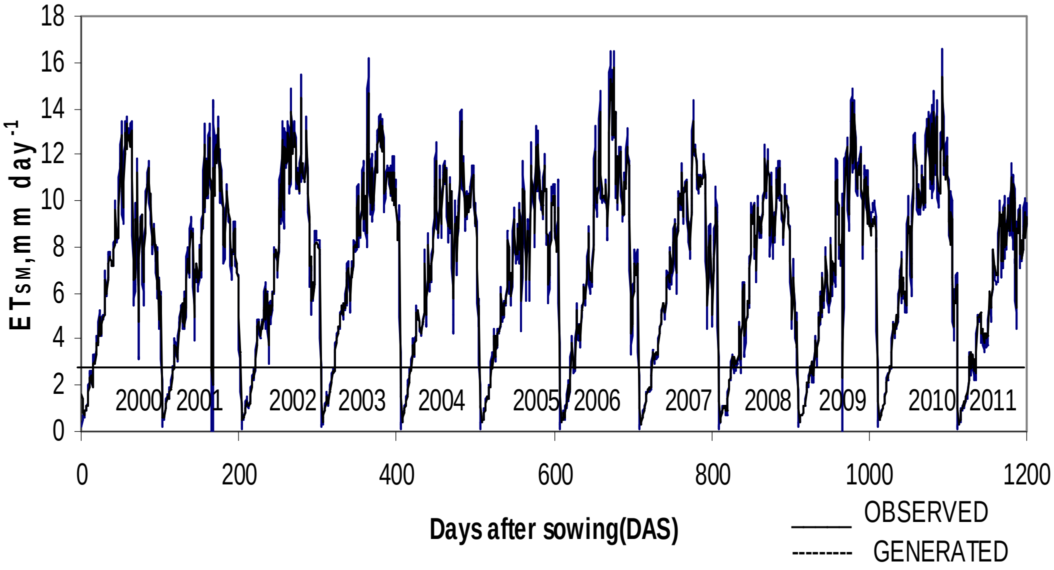

Figure 4.23 Variation of observed and generated daily spring mint evapotranspiration (ET_{SM}) for twelve years (2000-2011) at Udaipur

SUMMARY AND CONCLUSIONS

The objective of the study was to develop and evaluate appropriate model for spring mint evapotranspiration under climatic conditions of Udaipur region. Pan evaporation data for twelve years (2000-2011) were collected from Meteorological Observatory at the instructional farm of Rajasthan college of Agriculture, Udaipur. The climatic data of air temperature, relative humidity, wind speed and bright sunshine hours were also collected for the growing season of spring mint from 28th February 2011 to 11th June 2011. Mint evapotranspiration was measured using soil moisture depletion method. The evaporation data and mint evapotranspiration data were analysed to develop and evaluate appropriate deterministic and stochastic models under climatic conditions of Udaipur region. The results of present study are summarized as follows:

Spring Mint Crop:

1. The maximum mint evapotranspiration observed was 8 mm day^{-1} after 81 days of sowing of crop at mid season stage and minimum mint evapotranspiration observed was 0.50 mm day^{-1} after 21 days of sowing of crop at initial stage. The average mint evapotranspiration for the whole season (109 days) was found to be 4.35 mm day^{-1}. Total mint evapotranspiration for the whole season was found to be 474.39 mm.

2. The crop coefficient curves were developed for mint crop by (i) FAO-56 curve method (ii) Modified FAO-56 curve method and (iii) Quadratic curve method. Modified FAO-56 curve method was found to be best FAO-56 curve method and Quadratic curve method. .

3. The following model was found to predict mint evapotranspiration (ET_{SM}) quite accurately on the basis of days after sowing (DAS) of crops:

   $ET_{SM}/E_P = -0.0002(DAS)^2 + 0.0304DAS - 0.234$

   Performance of the models based on crop coefficients was found to be better than pan evaporation model for estimation of mint evapotranspiration.

