CROP WATER REQUIREMENT AND IRRIGATION SCHEDULING OF SELECTED CROPS USING CROPWAT: A CASE STUDY OF PATTAMBI REGION

By

AISWARYA JOHNSON (2015-02-002)

ASHIKA NP (2015-02-011)

PARVATHY NAYANA N (2015-02-027)

DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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AISWARYA JOHNSON (2015-02-002)

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PROJECT REPORT

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KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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2019

DECLARATION

We hereby declare that, this project entitled **"CROP WATER REQUIREMENT AND IRRIGATION SCHEDULING OF SELECTED CROPS USING CROPWAT: A CASE STUDY OF PATTAMBI REGION"** is a bonafide record of project work done by us during the course of study, and that the report has not previously formed the basis for the award to us of any degree, diploma, associateship, fellowship or other similar title of any other university or society.

Aiswarya Johnson
(2015-02-002)

Ashika NP
(2015-02-011)

Place: Tavanur

Date:

Parvathy Nayana N
(2015-02-027)

CERTIFICATE

Certified that this project entitled **"CROP WATER REQUIREMENT AND IRRIGATION SCHEDULING OF SELECTED CROPS USING CROPWAT: A CASE STUDY OF PATTAMBI REGION"** is a record of project work done jointly by **Ms. Aiswarya Johnson (2015-02-002), Ms. Ashika NP (2015-02-011) and Ms. Parvathy Nayana N (2015-02-027)** under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, associate ship, fellowship or other similar title of another university or society.

Dr. Asha Joseph
Professor
Dept. of IDE
KCAET, Tavanur

Place: Tavanur
Date:

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Aiswarya Johnson (2015-02-002)

Ashika N P (2015-02-011)

Parvathy Nayana N (2015-02-027)

DEDICATED TO OUR PROFESSION

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SYMBOLS AND ABBREVIATIONS

%	**Percentage**
&	And
⁰	Degree
℃	Degree Celsius
AEZ	Agro Ecological Zones
BC	Blaney Criddle
cm	Centimeter
CU	Consumptive use
CWR	Crop Water Requirement
dec	Decade
ER	Effective Rainfall
ETo	Reference crop evapotranspiration
ET	Evapotranspiration
et.al	and others
ETc	Crop evapotranspiration
etc…	Etcetera
es	Saturation vapour pressure
FAO	Food and Agricultural Organization
FFNN	Feed Forward Neutral Network
Fig.	Figure
G	Soil heat flux density
Ge	Ground water contribution
h	Hour

IR	Irrigation Requirement
KAU	Kerala Agricultural University
Kc	Crop coefficient
KCAET	Kelappaji College of Agricultural Engineering and Technology
kPa	Kilopascal
km/h	Kilometer per hour
m	Meter
m/s	Meter/second
mm	Millimeter
Max.	Maximum
Min.	Minimum
NDD	Net Derived Demand
NIR	Net Irrigation Requirement
PM	Penman – Monteith
RARS	Regional Agricultural Research Station
RAW	Readily Available Water
Rn	Net radiation at the crop surface
RH	Relative humidity
T	Air temperature
U2	Wind speed
USDA	United State Department of Agriculture
WR	Water Requirement

INTRODUCTION

CHAPTER-I

INTRODUCTION

Water is an essential natural resource for all living things including plants. Although water is available in all three forms, viz. solid, liquid and gas, fresh water that is being available is only 3%. The major contribution to this 3% fresh water is from polar ice caps. Currently, world is facing an acute water scarcity due to aridity and drought. On one side man made desertification and water shortage is aggravating the situation while on the other side the population blast is demanding more fresh water. Therefore, improved management and planning is required for the efficient utilization of quality water from fresh waterbodies.

Water is an essential input influencing the scale and pattern of agricultural growth and agriculture is the largest user of water among all human activities where irrigation water contributes almost 70% of the total anthropogenic use of renewable water. The major source through which plants get water is rainfall. If the rainfall could not meet the requirements of crops, water is applied externally and this external application of water is known as irrigation. Irrigation can be defined as the quantity and depth of water that need to be supplied in addition to the precipitation, to produce the desired crop yield and quality and to maintain acceptable salt balance in the root zone. With an ever increasing demand for water in municipal and industrial sectors, its allocation for agriculture is decreasing steadily. Therefore, many more interpretations and innovations are required to increase the efficiency of use of water that is available.

The required timing and amount of water that need to be applied is determined by prevailing climatic conditions, crop growth stages, root development and type of soil. Water within the root zone is available to plants for evapotranspiration. Therefore, it is necessary to conduct field water balance to find the irrigation requirements. All crops will be having a critical growth period during which a slight variation in the moisture content could affect its growth. This critical growth period varies from crop to crop. Sufficient care must be taken to ensure that crops do not undergo a stressed condition due to soil moisture deficit. Irrigation scheduling involves determining the irrigation method, quantity of water to be provided and the frequency at which water need to be applied.

Many researches have undergone so far to investigate the impacts of socio-economic development, climatic change and variability on crop production but less on irrigation water use; both globally and regionally. Changes in precipitation combined with the changes in evapotranspiration demands is likely to increase the irrigation demands by 8% by 2070(Doll, 2001). Only the scientific management of irrigation water could combat the weather induced uncertainties and thereby enhance the agricultural production.

A higher yield is likely to obtain when water is maintained between two limits such that it is not that much higher to cause leaching and should not be much lesser to induce stress in crops. For the irrigation purpose the water that is being available to the plants is defined as the difference between the field capacity and permanent wilting point. Irrigation needs to be provided when a certain percentage (normally 30%-60%) of the total available water is being depleted. In order to determine the irrigation requirements and irrigation scheduling, a thorough knowledge on the crop water use is necessary. Daily and weekly crop water use data is used for the irrigation scheduling while annual water use estimates are required to specify the storage and conveyance system capabilities. Here comes the need to establish a procedure to estimate the water use in the present scenario of climatic change.

Proper irrigation practices could enhance the productivity in any country. But it is being estimated that around 50% of the agricultural water withdrawals reach the crops and the remainder is lost in irrigation infrastructure. The primary goal of irrigation is to apply water to maintain crop evapotranspiration if the precipitation is insufficient. Hess (2005) defined crop water requirements as the total water needed for evapotranspiration, from planting to harvest for a given crop in a specific climate regime, when adequate soil water is maintained by rainfall and/or irrigation so that it does not limit plant growth and crop yield.It is necessary to know the crop water requirement that has to be met by irrigation, for sustainable development of agriculture. Good irrigation scheduling will apply water at the right time and in the right quantity in order to optimize production and minimize adverse environmental impact. Under or over watering can lead to reduced yields, lower quality and inefficient use of nutrients.

Many methods are being available to estimate the evapotranspiration rates. They are broadly classified into direct and indirect methods. The indirect methods that are being used for determining ET_O include empirical formulae like Blaney Criddle, Hargreaves method, radiation method, Penman method, Penman Moneith method, modified Penman method etc. while the direct methods include lysimeter, field experimental plots, water balance method, soil depletion method etc. Of this Penman Monteith method is the most accurate one. But still the use of numerous tables and calculations increase the complexity and errors are likely to occur. The unscientific estimation of ET_O could result in faulty irrigation practices leading to irrigation losses, deficit irrigation and decreased irrigation efficiency.

Hence in order to increase the productivity, accurate and scientific estimation of crop water requirement is necessary. One of the major practices done by researchers to estimate the crop water requirement is software modelling. For determining the crop water requirements, crop evapotranspiration and irrigation scheduling CROPWAT 8.0 developed by FAO (Food and Agricultural Organization) Land and water Development Division seems to be accurate and reliable. It includes a simple water balance model that allows the simulation of crop water stress conditions and estimation of yield reductions on the basis of well-established methodologies.

Temporal and spatial variations could be observed in rainfall. Agriculture in a region mainly depends upon the total rainfall availability, its intensity, distribution and frequency. But the recent trends in rainfall showing abnormalities has put agriculture under a risk. India which is basically an agrarian economy will be affected by this badly. Even though Kerala receives a fairly good amount of rainfall, the productivity of the state is far below the national average. The uneven rainfall distribution, decreased water holding capacity and increased stress conditions during summer season are the major limiting factors (Surendran*et.al* 2015).

Although Kerala is blessed with timely and adequate rainfall with an annual rate of 3107 mm in recent times the rate of rainfall has weakened, causing serious concern for both power generation and drinking water. Normally, the South-West Monsoon (June- September) and North-East (October-December) contribute 66 percent each; the North-East (October-December) 16 percent, the winter rains (January-February) 3 percent and the summer rains (March-May) 15 percent to the water availability of the state. Nonetheless, large deviations occur in monthly rainfall and rainfall across the regions, which make irrigation a necessity for the stabilization ofthe water requirement of the crops (Kannan, 1989). Hence soil moisture deficit throughout summer season is one of the foremost limiting factors for higher yield in the state.

Adequate data on irrigation water requirement for crops are not available in developing countries like India. This is the reason for the failure of irrigation projects in such countries. The present irrigation practices in the state of Kerala have a general nature and does not account for all types of soil, crop and climate in various zones. Lacunae of site specific information on irrigation requirement for various crops are one of the main reasons for the low irrigation efficiency in the state. Hence there is a need for regional scale information with respect to crop water needs to improve or sustain productivity. On the whole, it can be said that irrigation in the state has the status of protective irrigation, the focus being on the efficient management of water to improve or sustain productivity.

In view of all the above facts an attempt was made to compute crop water requirement and irrigation schedules for major crops of Pattambi region. The specific objectives of the study are:

1. To study the variability in ET demand of selected crops in Pattambi region due to climate change.
2. To estimate the crop water requirement of selected crops and develop irrigation schedule for the crops.
3. To analyze gap between rainfall and crop water requirement.

REVIEW OF LITERATURE

CHAPTER-II

REVIEW OF LITERATURE

A computer based software model will be able to estimate accurate crop water requirement scientifically based on soil, crop and climate. The FAO developed the CROPWAT 8.0 seems to be sufficiently good in this content. Hence this study estimated ET_0, $ET_{c,}$ irrigation requirement and irrigation scheduling of major crops grown in Pattambi using FAO CROPWAT 8.0 model.

The review has been organized objective wise under the following subheads.

1. Estimation of evapotranspiration.
2. Determination of crop water requirement and irrigation requirement.
3. Crop water requirement and irrigation scheduling by FAO CROPWAT.
4. Soil water balance studies.

2.1 **Estimation of evapotranspiration.**

Gupta and Goyal (2001) conducted a study to compare performance of various methods of ET estimation and presented their interrelationship with respect to each other for arid region of Rajasthan State.

Sakellariou and Vagenas (2006) conducted a study using FAO Penman-Monteith method to map the reference crop evapotranspiration and rainfall. They estimated the total irrigation crop water requirement in central Greece with the aid of these maps which was irrigated by both private and public boreholes and by surface waters during the irrigation period of the year 2001 by using FAO penman- Monteith method. Crop evapotranspiration and net water requirements were computed for each crop in the municipalities on the prefectures for the whole irrigation period.

Ghazala and Ghulam (2007) conducted a study to analyze the subsequent effects of increasing temperatures on the ET_o and on the agricultural water demand in the Pakistan. This study helped in crop monitoring and in the assessment of how much water is available in future for crops and which type of crops would suit the climate. They found that better management and building of new water reservoirs may help to cope the situation for an improved agricultural growth.

Junzeng *et al*. (2008) conducted a lysimeter experiment to investigate tomato and cow pea crop evapotranspiration inside the green house in eastern China. The result showed remarkable decline in crop evapotranspiration inside the green house as compared to outside and ET increased with the growth stage of the crop and varied in accordance with the temperature inside the green house.

Choudhary and Shrivastava (2010) estimated the monthly reference evapotranspiration by FAO Penman-Monteith method and irrigation requirements for the system were estimated based on the methodology suggested in FAO 24. Artificial Neutral Network approach was found to be appropriate for the modelling of reference evapotranspiration for MRP command area. The study explored the potential of feed forward neutral (FFNN) for estimation and forecasting of monthly ET_o values in MRP command area.

Shekar (2012) explained evapotranspiration more broadly as a need of hour because in context of climate change as the average temperature is rising and certainly evaporative demand is shooting up. The different model for estimating ET differs in the effect of specific meteorological parameters on ET demand. The variations in temperature also caused variations in other parameters such as humidity, wind speed and vapour pressure which directly changed ET. In this study 10 years (2002-2011) weather data taken from ozone unit, Indian Meteorological Department, Banaras Hindu University (BHU), Varanasi had been analyzed for the change in temperature, wind speed and solar radiation.

Hashim *et al*. (2012) conducted experiments for determining water requirement and crop water productivity of crops grown in Makkah region of Saudi Arabia. Using neutron probe and mini lysimeter ET data was acquired at different crop growth stages. The data thus obtainedwere used for assessing the total water requirements of different crops. Results revealed that crop water requirements were found to vary from 303 to 727.8 mm in seasonal crops and from 436.7 to 1821.94 mm in forage crops.

2.2 **Determination of crop water requirement and irrigation requirement**

Pakhale *et al*. (2010) focused on analyzing the irrigation water requirement of wheat crop for rabi season from 1999 to 2003 in Karnal district of Haryana state, India. Area under wheat cultivation was determined using Landsat ETM+ image by applying Artificial Neural Network (ANN) classification technique. Potential Evapotranspiration and crop coefficient for wheat was used for estimating crop water requirement. They found that the water requirement for wheat was higher in the vegetative and mid-season stage where as a decreasing trend was shown towards the maturity stage. They also found that the irrigation water requirement was highly correlated with crop water requirement.

Chowdhury *et al.* (2013) carried out a study on implications of climate change on crop water requirements in arid region. This study sheds a light on the possible implications of climate change on crop water requirements and its direct and indirect effects on water resources management.

Aguilar *et al.* (2015) conducted a study on irrigation scheduling based on soil moisture sensors and evapotranspiration. The moisture sensors helped to schedule irrigation. The study validated the importance of moisture sensors to be installed in representative locations with good soil - sensor contact.

Zhe Gu *et al*. (2017) carried out a study on irrigation scheduling using RZZWQM2 model (Roots Zone Water Quality Model). This software predicted the development of crop water stress and its evaluation. They found that in semi-arid region the water stress-based irrigation scheme saved water use and maintained the crop yield.

2.3 **Crop water requirement and irrigation scheduling by FAO CROPWAT**

Halim and Sener (2001) carried out a study to analyze the response of onion to different irrigation scheduling and crops were subjected to four irrigation treatments during the years of 1997-1998 according to available soil water depletion fractions of 0.30, 0.50, 0.70 and no irrigation. The highest yield was obtained from the plots in which irrigation water was applied at soil water depletion fraction level of 0.30. Maintenance of soil moisture depletion level at 0.30 required 339.4 mm and 227.2 mm of irrigation water in 1997 and 1998 respectively. The seasonal evapotranspiration of onion was 420 mm in 1997 and 351.2 mm in 1998.