4. Relationships were developed between mint evapotranspiration, leaf area index (LAI) and plant height (H_t). It was found that the relationship of power form gives good result for estimation of mint evapotranspiration based on plant height and the Logarithmic model gives good result based on leaf area index. The models based on leaf area index and plant heights are as under:

$ET_{SMCM} = 0.3968Ht_{SM}\ 1.762$

$ET_{SMCM} = 202.72Ln\ (LAI_{SM})-129.86$

5. A relationship was developed between leaf area index and plant height which is given by the following expression:

$$LAI_{SM} = 0.2884e0.0538Ht_{SM}$$

6. Following model was found to predict mint evapotranspiration rate (ET_{SM}) quite satisfactory on the basis of time (days after sowing, DAS):
   $ET_{SM=}-0.0018(DAS)^2 + 0.2617(DAS) - 3.3223$

7. Following model for prediction of cumulative mint evapotranspiration (ET_{SMCM}) was found to provide accurate estimates on the basis of time (days after sowing, DAS):

$$ET_{SMCM=}-1x\ 10^{-5}(DAS)^4+0.0024(DAS)^3-0.057(DAS)^2+0.6053(DAS)+8.7062$$

8. From the analysis of coefficient of variation and serial correlation coefficient it can be said that the mint evapotranspiration is time variant and mutually dependent and can be modeled on stochastic theory.

9. It was found that the daily time series of mint evapotranspiration is trend free and periodic-stochastic in nature with the periodicity of 109 days. Hence, the developed model superimposes a periodic deterministic process and a stochastic component results from non-deterministic process. The deterministic periodic component of the average daily mint evapotranspiration was represented by first two harmonics only. The developed model is given as follows:

$$X(t)=4.3-9103.755Cos(2\pi t/P)-483.021Sin(2\pi t/P)-9509.756Cos(4\pi t/P)-$$

$$593.575Sin\ (4\pi t/P)+ 0.898\ S_{t-1} + 0.769\ S_{t-2} + 0.144\ S_{t-3} +a_t$$

The results of serial correlation analysis and sum of square tests confirmed the appropriateness of the developed model. Therefore, the model may be employed to generate mint evapotranspiration data for planning and designing of irrigation schemes in the Udaipur region.

REFERENCES

Ahmed M. and Mahmoud F.A. 2010 Effect of irrigation on consumptive use, water use efficiency and crop coefficient of sesame (*Sesamumindicum L.).Journal of Agricultual Extension and Rural Development.*2 (4): 59-63

Allen, H. S. 2009. Crop coefficients for cotton in Northern Louisiana. Submitted to Faculty of the Agricultural and Mechanical College, Department of Geography and Anthrolopology, Louisiana State University.

Allen, R. C. and Fisher, D. K. 1990. Low cost electronic weighining lysimeters. *Transaction ASCE*. **33**:1823-1833.

Allen, R.G., Brockway, C.E. and Wright, J.L.1983. Weather station siting and consumptive use estimates. *Journal of Water Resource Planning and Management*, **109**:134-146.

Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. 1998. Crop evapotranspiration, guidelines for computing crop water requirements. FAO Irrigation and Drainage paper no. 56. FAO Rome, Italy: 300.

Aslyng, H.C. and Kristensen, K.J. 1961. Water balance recorder. *Journal of Irrigation and Drainage division Proceeding. ASCE.* **87**:15-21.

Asokan D. 2010 Developed and evaluated evapotranspiration (ET) models for zaid and kharif groundnut under climatic conditions of Udaipur. Thesis of Doctor of Master of Engineering submitted to faculty of Agricultural Engineering, Department of Soil and Water Engineering, CTAE, MPUAT, Udaipur, P 167.

Ayman, A. S. 2007. Comparison of Priestley-Taylor and FAO-56 Penman- Monteith for Daily Reference Evapotranspiration Estimation in Georgia *Journal of Irrigation and Drainage Engineering* .**133**:175-182.