Farhad and Jayasree (2010) conducted a study on net derived demand (NDD) for irrigation water based on CROPWAT model, remote sensing and GIS techniques for Malayer in Iran. Satellite images (IRS LissIII 11th June 2006) were used to determine type and area of cultivated crops. CROPWAT model was used to calculate evapotranspiration. The estimation of irrigation water was based on local climate data and from the information on agricultural details obtained from the satellite images. This study indicated that perennial plants can be better classified in comparison with annual plants. Results also indicate to change the existing traditional irrigation methods, otherwise farmers may face shortages of irrigation water.

Adeniran *et al.* (2010) carried out a study to determine the crop water requirement of some selected crops for the area kampe (Omi) Dam irrigation project. Crop water requirement for each of the crops was determined by using 25-year climatic data using CROPWAT. The study showed that the dam can conveniently supply the water required for irrigation in the area.

Nurul and Sobri (2012) conducted a study with the objective of measuring irrigation water requirement of Pedu-muda reservoir for the paddy crop (two seasons) using two different methods (Blaney -Criddle method and CROPWAT model). In this study, the SDSM tool was used to simulate future climate trend from the year 2010 to 2099. In effort to measure the irrigation needed for the region, CROPWAT model was found to be more reliable and capable compared to the Blaney-Criddle method.

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

Karim *et al.* (2012) used FAO CROPWAT model along with remote sensing for estimating CWR for paddy crop located in the main branch canal of Bhadra command area in Karnataka. The results found that water requirements for Rabi crops were higher than those of the Kharif crops. The water requirement of paddy was found to be 1180.4mm for the entire growth period.

Gowda *et al.* (2013) carried out a study on water requirement of maize using CROPWAT mode in northern transitional zone of Karnataka. They did this study under rainfed condition at Dharwad during Kharif season. The field experimental data with the two dates of sowing of maize i.e June 16, 2010 and July 30, 2010 were collected and analyzed. They found that the total water requirement of maize sown at an early date was 116.0 mm and that of sown at late date was 183.8 mm.

Ma'an (2013) used the software CROPWAT 8.0 to study effect of deficit irrigation on wheat crop production in Sumel area. The climate data included temperature, humidity, wind and sunshine hours. Crop and soil data were obtained from the manual of FAO 56. By the application of this software, crop water requirements were found out along with irrigation scheduling for this area.

Banik*et al.* (2014) investigated the potential of CROPWAT model 8.0 to schedule the crop water assessment using filed data. They cultivated paddy and wheat in Karnal (Haryana) and Dehradun(Uttarakhand) for plain and hilly region. The results showed that reference evapotranspiration of rice and wheat crop were more for plain region as compared to hilly region. While crop evapotranspiration of rice was more for hilly region and it was more for wheat in plain region.

Manikandan *et al.* (2014)used the CROPWAT model to estimate stage-wise information of irrigation water requirement for mustard crop in Raipur to help judicious utilization of available water which may reduce the over utilization of ground water source.

Surendran *et al.*(2015)carried out a study on modelling the crop water requirement using FAO-CROPWAT and assessment of water resources for sustainable water resource management. They computed the crop water requirements of major crops in different agro-ecological zones of Palakkad using CROPWAT 8.0 model of FAO and compared the same with the available water resources of the district. The major cultivated crops are rice, coconut, banana, areca nut, vegetables, pulses, rubber, tea, coffee, cotton etc. The total water requirement for these crops in various agro-ecological zones was computed. The deficit results indicated that if the total area is brought under irrigation there will be deficit years and during such periods deficit irrigation or reduction in command area may have to be adopted.

Shah *et al.* (2015) conducted a study on irrigation scheduling using CROPWAT. They determined the crop water requirement and irrigation scheduling of major crops namely sugarcane, rice, tobacco, etc. using different approaches by CROPWAT model.

Nithya and Shivapur (2016) carried out a study to determine the crop water requirement of few selected crops for the command area in Tarikere taluk in Karnataka state, India. The crops include areca nut, coconut, and cotton, banana for two seasons, sweet pepper, onion, potato, rice, pulses, mango, and cotton, sugarcane and millet (ragi). Crop water requirement for each crop was determined by using 30-year climatic data in CROPWAT. The study showed that reference evapotranspiration (ET_0) varies from 2.5 to 3.36 mm/day for the area under study. The gross water requirement was 342.42 mm/year with an application efficiency of 70. Thus, the dam can conveniently supply the water required for irrigation in the area.

Hossain *et al.* (2017) conducted a study to estimate irrigation requirement and made irrigation scheduling of T. Aman (wet season) and Boro (dry season irrigated) rice in the western region of Bangladesh using CROPWAT model. The model estimated1408 mm annual ETo in the study area, of which the highest amounts of 175 mm was in April and the lowest (70 mm) in December. The average annual rainfall was 1592 mm of which 986 mm was effective for plant growth and development.

Surendran *et al.*(2017) calculated the water needs for various crops in different agro-ecological units (AEUs) of Kollam district (a humid tropical region of Kerala) using FAO-CROPWAT. The major cultivated crops are rice, coconut, rubber, pepper, banana, brinjal, tomato, tapioca, cardamom, tea, etc. Using evapotranspiration and effective rainfall in each unit, a water balance has been worked out.

Bhat *et al*. (2017) conducted a study on water requirement and irrigation scheduling of maize using CROPWAT model. This study focused on developing an optimal irrigation scheduling, to increase crop yield under water scarcity conditions. The crop water requirement and irrigation requirement were found to be 304 mm and 288.2 mm respectively.

The model calculated evapotranspiration and crop water requirements, allowed the development of recommendations for improved irrigation practices and planning of irrigation schedules under varying water supply conditions.

Shah (2018) carried out a study to determine the crop water requirements and irrigation scheduling for rabi and hot weather crops for the Waghodia region at Vadodara. Crop water requirement of each crop was determined using 7 year climatic data with the help of FAO CROPWAT model. Irrigating at critical depletion and irrigating at fixed interval per stage were the two approaches used in this study. The results showed that irrigation requirement for the crops like wheat, maize, potato and castor bean were 264.8 mm, 236.9 mm, 365.5 mm and 465.6 mm respectively.

Trivedi *et al.* (2018) conducted a study on estimation of evapotranspiration using CROPWAT 8.0 model for Shipra river basin in Madhya Pradesh, India. In this study they determined the potential evapotranspiration and actual evapotranspiration using crop coefficient in the Shipra river basin for the time series 1990 to 2010. From the study it was found out that the maximum average actual ET was in the month of May i.e., 288mm due to highest temperature in this month and the minimum average actual ET was in the month of November i.e., 34mm due to minimum temperature in this month. Thus the study concluded that PET and AET increased when temperature increased and vice –versa.

2.4 **Soil water balance studies.**

Gouranga (2005) conducted a study on spatial variations of climatic water balance, (water surplus, actual evapotranspiration), probabilistic monthly monsoon rainfall and mapping of cold periods in Agro-Ecological Region (AER) of India using GIS and models. The study found that as per the climatic water balance, large to moderate water surplus (520-70 mm) was available in AESR 12.1.

Kothari *et al.* (2007) carried out a study on water balance-based crop planning for Bhilwara district of Rajasthan using daily meteorological data of 45 years (1960-2004). The study revealed that on an annual basis, the region requires 1691.3 mm water, whereas the rainfall was only 669.1 mm. The actual evapotranspiration in the region was 476.6 mm and water deficit was 1214.7 mm. The water surplus was 189.6 mm during 31^{st} to 36^{th} week and water deficit was observed in remaining weeks. The surplus water was available in driest year, which could be harvested and utilized during the period of soil moisture deficit.

Diro and Ketema (2009) conducted a study on deficit irrigation scheduling for onion crop.Water was applied using low head drippers. There were eight treatments with three replications: stress at 1st, 2nd, 3rd, and 4th growth stages and partial stresses of 50% ETc, 75% ETc with two controls of 25% ETc and 100% ETc of the water requirement throughout the growing season. The input data for CROPWAT program include climatic, rainfall, crop and soil data. They found that yield reductions simulated by CROPWAT program were comparable with yield reduction measured under field condition.

Raj and Shakya (2017) conducted a studyto analyze the water balance components and their temporal and seasonal variations in Kathmandu valley, Nepal. They applied three hydrological models (SWAT, HBV and BTOPMC). The water balance components were investigated using precipitation, climatic data and potential evapotranspiration (PET) as input variables for each model. Although there were variations in the estimates among the different models, results indicated a possible range of variation for those values which is a useful finding for the short and long term planning of water resource development projects in the study area.

MATERIALS AND METHODS

CHAPTER-III

MATERIALS AND METHODS

This chapter explains the various methods used in the study, description of the study area and collection of data. The methods pertaining to the analysis of variability in ET, water requirement and scheduling of irrigation were explained in detail. A comparison was made between irrigation scheduling at critical depth and at fixed intervals during different stages. Each of these parts are discussed in detail under the following sub-heads.

3.1 STUDY AREA

The Pattambi region coming under the agro climatic zone AEZ10 was selected for the study. Pattambi is located in Palakkad district of Kerala in India which is at 10.76^0N latitude and 76.57^0 E longitudes. The entire region is at an elevation of 63 m above the mean sea level. The area was selected due to the availability of all parameters needed for this study.

3.2 CLIMATE

The average minimum and maximum temperature of Pattambi region is 22.8 °C and 27.6 °C respectively. The region falls under humid tropical climate. The average annual rainfall of the region is about 2749 mm. The rainy season in the area begins in late May and ends in the months of September. Summer season is hot with a maximum temperature of 36 °C during April and May. The relative humidity is low in summer with 35% and it goes up to 85% during the monsoon season. The wind speed in the region is about 3-6 km/hr.

3.3 SOIL TYPE

The major part of the study area contains Laterite soils in which clay content is more. These soils fall under the category of the soil group Ultisols (Jose *et al*. 2012).

3.4 MAJOR CROPS

The major crops grown in RARS Pattambi include rice, horticultural crops such as banana and mango, spices such as pepper, ginger and turmeric, pulses such as cow pea, green gram, black gram and vegetables such as tomato, pumpkin, ash guard, bindi, tomato etc.

3.5 ESTIMATION OF CROP WATER REQUIREMENT

The crop water requirement of a crop is defined as the amount of that is required to meet its evapotranspiration demands. Consumptive use (CU) is used to designate the losses due to ET and water that is used for its metabolic activities of plants. Thus CU exceed ET by the amount of water used for digestion, photosynthesis, transport of minerals and photosynthates, structural support and growth. Since this difference is usually less than 1%, ET and CU are normally assumed to be equal. The crop water need mainly depend on the climate, crop type and stage of growth of crop. The crop evapotranspiration can be directly estimated by the mass balance or energy transfer methods. It can also be determined by from lysimeters or from the studies of soil water balance. Sometimes Penman – Monteith equation is also applied for the estimation of crop water requirement directly but the lack of consolidate information on the aerodynamic and canopy features of the cropped area restricts its use.

Nowadays, the crop water requirement is usually calculated from the crop coefficient approach. The formula used is as follows.

$$ET_c = K_c \times ET_o$$

where Kc is crop coefficient

ETo is reference crop evapotranspiration.

ETc is the crop evapotranspiration

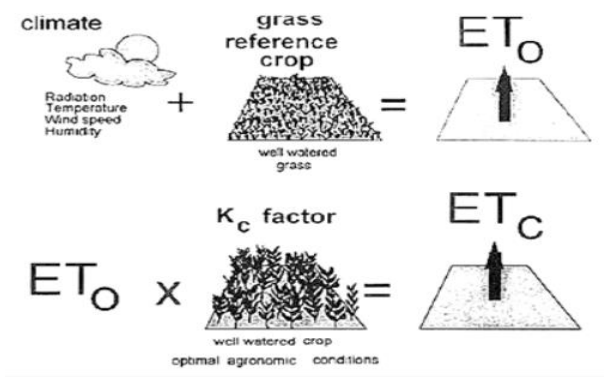


Fig 3.1 Estimation of evapotranspiration (Source: Allen *et al.* 1998)

Crop evapotranspiration (ETo) refers to the amount of water that is lost through evapotranspiration, while crop water requirement (ETc) refers to the amount of water need to be supplied.

3.5.1 Crop Coefficient (Kc)

The crop coefficient is generally the ratio of crop evapotranspiration to the reference crop evapotranspiration. Kc values mainly depend upon type of crop, climate and growth stage of crop. The crop coefficient predicts ETc under standard conditions, i.e, conditions where there are no limitations on crop growth due to water shortage, crop density, disease, weed, insect or salinity pressures. This represents the upper envelope of evapotranspiration.

In order to determine Kc it is necessary to determine the total growing period of each crop, various growth stages of each crop and the value of Kc in different growth stages.

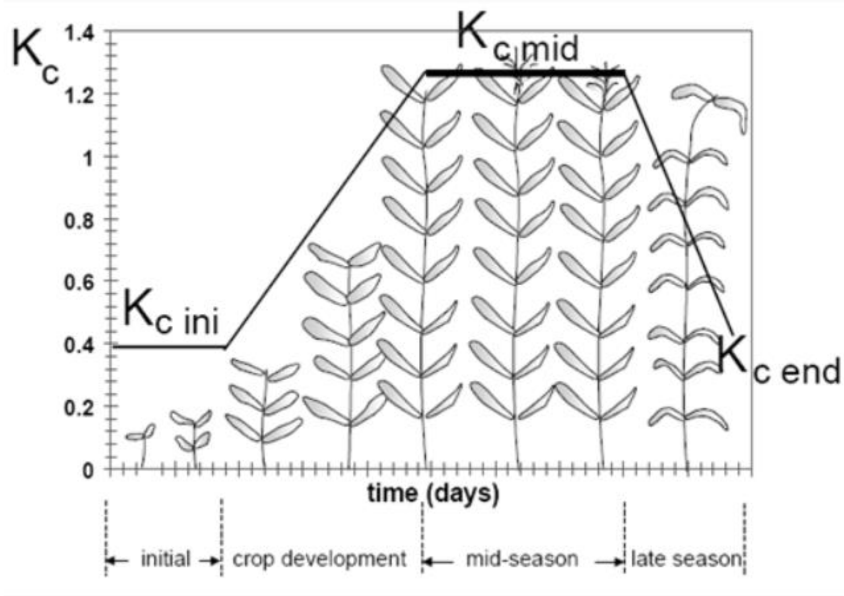


Fig 3.2 Variation of crop coefficient with crop growth stages (Source: Allen *et al.* 1998)

3.6 ESTIMATION OF REFERENCE CROP EVAPOTRANSPIRATION (ETo)

Evapotranspiration is a combination of two processes- evaporation and transpiration. Crop evapotranspiration from an extensive surface of green grass of uniform height(0.12m), actively growing, completely shading the ground with an albedo of 0.23 and having ample water supply is called reference crop evapotranspiration and is denoted by $ET_{o.}$ Various methods are in use for the determination of ETo.

FAO-56 Penman – Monteith Method

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma \frac{900}{T+273} U_2(e_{s-e_a})}{\Delta + \gamma(1 - .34U_2)}$$

Where,

ETo = Reference crop evapotranspiration (mm/day)

Rn = Net radiation at the crop surface ($MJ/m^2/day$)

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

T = Air temperature at 2 m height (°C)

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

e_s = Saturation vapour pressure (kPa)

The Penman-Monteith equation is used widely nowadays for the estimation of ETo.