Bhakar, S.R. 2000. Modeling of Evaporation and Evapotranspiration under climatic conditions of Udaipur. Thesis of Doctor of Philosophy submitted to faculty of Agricultural Engineering, Department of Soil and Water Engineering, CTAE, MPUAT, Udaipur, P 327.

Bhakar S.R. and Singh, R.V. 2001. Computer application in estimation of evapotranspiration *World Congress on Computers in agriculture and Natural resources* 864-870.

Bhakar, S.R. and Singh, R.V. 2003. Estimation of reference evapotranspiration under sub humid climatic condition of Rajasthan. Proceedings 37th ISAE Convention, held during January 29-31, 2003 at CTAE, Udaipur.

Bhakar, S.R. and Singh R.V. 2008. Forecasting monthly wind speed for Udaipur region. *Journal of Agrometeorology* **10** : 46-52.

Bhakar, S. R., Singh, R. S., Chhajed, N. and Bansal, A. K. 2008. Stochastic modeling of relative humidity at Banswara. *Journal of Agrometeorology* **10** : 53-58.

Bhardwaj, S.P. 1992. Lysimeter technique and application in India. In: Lysimeter for Howell, Evapotranspiration and Environmental Measurements (Ed by Allen R.G., T.A. W.O. Pruitt, I.A. Walter and M.E. Jensen) *ASCE New York*. 210-218.

Bhardwaj, S.P. and Shastry, G. 1979. Development and installation of simple mechanical weighing lysimeter. *Transaction of ASAE.22*:797-802.

Black, T.A., Thurtell, G.W. and Tanner, C.B. 1968. Hydraulic load cell lysimeter, construction, calibration and tests. *Soil Science Society. American Proceeding* **32**:623-629.

Blaney, H.F. and Criddle W.D. 1962. Evaporation from free water surface at high altitudes. *Transtion ASCE*. **123**:243-265.

Box, G.E.P. and Jenkins G.M.,1976. Time Series Analysis, Forecasting and Control. Holden-Day, San Francisco, Calif. 553.

Brutsart, W.H. 1982. Evaporation into the Atmosphere. R. Defield Publishing Company, Dondrecht, Holland. 299.

Bryla D.R.2010 worked on weighing lysimeter for developing crop coefficients and efficient irrigation practices for vegetable crops.U.S. Department of Agriculture,22:214-564

Calil A. 2006. Estimation of monthly reference evapotranspiration at Parana state. Thesis submitted to CASCAVEL University -Parana-Brazil.

Campbell, G. S. 1977. An Introduction to Environmental Biophysics. Springer- Verlag, New York. 159.

Cerekovic ,2010 The relationship between leaf area index and crop coefficient for tomato crop grown in southern Italy.Department of land,Air & water Resources,University of California.P 298

Chandra, J., Gupta, V.P. and Chowdhary, R.C. 1996. Determination of pan coefficient for evapotranspiration at Jodhpur. *Journal of Indian Water Resources Society*. **2**:59-62.

Chin, D.A. and Zhao, S. 1995. Evaluation of evaporation pan-network. *Journal of Irrigation and Drainage Engineering.ASCE.***121**:338-44.

Chuanyan Z. and Zhongren N. 2007, Estimating water needs of maize (*zea maysL.*), using the dual crop coefficient method in the arid region of northwesthern china.*african Journal of Agricultural Reserch* 2(7): 325-333

Clarke, R.T. 1973. Mathematical Models in Hydrology. FAO Irrigation and Drainage Paper 19, U.N. Food and Agriculture Organization, Rome.

Dabral, P.P. and Rao K. A. 1997. Estimation of crop coefficient and irrigation requirement under various irrigation levels for tea during dry period. *Indian Journal of Soil Conservation* **25**(3):233-235.

Dabral, P.P., Roy S. and Baithuri N. 2006. Rainfall analysis using probability distribution for Doimukh (Itanagar) in Arunachal Pradesh. *Indian Journal of Soil Conservation.***34**:157-160.

Doob, J.L. 1953. Stochastic Process. Wiley, New York.