3.7 DESCRIPTION OF CROPWAT 8.0 MODEL

The estimation of crop water requirements manually using these equations is a tedious job. Computerized programs could easily access the wide range of data and could give the desired results on crop water requirements and irrigation scheduling. The land and water development division under the Food and Agricultural organisation has developed a software CROPWAT 8.0 for the determination of crop water requirement and irrigation scheduling. It is meant as a standard tool for carrying out calculations for reference crop evapotranspiration, crop water requirement and crop irrigation requirement. The CROPWAT model offers the possibility to:

1. Design an indicative irrigation schedules and its impact over yield
2. Evaluate field irrigation program in terms of efficiency of water use and yield reduction.
3. Simulate field irrigation program under water deficiency conditions, rain-fed conditions, supplementary irrigation, etc.

This computer program utilises FAO Penman-Monteith equation for the calculation of ETo. The program allows development of irrigation schedules under various management and water supply conditions. The major features of CROPWAT 8.0 include:

1) Monthly, decade and daily input of climate data.
2) Possibility to estimate climate data in the absence of measured value.
3) Decade and daily calculation of crop water requirements based on update calculation algorithms including adjustment of crop-coefficient value.
4) Calculation for dry crops and for paddy and upland rice
5) Daily soil water balance output tables.
6) Easy saving and retrieval of session and of user defined irrigation scheduling.
7) Graphical presentation of input data and calculation results.
8) Easy import/export of data and graphics through clipboard or ASCII text file.

9) Extensive printing routines.
10) Context-sensitive help system.

3.8 INPUT REQUIREMENTS FOR CROPWAT 8.0 MODEL

The input data required for CROPWAT 8.0 include

3.8.1 Meteorological Data

i) Climate Data

The meteorological data were collected for the past 35 years from RARS, Pattambi. These data include daily maximum and minimum temperatures, relative humidity, daily wind speed and daily sunshine hours. The average values of these data are calculated using the model.

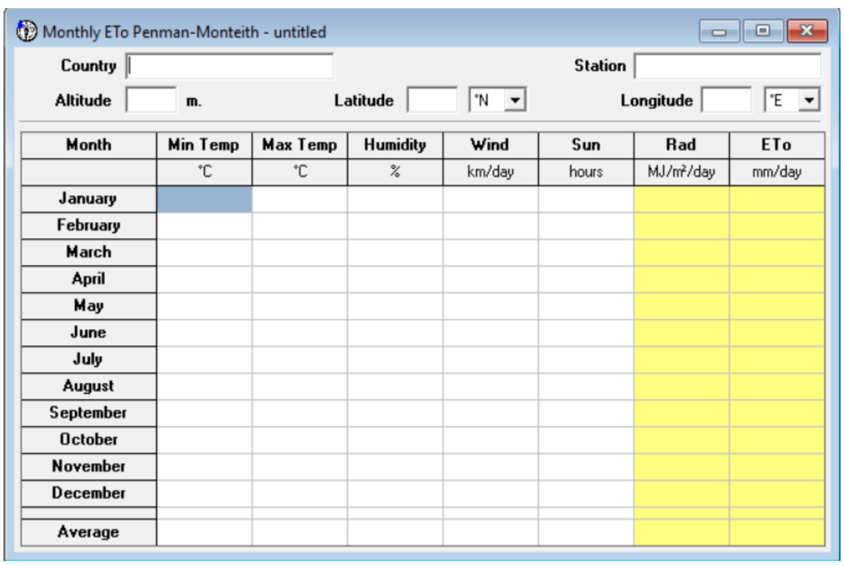


Fig 3.3 Input window for climate data CROPWAT

These parameters are used by CROPWAT in order to calculate the radiation and ETo.

ii) Rain Data

The daily rainfall data was collected from RARS Pattambi. The average of 35 year data was used by CROPWAT model to calculate the effective rainfall. The effective rainfall was calculated in CROPWAT using USDA soil conservation service method.

$$P\text{eff(dec)} = (P\text{dec} * (125 - 0.6 * P\text{dec}))/125$$

for $P\text{dec} \leq (250/3)$ mm

$$Peff(dec) = (125/3) + 0.1 * Pdec$$

for $Pdec > (250/3)$ mm

where *P*eff is the effective rainfall and *P*dec is the rainfall for 10 days

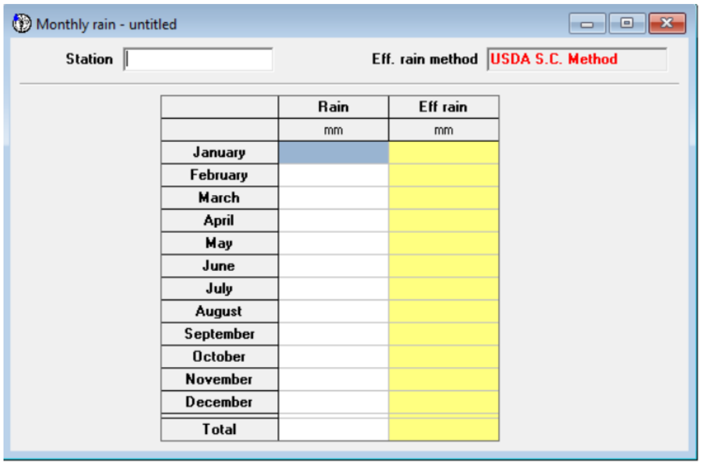


Fig 3.4 Input window for rainfall data CROPWAT

Table 3.1 Mean monthly values of weather parameters of Pattambi (1983-2017)

Sl no	Month	Max. Temp, °C	Min. Temp, °C	RH, %	Wind speed, km/hr	Sunshine (hr)	Rainfall
1	January	33.3	20.48	58.5	5.81	8.61	10.759
2	February	35.28	21.05	61	4.81	8.86	8.666
3	March	36.11	23.36	62.5	4	8.5	14.175
4	April	35.28	24.53	71.85	3.222	7.9	66.276
5	May	33.75	24.71	76.75	3.08	7.25	152.179
6	June	30.2	23.43	84.75	2.64	4.47	603.833
7	July	29.44	22.88	83.5	3.13	3.35	572.096
8	August	29.61	23.09	83	3.49	4.44	358.42
9	September	30.47	23.61	80.25	3.13	5.76	236.25
10	October	31.2	23.26	79	2.08	5.62	255.071
11	November	32.2	22.22	73.5	2.83	6.65	89.544
12	December	32.12	21.04	69.25	5.17	7.85	19.297

3.8.2 Soil Data

The soil in Pattambi region comes under the category of ultisols which is a heavy soil. The major data requirements for soil include total available soil water content, maximum infiltration rate, maximum rooting depth and initial soil water content.

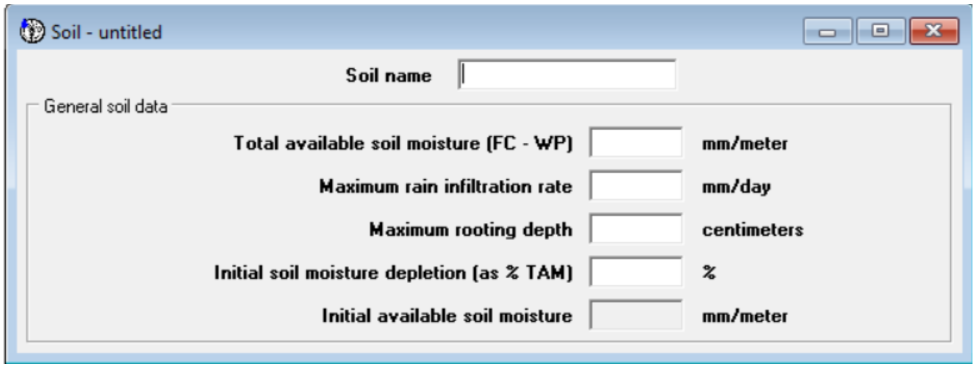


Fig 3.5 Input window of soil data (dry crop) CROPWAT

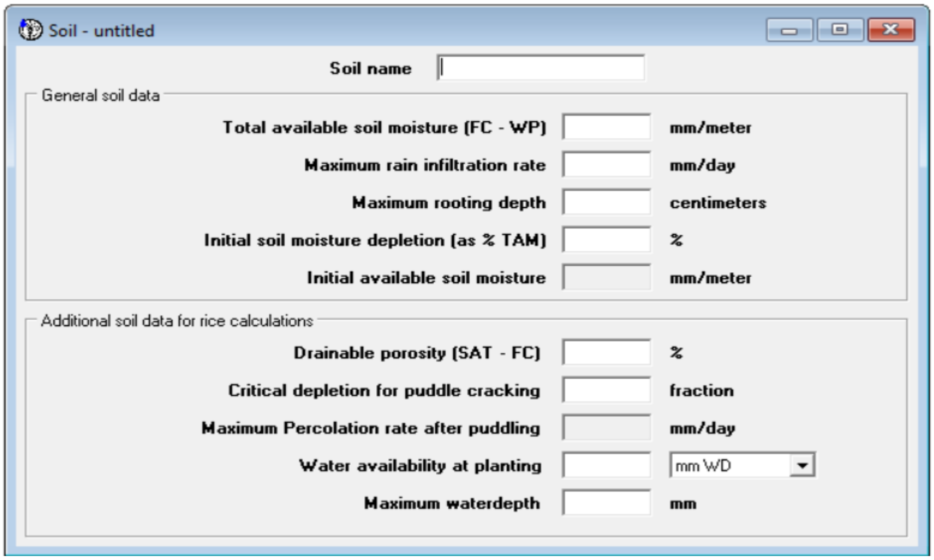


Fig 3.6 Input window of soil data for rice CROPWAT

Table 3.2 Soil data

Type of soil	Laterite soil
Total available soil water content	200 mm/m
Maximum infiltration rate	40 mm/day
Maximum rooting depth	900 cm
Initial soil water content	200 mm/m

3.8.3 Crop Data

The major crops selected for the study include rice (direct sowing), rice(transplant), banana, pulses, pepper and vegetables. The data collected include crop coefficient, critical depletion and length of growing season. The data is being collected from FAO 56 paper for each crop.

Table 3.3 Crop data for rice (transplant)

Date of sowing		01/05	**Date of harvest**		28/08
Crop Parameter	**Initial**	**Development**	**Mid- season**	**Late**	**Total**
Kc (dry)	0.5	1.05	1.05	0.7	
Kc (wet)	1.1	1.2	1.2	1.05	
Length, days	20	30	40	30	120
Puddling depth	0.4				
Rooting depth	0.1		0.6	0.6	
Critical depletion factor	0.2	0.2	0.2	0.2	
Yield response factor	1	1.09	1.32	0.5	1.1
Crop height, m		1			

Table 3.4 Crop data for rice (direct sowing)

Date of sowing		01/05	Harvesting Date			28/08
Crop Parameter	**Nursery**	**Initial**	**Development**	**Mid- season**	**Late**	**Total**
Kc (dry)	0.7	0.3	0.5	1.05	0.7	
Kc (wet)	1.2	1.05	1.1	1.2	1.05	
Length, days	30	20	30	40	30	120
Puddling depth		0.4				
Rooting depth	0.1		0.6	0.6		
Critical depletion factor	0.2	0.2	0.2	0.2	0.2	
Yield response factor	1	1.09	1.32	0.5	1.1	
Crop height, m			1			

Table 3.5 Crop data for banana

Date of sowing		01/06	Harvesting Date		31/05
Crop parameter	**Initial**	**Development**	**Mid-season**	**Late**	**Total**
Kc	1	1.2	1.2	1.1	
Length, days	120	60	180	5	365
Rooting depth	0.9		0.9		
Critical depletion factor	0.55		0.45	0.45	
Yield response factor	1	1	1	1	1
Crop height, m		4			

Table 3.6 Crop data for pepper

Date of sowing		01/06	**Harvesting Date**		3/10
Crop parameter	**Initial**	**Development**	**Mid-season**	**Late**	**Total**
Kc	0.6		1.05	0.9	
Length, days	30	35	40	20	125
Rooting depth	0.25		0.8		
Critical depletion factor	0.2		0.3	0.5	
Yield response factor	1.4	0.6	1.2	0.6	1.1
Crop height, m		0.7			

Table 3.7 Crop data for pulses

Date of sowing		01/01	**Harvesting Date**		10/04
Crop parameter	**Initial**	**Development**	**Mid-season**	**Late**	**Total**
Kc	0.4		1.05	0.35	
Length, days	20	30	30	20	100
Rooting depth	0.6		1		
Critical depletion factor	0.45		0.45	0.45	
Yield response factor	0.8	0.4	1.2	1	1
Crop height, m		0.4			

Table 3.8 Crop data for vegetables

Date of sowing		26/01	Harvesting Date		09/06
Crop parameter	**Initial**	**Development**	**Mid-season**	**Late**	**Total**
Kc	0.6		1.15	0.8	
Length, days	30	40	40	25	135
Rooting depth	0.7		1.5		
Critical depletion factor	0.4		0.4	0.4	
Yield response factor	1.05	1.05	1.05	1.05	1.05
Crop height, m		0.4			

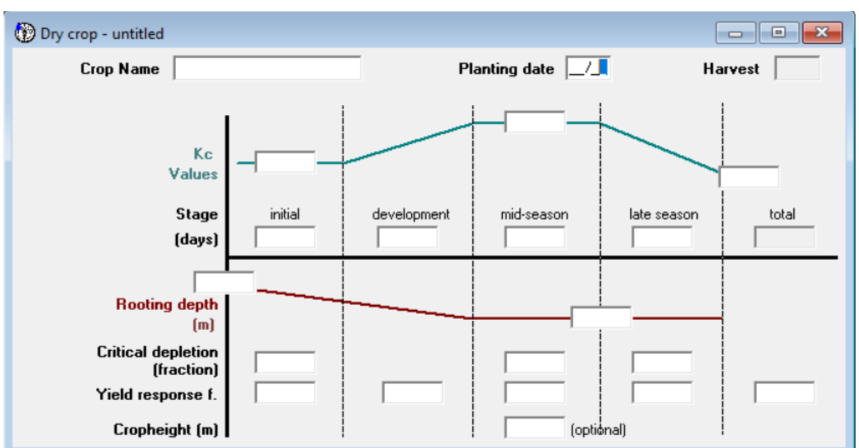


Fig 3.7 Input window for dry crop data

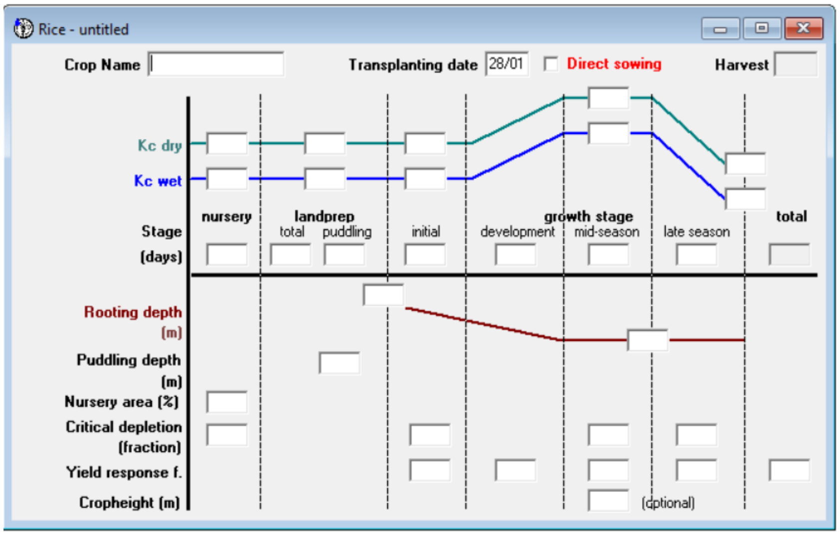


Fig 3.8 Input window for rice crop

3.9 NET IRRIGATION REQUIREMENT (NIR)

Irrigation is necessary when rainfall could not meet the evapotranspiration demands of the crops. Irrigation should apply the right quantity of water at the right time. The timing and depth of future irrigations can be planned by calculating soil water balance in the root zone on a daily balance. The irrigation requirement, expressed in mm is calculated for the specified interval. Net irrigation requirement is the variation between concerned crop evapotranspiration growing under standard conditions with the effective rainfall for the specified time interval. It indicatively represents the fraction of crop water requirements that needs to be satisfied through irrigation contribution in order to ensure optimum crop growing conditions.

$$NIR = WR – ER – Ge$$

where,

WR = Water Requirement (ETc)

ER = Effective Rainfall

Ge = Groundwater contribution from the water table (not considered in the study as this is negligible).

3.10 IRRIGATION SCHEDULING

Irrigation scheduling primarily aims at determining how to irrigate, when to irrigate and how much to irrigate. The primary aim of scheduling is to maintain optimum water supply to improve productivity so that the water level in the root zone is maintained between the confines of readily available water (RAW). CROPWAT model handles irrigation scheduling of each crop individually. The schedule not only enables the efficient management of water but also develop effective water delivery schedules under restricted supply conditions.

The irrigation scheduling option in CROPWAT provides a number of options depending on user's objectives, available water sources the conditions of the irrigation system. Here in this study two approaches are used for irrigation scheduling. The best method among these two is selected. Current one year data (Jan – Dec, 2017) is used for scheduling the irrigation.

Two approaches are used for the scheduling of irrigation for dry crops.

1. Irrigate at 100% critical depletion.

2. Irrigate at fixed interval (10days) per stage

In both these approaches the soil moisture content is refilled to field capacity and the irrigation is supposed to have an efficiency of 70%.

Two main approaches are being used for the irrigation scheduling of rice crop.

1. Irrigate at fixed water depth (5 mm).

2. Irrigate at fixed interval (10days) per stage

Here the soil is being refilled to a water depth of 100 mm at an assumed irrigation efficiency of 70%.

3.11 SIMULATIONS

The model is run for the selected crops with daily average climatic data and single scheduling criteria. The model results are analysed and the best fit irrigation scheduling option is selected.

RESULTS AND DISCUSSIONS

CHAPTER-IV

RESULTS AND DISCUSSIONS

The evapotranspiration rate and thereby the water requirement of crops are dependent upon the various weather parameters. The variability of these parameters over years has greatly influenced the water demands of crops. The rainfall alone could not meet the ET demand of crop. The remaining water has to be applied externally via irrigation. A good irrigation practice applies right quantity of water at the right time. Here comes the need to establish a better scheduling for irrigation. This could result in the judicious use of water in the current scenario of water scarcity. An analysis of gap between the rainfall and water requirement of crop will help whether rainfall could meet the required demand. Results and discussion pertaining to all the above aspects were discussed in the following sub heads.

4.1 CHANGES IN ETo DEMAND DUE TO CLIMATIC VARIABILITY

ETo demand of selected crops in Pattambi region for each year from 1983-2017 was calculated using FAO CROPWAT model. Change in ETo demand was analyzed by considering 5-year average values of climatic parameters presented in Table 4.1 and Fig. 4.1.

Table 4.1 Variation in ETo with climatic parameters (1983-2017)

YEAR	5 YEAR AVERAGE						
	Min. Temp, °C	Max.Temp, °C	Humidity, %	Windspeed, kmph	Sunshine, hrs	Radiation, Mj/m/day	ETo, mm/day
1983-87	22.66	32.6	77	82	6.94	18.7	4.1
1988-92	21.78	32.7	75.2	106	6.58	18.52	4.196
1993-97	22.26	32.36	84.6	114	6.76	18.82	4.036
1998-2002	23.12	32.16	73.8	99	6.62	18.58	4.2
2003-2007	22.94	32.34	76	100.4	6.58	18.5	4.158

2007-2012	23.22	32.52	75	89.2	6.42	18.26	4.104
2012-2017	23.1	32.32	74	78	5.93	17.55	3.94

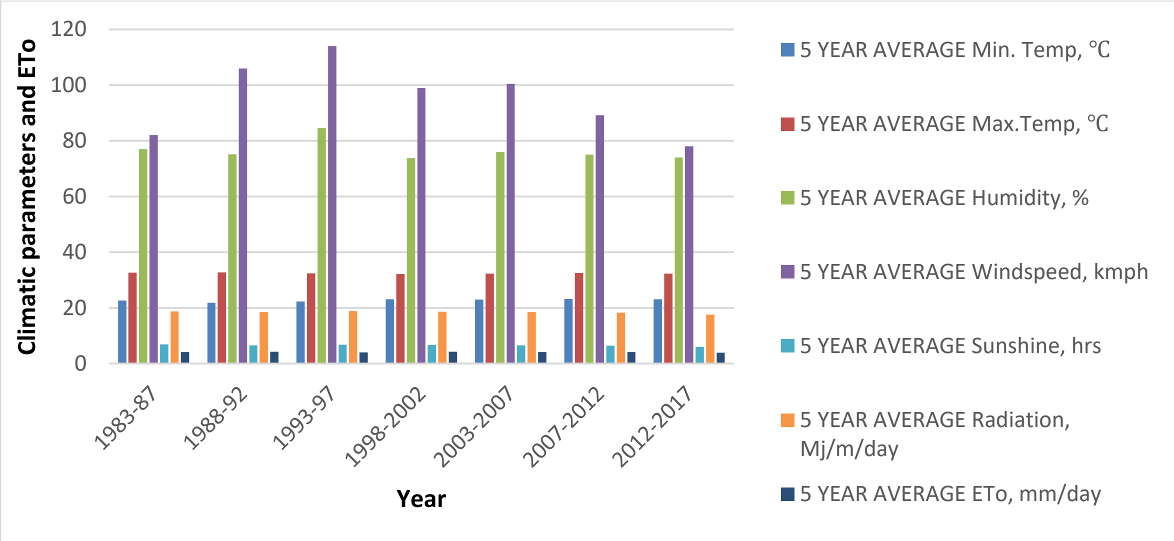


Fig. 4.1 Variation of climatic parameters and ETo during 1983-2017 (5-year average)

The ETo demand in Pattambi region during the period 1983-2017 was found to be almost constant with an average of 4.00 mm/day. The ETo varies from 4.2mm/day during the fourth 5-year (1998-2002) to 3.94mm/day during the seventh 5-year (2012-2017). It has been found that there is not much variation during the period 1983-2017, still there was a decreasing trend for ET.

4.1.1 Variation of CWR and IR of crops with climatic parameters (1983-2017)

Changes in climatic parameters and ETo values significantly affect the water requirements of crops. In most of the cases rainfall could not meet the CWR, hence, deficit water must to be supplied through irrigation. Change in CWR (ETc) and IR of selected crops are shown in Fig. 4.2, 4.3, 4.4, 4.5, 4.6 and 4.7.

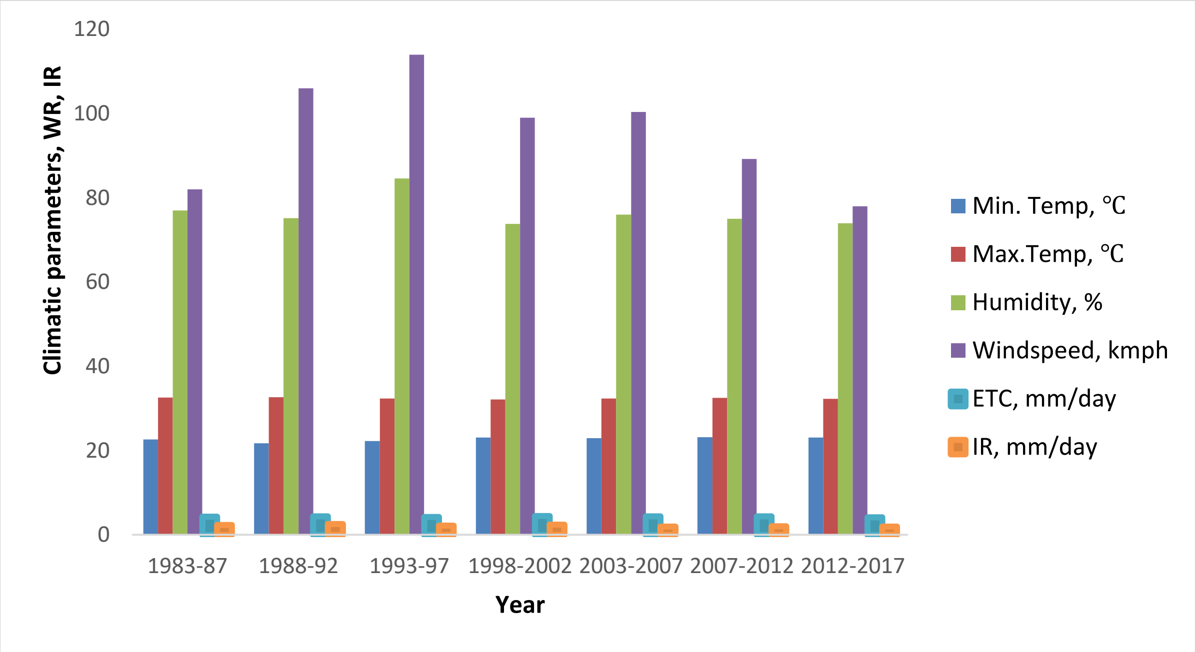


Fig. 4.2 Variation of CWR and IR for banana during 1983- 2017 (5- year average)

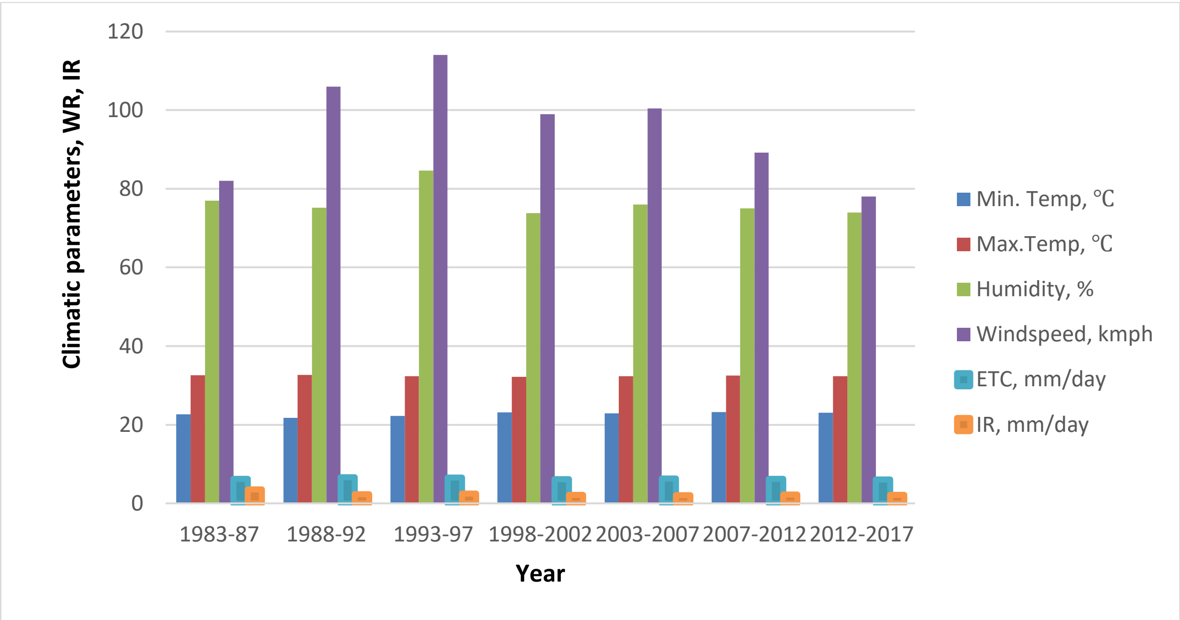


Fig. 4.3 Variation of CWR and IR for rice (direct sown) during 1983- 2017

(5-year average)

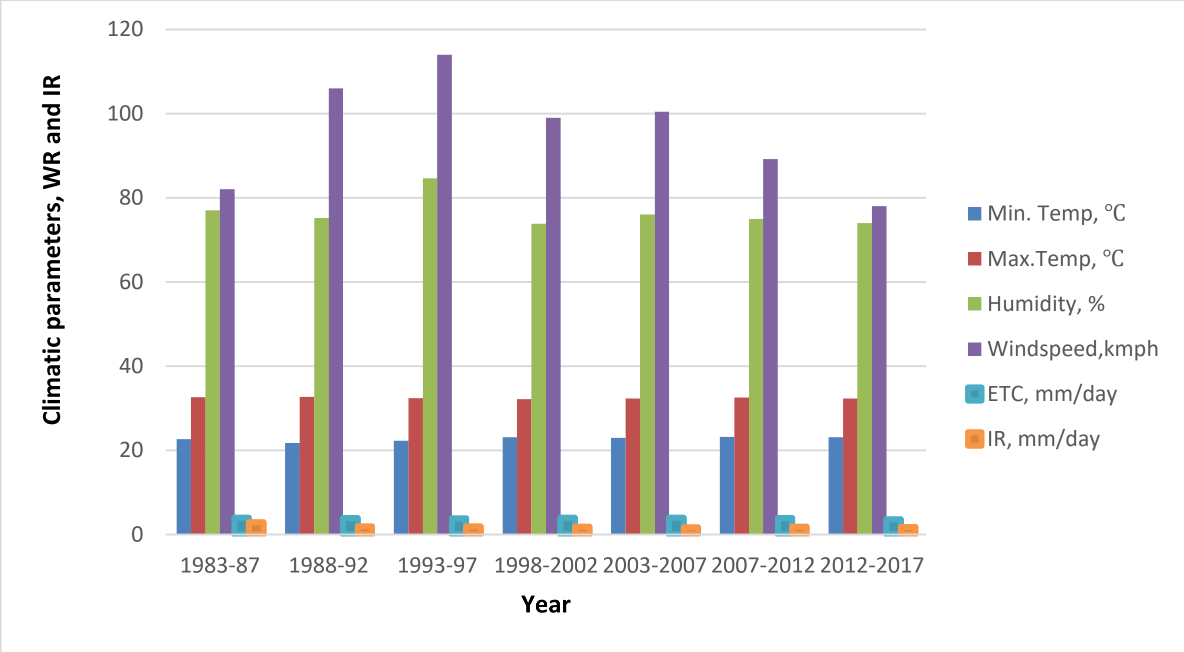


Fig. 4.4 Variation of CWR and IR for transplanted rice during 1983- 2017

(5-year average)