Doorenbos, J. and Pruitt, W.O. 1977. Guideline for Predicting Crop Water Requirements *FAO Irrigation and Drainage Paper* No.24.

Fang X. and Ren L.(2011) Estimation and validated basin-scale actual evapotranspiration using MODIS images and hydrologic models.Hydrology Reserch 43(2): 156-166

Garcia M. , Rick Allen, and Carlos Herbas, 2004. Dynamics of reference evapotranspiration in the Bolivian highlands (Altiplano).*Agricultural and forest meteorology*. **125**:67-82.

Gupta, R. K. and Kumar R., 1994. Stochastic analysis of weekly evaporation values. Indian J*ournal of Agricultural Engineering*. **4**(4):140-142.

Goyal, R.K., 2004. Sensitivity of evapotranspiration to global warming; a case study of arid zone of Rajasthan (India) *Agriculture Water Management.*(69).

Hameed T. and Marino M.A. and Shumway R.N. 1995. Evapotranspiration – function-noice modelling. *Journal of Irrigation and Drainage Engineering*. **121**:159-169.

Hanks, R.J. and Shawcroft, R.W. 1965. An economical lysimeter for evapotranspiration studies *Journal of Agronomy*.**57**:634-636.

Hargreaves, G.L. and Allen, R.G. 2003. History and evaluation of Hargreaves evaporation equation. *Journal of irrigation. And drainage engineering.ASCE.* **129**:53-63.

Hipel, K.W., and McLeod A.I. 1978. Preservation of the rescaled adjusted range: 2. simulation studies using Box-Jenskins models. *Journal of Indian Water Resources Society*.**14**: 509-516

Hosking, J.R.M. 1985. Fractional Differencing Modelling in Hydrology. Water Resources Bulletin, **21**: 670-682.

Hunsaker, D.J. 1999. Basal crop coefficient and water use for early maturity cotton. *Transactions ASAE*. **42**: 927-936.

Hupet, F. and Vanclooster, M., 2001. Effect of sampling frequency of, meteorological variables. *Journal of hydrology*. **22**:55-59.

Hutson, J.L., Green and Meyer, W.S. 1980. A weighing lysimeter facility at Roodeplaat for crop evapotranspiratiopn studies. Water SA **6**:41-46.

Jabloun, M. and Sahli, A.. 2008. Evaluation of FAO-56 methodology for estimating reference evapotranspiration using limited climatic data Application to Tunisia. Agriculture Water Management.**95**:309-321.

Jackson, R.D., Reginato, R.J. and. Pinter, P.J. 1980. Remotely sensed crop temperature and reflectance as inputs to irrigation scheduling. Proc.Am. Civil Engg. *Irrigation and Drainage Division Conference. Boise.Idaho*.390-397.

Jensen, M. E. And Haise, H. R., 1963. Estimating evapotranspiration from solar radiation. *Journal of Irrigation and Drainage*. Div., ASCE **89**(4): 15-41.

Jhajharia, D., Ali M. D., Barma S. D., Durbude D. G. And Kumar R. 2009. Assessing reference evapotranspiration by temperature based methods for humid regions of Assam. *Journal of Indian Water Resources Society*. **29**(2): 1-8.

Jiabing C., Seki D. and Brown K. 2007. Estimating reference evapotranspiration with the FAO Penman–Monteith equation using daily weather forecast messages. *Journal of Agricultural and Forest Meteorology*. **145**, Pages 22-35.

Kashyap P.S. and Panda, R.K., 2001. Evaluation of crop evapotranspiration estimation methods and development of crop coefficient for potato crop in sub humid region. *Agricultural Water Management* **50**:9-25.

King, K.M., Tanner C. M. and Suomi, V.E., 1956. A floating lysimeter and its evaporation recorder. *Transaction Am. Geo.Union*.**37**:736-742.

Korven, H.C. and Pelton, W.L, 1972. Hydraulic load cell lysimeter .*Can.Agr.Engineering.* **14**:33-36.