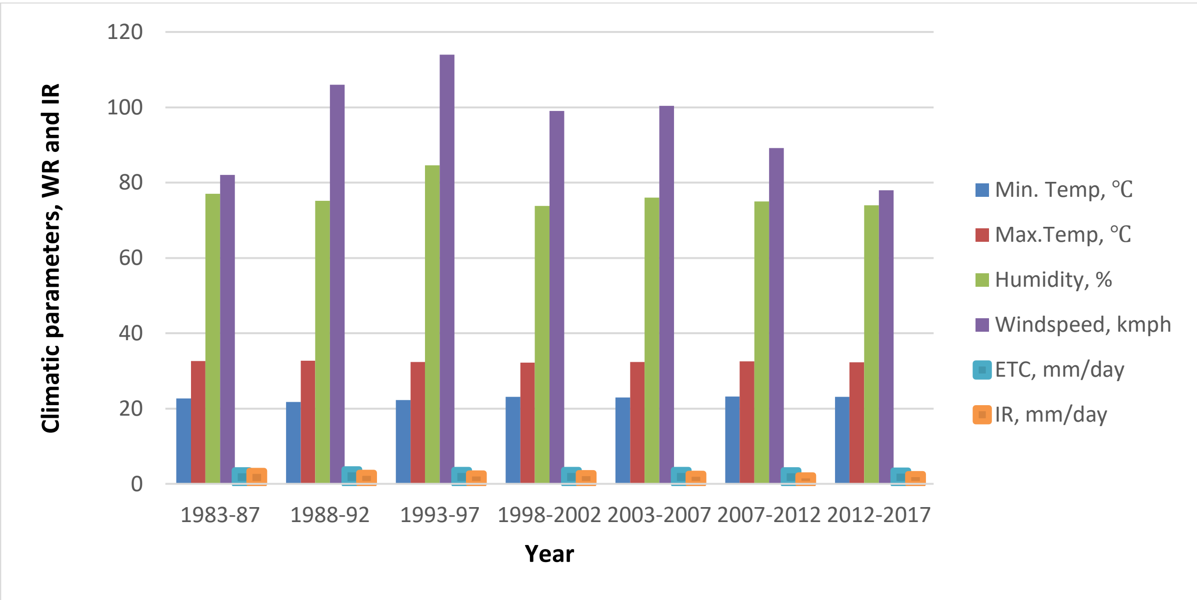


Fig. 4.5 Variation of CWR and IR for pulses during 1983- 2017 (5- year average)

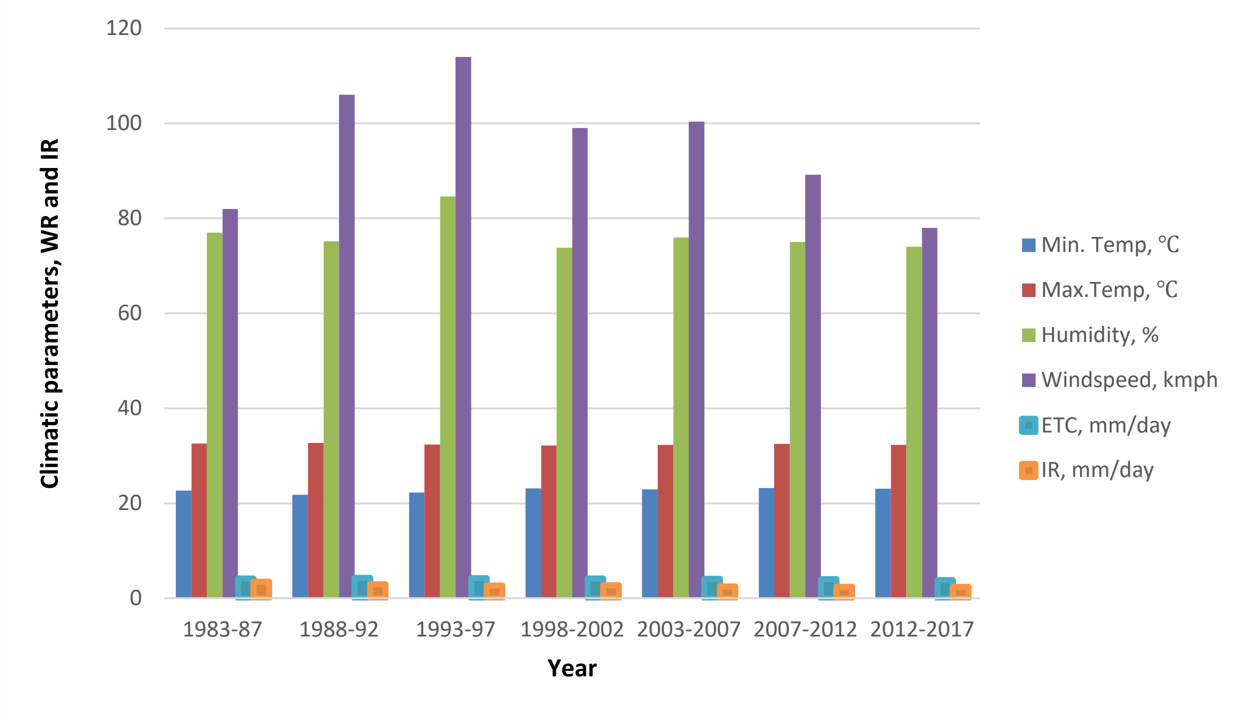


Fig. 4.6 Variation of CWR and IR for pepper during 1983- 2017 (5- year average)

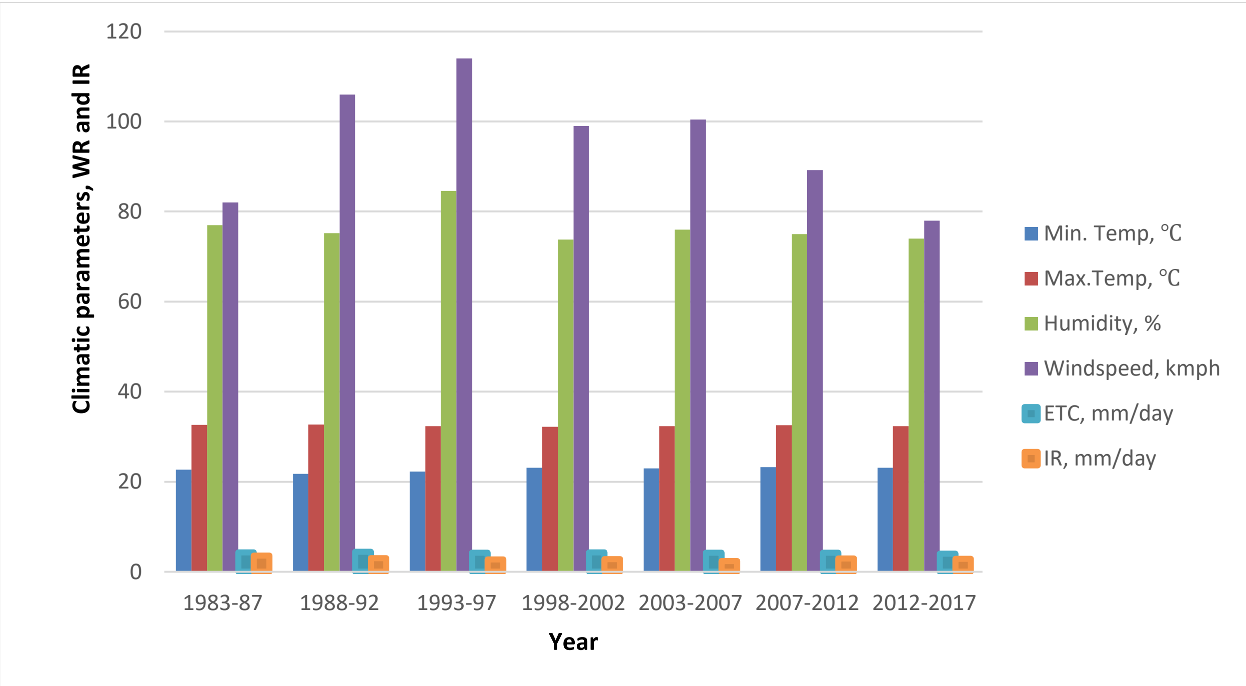


Fig. 4.7 Variation of CWR and IR for vegetables during 1983- 2017 (5- year average)

The highest IR of direct sowed rice, 3.6 mm/day was observed during the period 1983-1987 during which the ET demand was 6.273 mm/day. The lowest IR for the same was 2.11 mm/day during the period 2003-2007. In the case of transplanted rice, highest IR of 2.963 mm/day was observed during the period 1983-1987 while lowest IR of 1.745 mm/day was observed during the period 2003-2007.

From Fig. 4.3, it can be found that highest water requirement for banana of 4.44 mm/day was observed during the period 1998-2002 while lowest was observed during 2012-2017 with a value of 1.956 mm/day. In the case of pulses, it was found that a highest CWR of 3.92 mm/day was observed during the period 1983-1987 while the IR for the same year was 3.46 mm/day. The CWR of 3.547 mm/day observed during the period 2007-2012 was the lowest for the pulses. The highest CWR of pepper was observed as 4.29 mm/day during the period 1983-1987 while the lowest was observed as 3.859 mm/day during the period 2007-2012. In the case of vegetables, a higher CWR was observed during 1983-1987 as 3.6 mm/day while the lowest was recorded as 4.014 mm/day during 2003-2007. The change in climate did not affect much on CWR and IR.

4.2 WATER REQUIREMENT AND IRRIGATION SCHEDULING FOR THE SELECTED CROPS UNDER THE CURRENT SCENARIO

Water requirement and irrigation scheduling for the selected crops were estimated by inputting the climatic parameters of the year 2017 in CROPWAT model. The scheduling criteria under the two different conditions were used to determine the most appropriate irrigation scheduling for different crops.

4.2.1 Water Requirement of Banana during 2017

The water requirement of banana was found for the year 2017 using CROPWAT model. The model calculated the IR for the entire growth period, in a decade wise pattern (10 days). The results obtained from the model are shown in Table 4.2.

Table 4.2 Crop water requirement of banana, 2017

Month	Decade	Stage of crop	Kc values	ETc	ETc	ER	IR
	dec		coefficient	mm/day	mm/dec	mm/dec	mm/dec
Jun	1	Initial	1	3.31	33.1	56.8	0
Jun	2	Initial	1	2.77	27.7	63.2	0
Jun	3	Initial	1	2.93	29.3	59.9	0
Jul	1	Initial	1	3.15	31.5	54.9	0
Jul	2	Initial	1	3.25	32.5	52.3	0
Jul	3	Initial	1	3.21	35.3	53.4	0
Aug	1	Initial	1	3.17	31.7	55.3	0
Aug	2	Initial	1	3.13	31.3	56.2	0
Aug	3	Initial	1	3.27	36	54.6	0
Sep	1	Initial	1	3.41	34.1	55.4	0
Sep	2	Initial	1	3.55	35.5	55.4	0
Sep	3	Development	1	3.5	35	43.3	0
Oct	1	Development	1.02	3.49	34.9	26	8.9
Oct	2	Development	1.04	3.51	35.1	13.4	21.8
Oct	3	Development	1.06	3.61	39.7	18.4	21.3
Nov	1	Development	1.09	3.7	37	27.8	9.2
Nov	2	Development	1.11	3.8	38	32.1	5.8
Nov	3	Mid	1.13	4.01	40.1	25.1	15
Dec	1	Mid	1.13	4.17	41.7	16.3	25.4
Dec	2	Mid	1.13	4.31	43.1	10.3	32.8

Dec	3	Mid	1.13	4.64	51.1	6.9	44.2
Jan	1	Mid	1.13	4.98	49.8	0.1	49.7
Jan	2	Mid	1.13	5.31	53.1	0	53.1
Jan	3	Mid	1.13	5.36	59	0	59
Feb	1	Mid	1.13	5.41	54.1	0	54.1
Feb	2	Mid	1.13	5.47	54.7	0	54.7
Feb	3	Mid	1.13	5.46	43.7	0.1	43.6
Mar	1	Mid	1.13	5.46	54.6	11.2	43.4
Mar	2	Mid	1.13	5.46	54.6	16.8	37.8
Mar	3	Mid	1.13	5.41	59.6	11.4	48.2
Apr	1	Mid	1.13	5.37	53.7	0.4	53.3
Apr	2	Mid	1.13	5.32	53.2	0	53.2
Apr	3	Mid	1.13	5.21	52.1	1.3	50.7
May	1	Mid	1.13	5.16	51.6	32.2	19.4
May	2	Mid	1.13	5.08	50.8	48.1	2.7
May	3	Late	1.1	4.36	48	52.1	0
					1546.2	1010.8	807.2

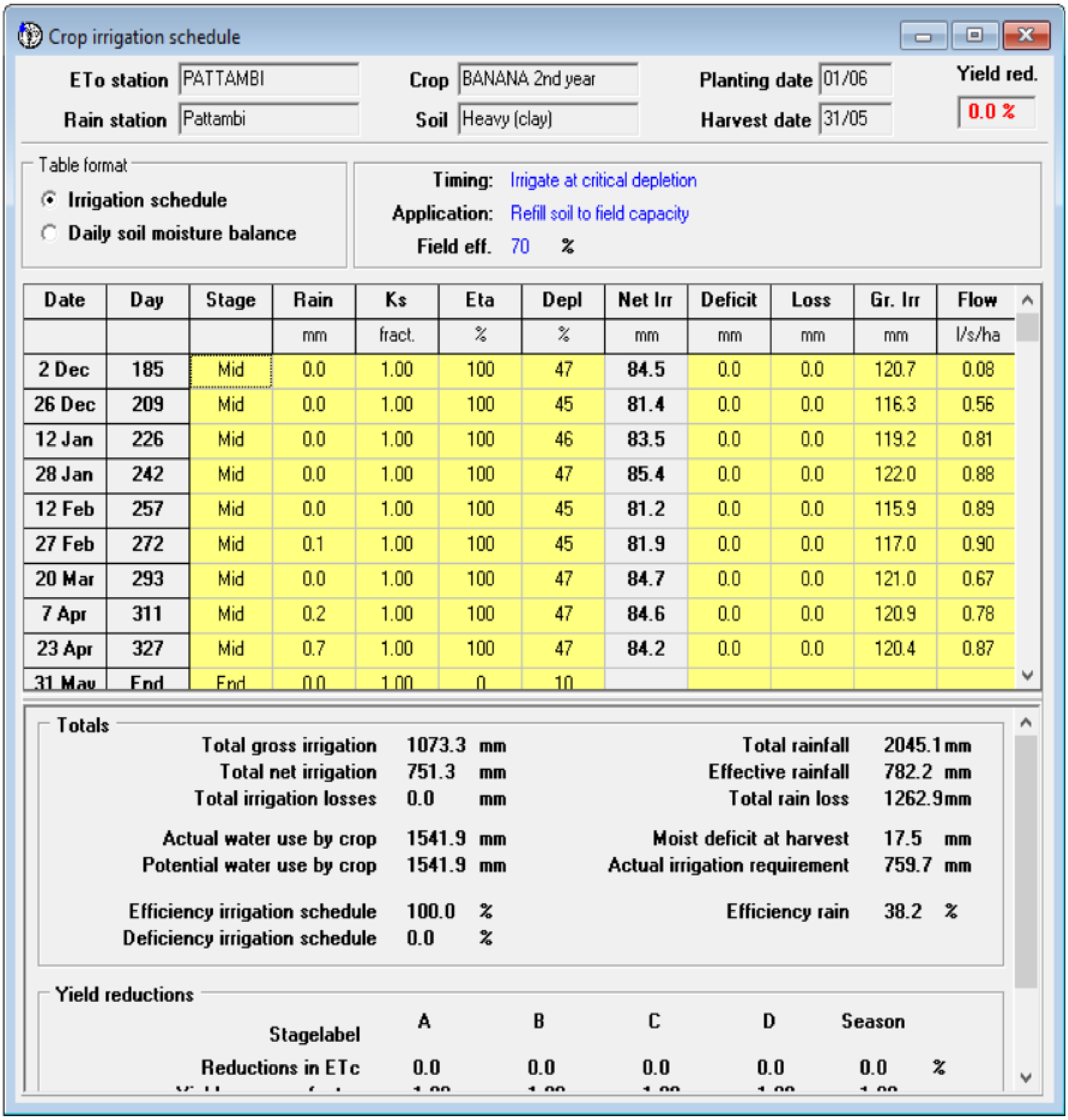
From the Table 4.2, it was inferred that the initial days does not need any additional irrigation water since the demands are met from rainfall. The mid and development stages required more water to be supplied through irrigation. The total CWR and IR for banana were found to be 1546.2 mm and 807.2 mm respectively for its entire growth period.

4.2.2 Irrigation Scheduling of banana during 2017

The scheduling of irrigation is done under two criteria:

1. Irrigation at 100% critical depletion.

The Fig. 4.8 represents the output window obtained from CROPWAT model for irrigation scheduling of banana at critical depletion. It was found that the total gross irrigation was about 1073.3 mm, NIR was 751.3 mm and the efficiency of rain was 38.2%.

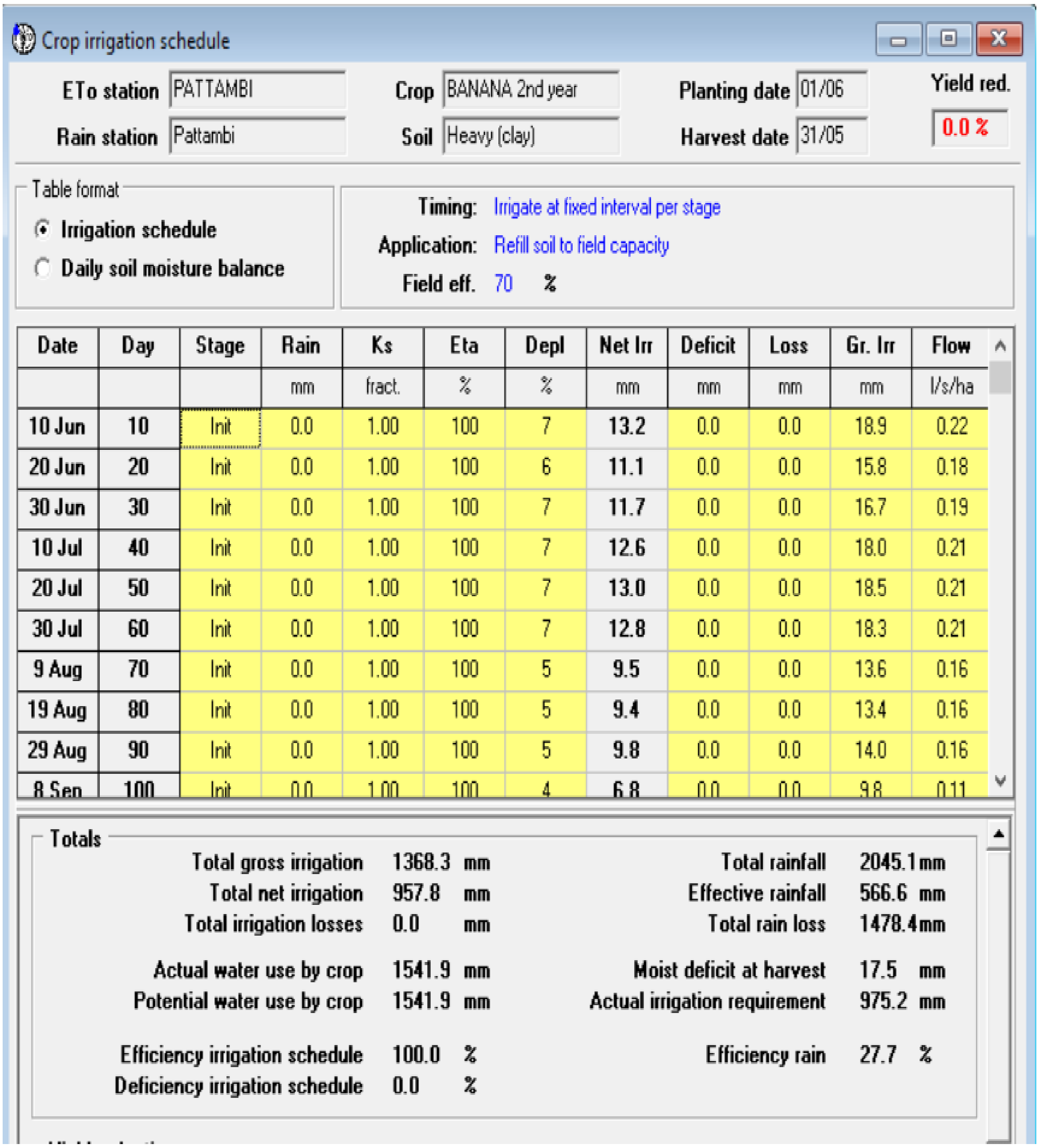


Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
2 Dec	185	Mid	0.0	1.00	100	47	84.5	0.0	0.0	120.7	0.08
26 Dec	209	Mid	0.0	1.00	100	45	81.4	0.0	0.0	116.3	0.56
12 Jan	226	Mid	0.0	1.00	100	46	83.5	0.0	0.0	119.2	0.81
28 Jan	242	Mid	0.0	1.00	100	47	85.4	0.0	0.0	122.0	0.88
12 Feb	257	Mid	0.0	1.00	100	45	81.2	0.0	0.0	115.9	0.89
27 Feb	272	Mid	0.1	1.00	100	45	81.9	0.0	0.0	117.0	0.90
20 Mar	293	Mid	0.0	1.00	100	47	84.7	0.0	0.0	121.0	0.67
7 Apr	311	Mid	0.2	1.00	100	47	84.6	0.0	0.0	120.9	0.78
23 Apr	327	Mid	0.7	1.00	100	47	84.2	0.0	0.0	120.4	0.87
31 May	End	End	0.0	1.00	0	10					

Fig 4.8 Output window of irrigation scheduling of banana at 100 % critical depletion.

2. Irrigation at fixed interval (10 days) per stage.

The Fig. 4.9 represents the output window obtained from CROPWAT model for irrigation scheduling of banana at fixed interval (10 days). It was found that the total gross irrigation was 1368.3 mm, NIR was 957.8 mm and the efficiency of rain was 27.7 %.



Crop irrigation schedule

ETo station: PATTAMBI | Crop: BANANA 2nd year | Planting date: 01/06 | Yield red.: 0.0 %

Rain station: Pattambi | Soil: Heavy (clay) | Harvest date: 31/05

Table format: (•) Irrigation schedule ( ) Daily soil moisture balance

Timing: Irrigate at fixed interval per stage

Application: Refill soil to field capacity

Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
10 Jun	10	Init	0.0	1.00	100	7	13.2	0.0	0.0	18.9	0.22
20 Jun	20	Init	0.0	1.00	100	6	11.1	0.0	0.0	15.8	0.18
30 Jun	30	Init	0.0	1.00	100	7	11.7	0.0	0.0	16.7	0.19
10 Jul	40	Init	0.0	1.00	100	7	12.6	0.0	0.0	18.0	0.21
20 Jul	50	Init	0.0	1.00	100	7	13.0	0.0	0.0	18.5	0.21
30 Jul	60	Init	0.0	1.00	100	7	12.8	0.0	0.0	18.3	0.21
9 Aug	70	Init	0.0	1.00	100	5	9.5	0.0	0.0	13.6	0.16
19 Aug	80	Init	0.0	1.00	100	5	9.4	0.0	0.0	13.4	0.16
29 Aug	90	Init	0.0	1.00	100	5	9.8	0.0	0.0	14.0	0.16
8 Sep	100	Init	0.0	1.00	100	4	6.8	0.0	0.0	9.8	0.11

Totals

Total gross irrigation	1368.3	mm	Total rainfall	2045.1	mm
Total net irrigation	957.8	mm	Effective rainfall	566.6	mm
Total irrigation losses	0.0	mm	Total rain loss	1478.4	mm
Actual water use by crop	1541.9	mm	Moist deficit at harvest	17.5	mm
Potential water use by crop	1541.9	mm	Actual irrigation requirement	975.2	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	27.7	%
Deficiency irrigation schedule	0.0	%			

Fig. 4.9 Output window of irrigation scheduling of banana at fixed interval (10 days)

4.2.3 Water requirement of pepper during 2017

The water requirement of pepper was found for the year 2017 using CROPWAT model. The model calculated the IR for the entire growth period in decade wise. The results obtained from the model are shown in Table 4.3.

Table 4.3 Crop water requirement of pepper, 2017

Month	Decade	Stage	Kc	ETc	ETc	ER	IR
	dec		**coefficient**	**mm/day**	**mm/dec**	**mm/dec**	**mm/dec**
Jun	1	Initial	0.6	1.98	19.8	56.8	0
Jun	2	Initial	0.6	1.66	16.6	63.2	0
Jun	3	Initial	0.6	1.76	17.6	59.9	0
Jul	1	Development	0.66	2.07	20.7	54.9	0
Jul	2	Development	0.76	2.45	24.5	52.3	0
Jul	3	Development	0.86	2.76	30.4	53.4	0
Aug	1	Mid	0.94	2.99	29.9	55.3	0
Aug	2	Mid	0.95	2.98	29.8	56.2	0
Aug	3	Mid	0.95	3.11	34.2	54.6	0
Sep	1	Mid	0.95	3.24	32.4	55.4	0
Sep	2	Late	0.93	3.31	33.1	55.4	0
Sep	3	Late	0.86	3.02	30.2	43.3	0
Oct	1	Late	0.82	2.81	8.4	7.8	0
					327.7	668.6	0

From the Table 4.3, it can be observed that the IR for pepper is zero. This showed that the pepper did not require any irrigation as the ETc of pepper was less than the effective rainfall. Hence it could be inferred that the CWR was fully met from rainfall for the given period.

4.2.4 Irrigation scheduling of pepper during 2017

The results of irrigation scheduling under two different criteria is as shown:

1. Irrigation at 100% critical depletion

The Fig. 4.10 represents the output window obtained from CROPWAT model for irrigation scheduling of pepper at 100% critical depletion. The results obtained showed that both total gross irrigation and NIR was zero and the efficiency of rain was 20.0%.

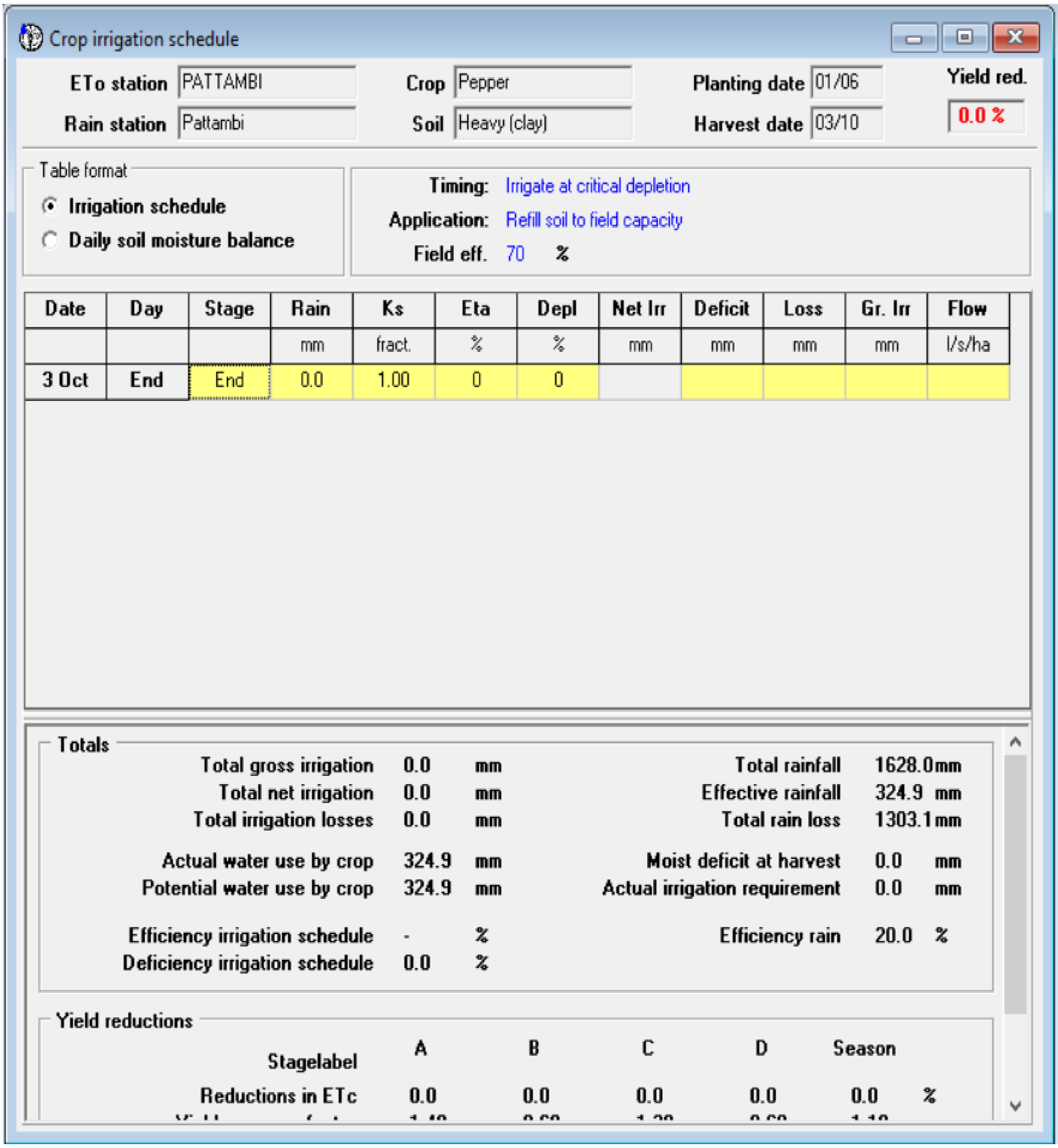
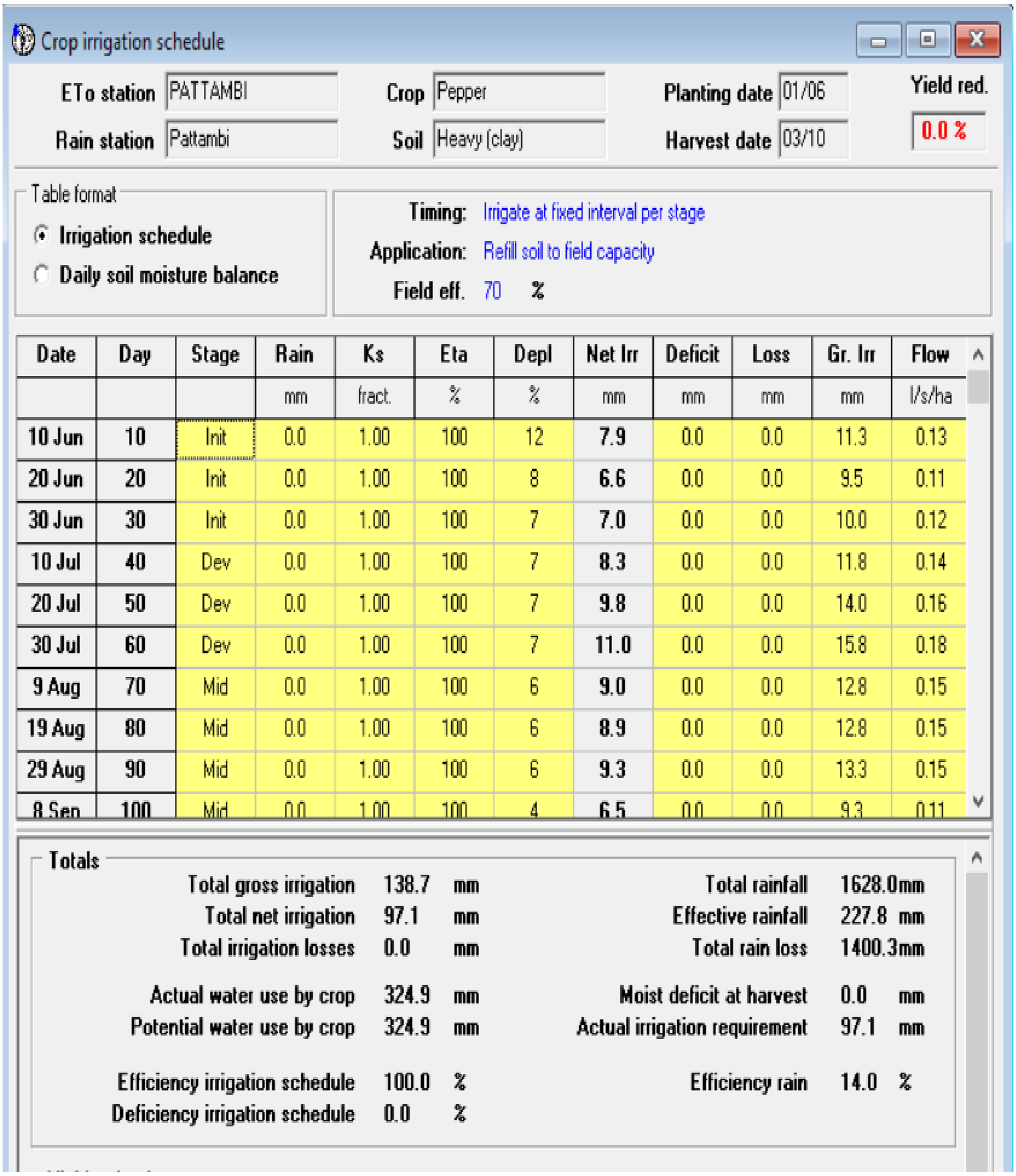