Kottegoda, N.T., 1980. Stochastic Water Resource Technology. The Macmillan Press Ltd., London. 384.

Kucharik, C.J., Norman J.M. and Gower S. T. 1998. Measurements of branch area and adjusting leaf area index indirect measurements. Agricultural and Forest Meteorology. **91**: 69-88.

Kumar, D., 2001. Modeling of maize evapotranspiration under climatic conditions of Udaipur. M.E. (Ag.) Thesis, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur.

Kumar A., 2002, Modeling of okra evapotranspiration under climatic conditions of Udaipur. M.E. (Ag.) Thesis, College of Technology And Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur.

Lepton, R.L. and Parton, W.J. 1996. Seasonal variabilities in the distribution of the microclimatic factors and evapotranspiration in short grass steppe. *Agricultural and Forest Meteorology*.**79**:113-130.

Lewis, P.A.W. 1985. Some simple models for continuous variate time series. Water Resource Bulletin, **21**: 635-644.

Liu-Yu and Zhi-gong, 2009**.** A review of monitoring and estimating methods for regional evapotranspiration. *Journal of China Institute of Water Resources and Hydropower Research*. **38:** 426-432

Liu . 2010 studied a consolidated evaluation of the FAO-56 dual crop coefficient approach using the lysimeter data in the North China Plain to evaluate whether or not the dual crop coefficient.Agricultural water Management.97(1):37-40

Lopez-Urrea, R., F. Martin de Santa, Olalla Fabeiro, and Mortalla, A., 2006. An evaluation of two hourly reference evapotranspiration equations for semiarid conditions. *Agricultural and forest meteorology* **86**:277-282.

Machiwal D. and Jha M. K. 2008. Comparative evaluation of statistical tests for time series analysis: application to hydrologic time series. *Journal.of Hydrological Science.* **53**: 353-366.

Mailhol J.C., Olufayo A.A. and Ruelle P. 1997. Sorghum and sunflower evapotranspiration and yield from simulated LAI . Agricultural Water Management. **35** : 167-182.

Maity, S.P., K. K. Ghosh and P. K. Jana. 1979. Comparison of measured and estimated evapotranspiration. Jour. Agril. Engg. 26(4): 157-161.

Mandelbrot, B.B. 1971. A fractional Gaussian noise generator. *Journal of Agriculture Engineering*. **7**: 543-553.

Mcmilillan, W.D. and Paul H.A., 1961. Floating lysimeter. *Journal of Agriculture Engineering*. **42**:498-499.

Medeiros G.A., Arruda F.B., Sakai E., Fujiwara M. 2001. The influence of crop canopy on evapotranspiration & crop coefficient of beans. Agriculture Water Management. **49**: 211-224.

Mishra A.K., Sarkar T.K. and Bhattacharya A.K. 2000. Estimation of actual crop evapotranspiration (ETc) using continuous crop coefficient (KC) function. *Indian Journal of Soil Conservation*. **28**: 117-125.

Monteith, J.L. and Unsworth M.S. 1990. Principles of Environmental Physics. Second edition. Edward Arnold, London.

Mottaram, R. and De Jagger, J.M.. 1973. A sensitive recording lysimeter. *Agro Chemo Physica*. **5**:9-14.

Murakmi S. 2000.Variation of evapotranspirationwith stand age & climate in a small Japanease forested catchment .*Journal of hydrology*.227:114-127

Pandey, P.K.. 2002. Modeling of black gram evapotranspiration under climatic conditions of Udaipur. M.E. (Ag.) Thesis, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur.

Pandey.P.K. 2011stochastic modelling of actual black gram to develop and evaluate evapotranspiration model for black gram (Vigna Mungo L.).*Journal of water Resource and* Protection.448-455

Parlange, B.M., Katul G.G., Cuenca R.N., Kaivas M.L., Nilesen D.R. and Mata M., 1992. Physical basis for time series model of soil water content. Water Resources Research. **28**:2437 -2446.