Fig. 4.10 Output window of irrigation scheduling of pepper at 100% critical depletion

2. Irrigation at fixed interval per stage.

The Fig. 4.11 represents the output window obtained from CROPWAT model for irrigation scheduling of pepper at fixed interval (10 days). The NIR for pepper was found to be 97.1 mm, total gross irrigation was 138.7 mm and the efficiency of rain was 14.0 %.



Crop irrigation schedule

ETo station PATTAMBI | Crop Pepper | Planting date 01/06 | Yield red.
Rain station Pattambi | Soil Heavy (clay) | Harvest date 03/10 | 0.0 %

Table format
Irrigation schedule
Daily soil moisture balance

Timing: Irrigate at fixed interval per stage
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
10 Jun	10	Init	0.0	1.00	100	12	7.9	0.0	0.0	11.3	0.13
20 Jun	20	Init	0.0	1.00	100	8	6.6	0.0	0.0	9.5	0.11
30 Jun	30	Init	0.0	1.00	100	7	7.0	0.0	0.0	10.0	0.12
10 Jul	40	Dev	0.0	1.00	100	7	8.3	0.0	0.0	11.8	0.14
20 Jul	50	Dev	0.0	1.00	100	7	9.8	0.0	0.0	14.0	0.16
30 Jul	60	Dev	0.0	1.00	100	7	11.0	0.0	0.0	15.8	0.18
9 Aug	70	Mid	0.0	1.00	100	6	9.0	0.0	0.0	12.8	0.15
19 Aug	80	Mid	0.0	1.00	100	6	8.9	0.0	0.0	12.8	0.15
29 Aug	90	Mid	0.0	1.00	100	6	9.3	0.0	0.0	13.3	0.15
8 Sep	100	Mid	0.0	1.00	100	4	6.5	0.0	0.0	9.3	0.11

Totals

Total gross irrigation	138.7	mm	Total rainfall	1628.0	mm
Total net irrigation	97.1	mm	Effective rainfall	227.8	mm
Total irrigation losses	0.0	mm	Total rain loss	1400.3	mm
Actual water use by crop	324.9	mm	Moist deficit at harvest	0.0	mm
Potential water use by crop	324.9	mm	Actual irrigation requirement	97.1	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	14.0	%
Deficiency irrigation schedule	0.0	%			

Fig. 4.11 Output window of irrigation scheduling of pepper at fixed interval (10 days)

4.2.5 Water Requirement of vegetables during 2017

The water requirement of vegetables was found for the year 2017 using CROPWAT model. The model calculated the IR for the entire growth period, decade wise. The results obtained from the model are shown in Table 4.4.

Table 4.4 Crop water requirement of vegetables, 2017

Month	Decade	Stage	Kc	ETc	ETc	ER	IR
	dec		coefficient	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Initial	0.6	2.63	26.3	0.1	26.2
Jan	2	Initial	0.6	2.81	28.1	0	28.1
Jan	3	Development	0.6	2.84	31.3	0	31.3
Feb	1	Development	0.68	3.26	32.6	0	32.6
Feb	2	Development	0.81	3.9	39	0	39
Feb	3	Development	0.92	4.45	35.6	0.1	35.5
Mar	1	Development	1.04	5	50	11.2	38.8
Mar	2	Mid	1.11	5.34	53.4	16.8	36.6
Mar	3	Mid	1.11	5.29	58.2	11.4	46.9
Apr	1	Mid	1.11	5.25	52.5	0.4	52.1
Apr	2	Mid	1.11	5.2	52	0	52
Apr	3	Late	1.03	4.73	47.3	1.3	45.9
May	1	Late	0.89	4.04	40.4	32.2	8.1
May	2	Late	0.78	3.49	17.4	24.1	0
					564.3	97.7	473.2

From the Table 4.4, it can be observed that the IR of vegetables was comparatively less at initial stages of plant growth and more water was required during the mid-stage. The total CWR and IR of vegetables were found to be 564.3 mm and 473.2 mm respectively.

4.2.6 Irrigation Scheduling of vegetables during 2017

The results of irrigation at two different criteria were obtained as follows:

1. Irrigation at 100% critical depletion

   The Fig. 4.12 represents the output window obtained from CROPWAT model of irrigation scheduling at critical depletion for vegetables. It was found that the total gross irrigation was 629.1 mm, NIR was 440.4 mm and the efficiency of rain was 99.1%.

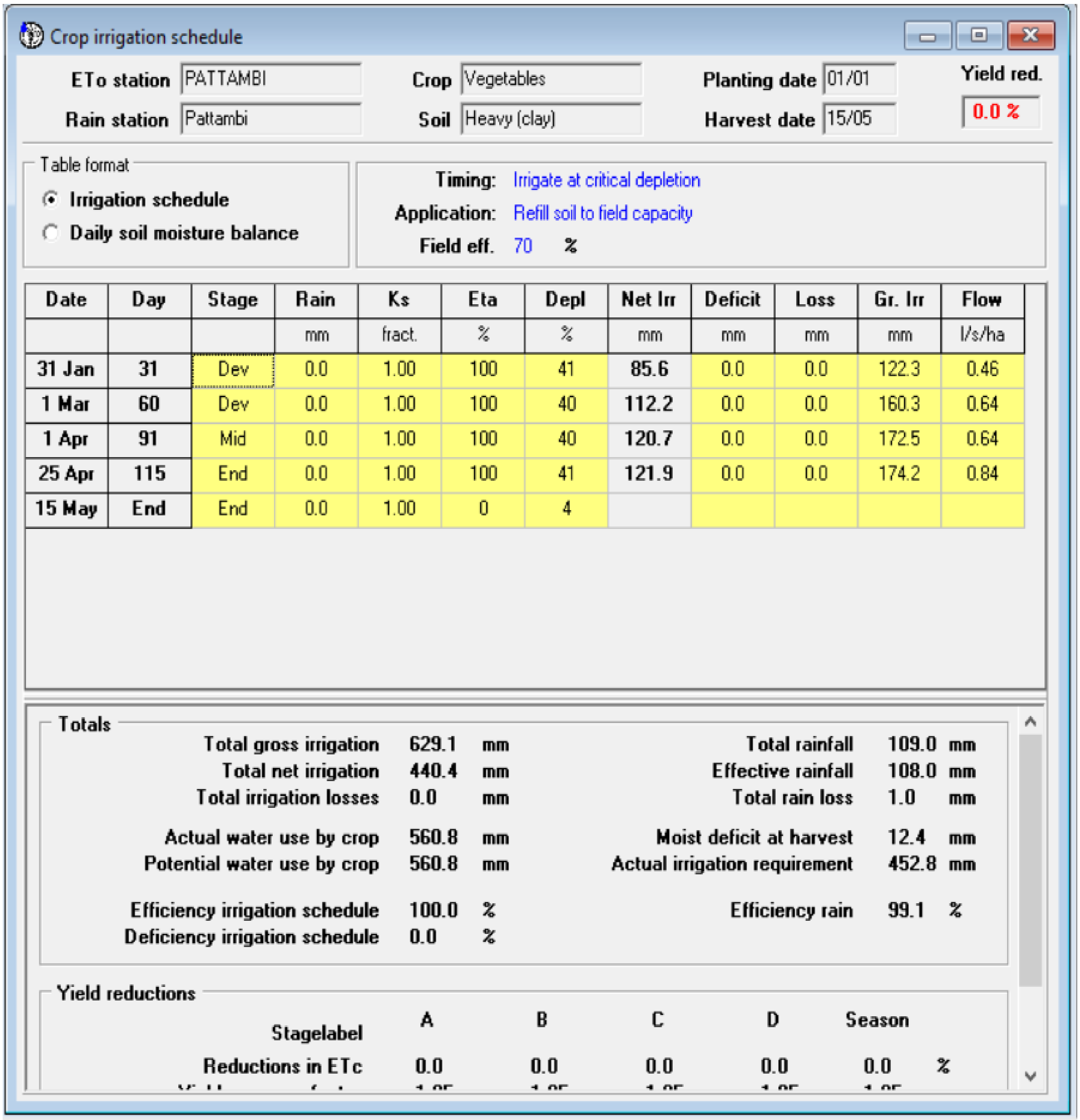
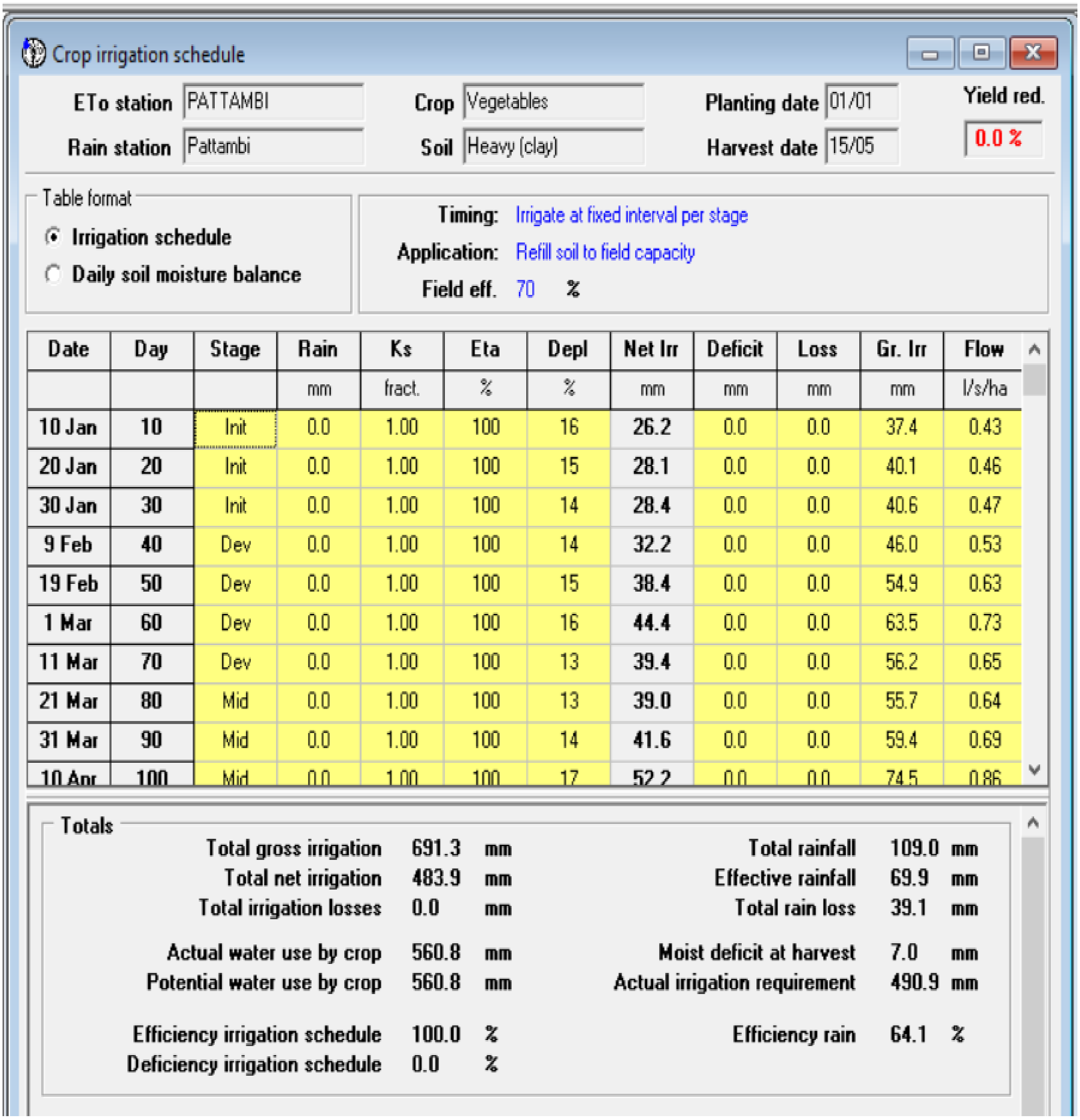


Fig. 4.12 Output window of irrigation scheduling of vegetables at 100% critical depletion

2. Irrigation at fixed interval per stage

The Fig. 4.13 represents the output window obtained from CROPWAT model of irrigation scheduling at fixed interval (10 days) per stage for vegetables. The NIR for vegetables was found to be 483.9 mm, total gross irrigation was 691.3 mm and the efficiency of rain was 64.1%.