Penman, H.L. 1948. Natural evaporation from open water, bare soil and grass. Proc. Royal Soc. London, Sev. A. **193**: 120-145.

Penman, H. L. 1956. Evaporation: An introductory survey. Netherland. *Journal of Agricultural Sciences*. **4**: 9-29.

Pruitt, W.O. 1992. Development of crop coefficients using lysimeters. Lysimeters for Evapotranspiration and Environmental Measurement. (Ed. Allen R.G., Howell T.A., Pruitt W. O., Walter L. A. and Jensen M. E.) ASCE, New York. 182-200.

Pruitt, W.O. and Angus, D. E. 1960. Large weighing lysimeter for measuring evapotranspiration. *Transaction, ASAE.* **3**:13-18.

Raghuwanshi, N.S. and Wallender, W. W. 1997. Field-measured evapotranspiration as a stochastic process. Agriculture Water Management. 32: 111-129.

Raghuwanshi, N.S. and Wallender, W. W. 2000. Forecasting daily evapotranspiration for grass reference crop. Agriculture Engineering Journal. ASCE. 9(1): 1-16.

Rank, H. D. 2008. Crop coefficient at various moisture stresses for different growth periods of cotton. *Hydrology Journal.* 31:15-22

Reyenga, W., Dunin, Bautovich, B.C., Rath, C.R. and Hulse, L.B. 1988. A weighing lysimeter is a regenerating eucalyoptus forest; design, construction and performance. *Hydrology Processes* **2**:301-314.

Ritchie, J.T. and Burnett, E. 1968. A Precision weighing lysimeter for row crop water use studies. *Agronomy journal*.**60**:545-549.

Rosenberg, N. J., Blad B. L. And Verma S. B. 1983. Microclimate, the Biological Environment. Second Edition. John Wiley ans Sons, New York. 495.

Rosenberg, N.J. Hant H. E. and Brown K. W. 1968. Evapotranspiration. Review of Research. Nebr. Agr. Exp. Station Misc. Bull. No.**20**: 80.

Ross, C., Dunin, Bautovich, B.C., Rath, C.R. and Hulse, L.B. 2000. Regenerating eucalyoptus forest; design, construction and performance on basis of leaf area index. *Hydrology Processes* **2**:301-314.

Salas J. D., Dellur W., Yevjevich V. and W. L. Lane. 1980. Applied modeling of Hydrologic Time Series. Water Resource Publication, Littleton, Coloredo. 484.

Samani, Z. 2000. Estimating solar radiation and evapotranspiration rates using minimum climatological data. *Journal of Irrigation and Drainage Divison. ASCE.* **126**:265-267.

Sepeskhah A.R., Andam M., 2001. Crop coefficient of sesame in a semi-arid region of Iran. Agriculture Water Management . **49**: 51-63.

Shah S.B. and R.J. Edling. 2000. Daily evapotranspiration prediction from Louisiana rice field. Journal of Irrigation and Drainage Div.ASCE. 126(1): 1-7.

Shaozhong, K., C. Huanjia and Jianhua Z. 2000. Estimation of maize evapotranspiration rate under water deficits in a semiarid region. Agriculture Water Management. 43:

1-14.

Sharma, A.K. 1998. Stochastic Modelling for Forecasting Jakham River Inflows. Ph.D. thesis submitted to Department of Soil and Water Conservation Engineering, College of Technology and Agricultural Engineering, Rajasthan Agricultural University, Bikaner. p-259.

Sharma M.L. 1985. Estimating evapotranspiration. In: Advances in Irrigation, D. Hillel (Editor), Academic Press, New York, **3**: 213-281.

Singh, R.V. 1987. Design requirement for installation of lysimeters. Proc. National Symposium on hydrology held at national institute roorkee from Dec.16-18, 1987.Vol.1.pVI-14 to VI-21.

Singh, R.V. 1988. Installation of monolith lysimeters for evaluation of agricultural hydrology. *Indian Journal Dryland Agriculture Resource .and devlopment*.**3**:171-181.

Singh, R.V. 2000. Watershed Planning and Management, *Yash Publication House. Bikaner*.P.470.

Singh, R.V. and Bhakar, S.R. 2002. Development of improved crop coefficient for precise estimates of wheat evapotranspiration. Third Asian Conference for Information Technology in Agriculture, held during October 26-28, 2002 at Chinese Academy of Agricultural Sciences, Beijing, China.p-6.

Singh, R.V. and Shukla, K.N. 1978. Installation of non-weighing lysimeter for measurement of evapotranspiration. *Journal of Agriculture Engineering ISAE.***18**:45-53.

Soeguard, H. and Boegh E. 1995. Estimation of evapotranspiration from a millet crop in the Schel combining sap flow, leaf area index and eddy correlation technique. *Journal of Hydrology*, **16**:265-282

Sone, S. and Clyma W. 1984. Leaf area index based design evapotranspiration, Paper, *American Society of Agrilculture Engineers*, **84**(20):18-21.

Sone C. and Saito K. 2009 Estimates of leaf area index (LAI) using two canopy analyzers (LAI-2000 and SunScan) was compared with destructively measured LAI for four upland rice (*Oryza* spp.).Crop Science ,49 : 1438-1443

Steele D.D., Sazid A. H. and Prunty L. D. 1996. New corn evapotranspiration rates crop curves for southern Dakota. *Transactions of ASAE*. **39**(3): 931-936.

Suleiman . 2011 Determined FAO-56 crop coefficients for peanut under different water stress levels.Irrigation Science.120:1007

Suryawanshi, S.N., Chaudhari D.A., Desai P.T. and Pawar V.S. 1990. Crop coefficient of various crop in semi-arid tropics. *Journal of Indian Water Resources Society.* **10**(3): 41-43.

Tarantino, E. 1992. Grass reference measurement in Italy. Lysimeters for evapotranspiration rates and Environmental Measurements (Ed. Allen, R.G., Howell T. A., Pruitt W. O., Walter I. A. and Jensen M. E.) ASCE, New York. 200-209.

Tyagi, N.K., Sharma, D.K., and Luthra, S.K. 2000a. Determination of crop coefficients of rice and sunflower. *Agriculture Water Management*.**45**:41-54.

Tyagi, N.K., Sharma, D.K., and Luthra, S.K. 2000b. Evapotranspiration and crop coefficient of wheat and sorghum. *Journal of Irrigation and Drainage Engg. ASCE.* **126**:215-222.

Tyner, J.S., Brown, G.O. and Garbrecht, J. 2003. Incorporation of chloride mass balance to improve estimates of evapotranspiration recharge and runoff. *Transaction of ASAE.* **46**:95-103.

Ustun S., Yasemin K., Talip T. and Fatih M. K. 2009. Determining Crop and Pan Coefficients for Cauliflower and Red Cabbage Crops Under Cool Season Semiarid Climatic Conditions

Van Baval, C.H.M. and Myers, L.E. 1962. An automatic weighing lysimeter. *Agriculture Engineering*.**43**:580-583 and 586-588.

Wright, J.L. and Jansen, M.E. 1982. Peak water requirements of crops in southern Idaho. *Journal of Irrigation and Drainage Division, Proc.ASAE.* **98**:193-201.

Yu-Lin L, Jian-Yuan C., Tong-Hui Z., Ha-Lin Z. 2003. Measurement of evapotranspiration of irrigated spring wheat and maize in a semi-arid region of north China.

Yang Z. 2011. hyper spectral estimating models of tobacco leaf area index.*African journal of Agricultural Research.* 6(2): 289-295

Zhao-Liang, L. 2009. A review of current methodologies for regional evapotranspiration estimation from remotely sensed data. Journal of Sensors 9(5): 3801-3853

Zheng, G.and Moskal L. M. 2009. Retrieving leaf area index (LAI) using remote sensing theories, methods and sensors. Jornal of sensors 9(4): 2719-2745.