Crop irrigation schedule

ETo station PATTAMBI — Crop Vegetables — Planting date 01/01 — Yield red. 0.0 %

Rain station Pattambi — Soil Heavy (clay) — Harvest date 15/05

Table format: Irrigation schedule / Daily soil moisture balance

Timing: Irrigate at fixed interval per stage

Application: Refill soil to field capacity

Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
10 Jan	10	Init	0.0	1.00	100	16	26.2	0.0	0.0	37.4	0.43
20 Jan	20	Init	0.0	1.00	100	15	28.1	0.0	0.0	40.1	0.46
30 Jan	30	Init	0.0	1.00	100	14	28.4	0.0	0.0	40.6	0.47
9 Feb	40	Dev	0.0	1.00	100	14	32.2	0.0	0.0	46.0	0.53
19 Feb	50	Dev	0.0	1.00	100	15	38.4	0.0	0.0	54.9	0.63
1 Mar	60	Dev	0.0	1.00	100	16	44.4	0.0	0.0	63.5	0.73
11 Mar	70	Dev	0.0	1.00	100	13	39.4	0.0	0.0	56.2	0.65
21 Mar	80	Mid	0.0	1.00	100	13	39.0	0.0	0.0	55.7	0.64
31 Mar	90	Mid	0.0	1.00	100	14	41.6	0.0	0.0	59.4	0.69
10 Apr	100	Mid	0.0	1.00	100	17	52.2	0.0	0.0	74.5	0.86

Totals

Total gross irrigation	691.3	mm	Total rainfall	109.0	mm
Total net irrigation	483.9	mm	Effective rainfall	69.9	mm
Total irrigation losses	0.0	mm	Total rain loss	39.1	mm
Actual water use by crop	560.8	mm	Moist deficit at harvest	7.0	mm
Potential water use by crop	560.8	mm	Actual irrigation requirement	490.9	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	64.1	%
Deficiency irrigation schedule	0.0	%			

Fig. 4.13 Output window of irrigation scheduling of vegetables at fixed interval (10 days)

4.2.7 Water Requirement of pulses during 2017

The water requirement of pulses was found for the year 2017 using CROPWAT model. The model calculated the IR for the entire growth period, decade wise. The results obtained from the model are shown in Table 4.5.

Table 4.5 Crop water requirement of pulses, 2017

Month	Decade	Stage	Kc	ETc	ETc	ER	IR
	dec		coefficient	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Initial	0.4	1.76	17.6	0.1	17.4
Jan	2	Initial	0.4	1.87	18.7	0	18.7
Jan	3	Development	0.52	2.48	27.3	0	27.3
Feb	1	Development	0.74	3.54	35.4	0	35.4
Feb	2	Mid	0.95	4.57	45.7	0	45.7
Feb	3	Mid	1.02	4.92	39.4	0.1	39.2
Mar	1	Mid	1.02	4.92	49.2	11.2	38
Mar	2	Mid	1.02	4.92	49.2	16.8	32.4
Mar	3	Late	0.85	4.08	44.8	11.4	33.5
Apr	1	Late	0.5	2.37	23.7	0.4	23.3
					351	40	311

From the Table 4.5, it can be observed that the IR for pulses was comparatively less at initial stages of plant growth and it requires more water in the mid stage. The CWR and IR were found to be 351 mm and 311 mm respectively.

4.2.8 Irrigation Scheduling of pulses during 2017

The results of irrigation scheduling at two different criteria as obtained from the model are as follows:

1. Irrigation at 100% critical depletion

   The Fig. 4.14 shows the output window obtained from CROPWAT model of irrigation scheduling of pulses at 100% critical depletion. It was found that the total gross irrigation was 380.8mm, NIR was 266.5 mm and the efficiency of rain was 95.2%.

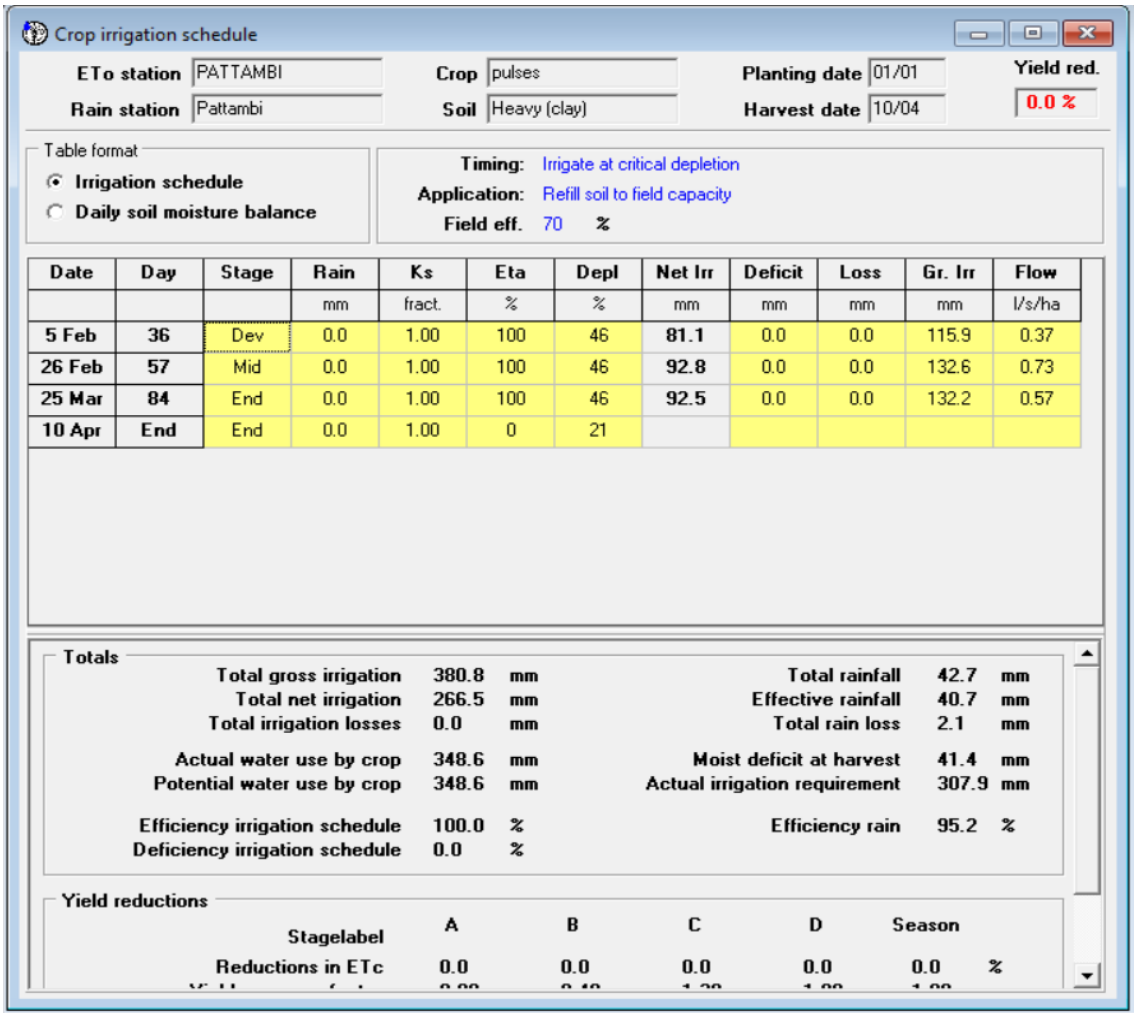
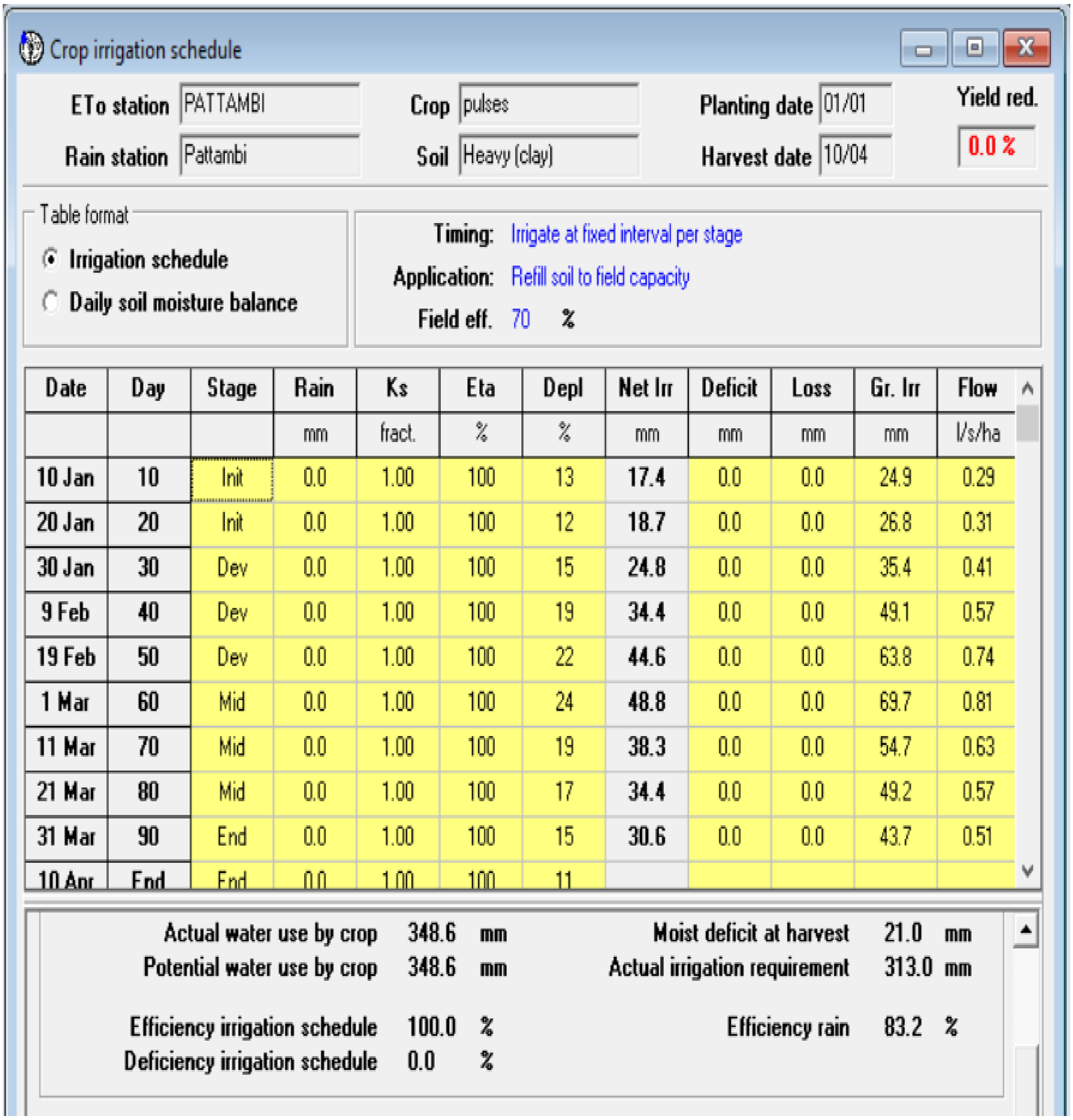


Fig 4.14 Output window of irrigation scheduling of pulses at 100% critical depletion

2. Irrigation at fixed interval per stage

   The Fig. 4.15 represents the output window obtained from CROPWAT model of irrigation scheduling at fixed interval per stage for pulses. The efficiency of rain was 83.2%.



Crop irrigation schedule

ETo station PATTAMBI | Crop pulses | Planting date 01/01 | Yield red.
Rain station Pattambi | Soil Heavy (clay) | Harvest date 10/04 | 0.0 %

Table format
Irrigation schedule
Daily soil moisture balance

Timing: Irrigate at fixed interval per stage
Application: Refill soil to field capacity
Field eff. 70 %

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
10 Jan	10	Init	0.0	1.00	100	13	17.4	0.0	0.0	24.9	0.29
20 Jan	20	Init	0.0	1.00	100	12	18.7	0.0	0.0	26.8	0.31
30 Jan	30	Dev	0.0	1.00	100	15	24.8	0.0	0.0	35.4	0.41
9 Feb	40	Dev	0.0	1.00	100	19	34.4	0.0	0.0	49.1	0.57
19 Feb	50	Dev	0.0	1.00	100	22	44.6	0.0	0.0	63.8	0.74
1 Mar	60	Mid	0.0	1.00	100	24	48.8	0.0	0.0	69.7	0.81
11 Mar	70	Mid	0.0	1.00	100	19	38.3	0.0	0.0	54.7	0.63
21 Mar	80	Mid	0.0	1.00	100	17	34.4	0.0	0.0	49.2	0.57
31 Mar	90	End	0.0	1.00	100	15	30.6	0.0	0.0	43.7	0.51
10 Apr	End	End	0.0	1.00	100	11					

Actual water use by crop 348.6 mm | Moist deficit at harvest 21.0 mm
Potential water use by crop 348.6 mm | Actual irrigation requirement 313.0 mm
Efficiency irrigation schedule 100.0 % | Efficiency rain 83.2 %
Deficiency irrigation schedule 0.0 %

Fig. 4.15 Output window of irrigation scheduling of pulses at fixed interval (10 days)

4.2.9 Water Requirement of rice (direct sown) during 2017

The water requirement of rice (direct sown) was found for the year 2017 using CROPWAT model. The model calculated the IR for the entire growth period, decade wise. The results of ETc, effective rainfall and IR obtained from the model are shown in Table 4.6.

Table 4.6 Crop water requirement of rice (direct sowing), 2017

Month	Decade	Stage	Kc	ETc	ETc	ER	IR
	dec		coefficient	mm/day	mm/dec	mm/dec	mm/dec
Apr	2	Land Preparation	1.05	4.93	49.3	0	75.1
Apr	3	Land Preparation	1.05	4.82	48.2	1.3	206
May	1	Initial	1.1	5.01	50.1	32.2	17.8
May	2	Initial	1.1	4.93	49.3	48.1	1.2
May	3	Development	1.1	4.38	48.2	52.1	0
Jun	1	Development	1.1	3.64	36.4	56.8	0
Jun	2	Mid	1.1	3.05	30.5	63.2	0
Jun	3	Mid	1.1	3.22	32.2	59.9	0
Jul	1	Mid	1.1	3.47	34.7	54.9	0
Jul	2	Mid	1.1	3.57	35.7	52.3	0
Jul	3	Late	1.1	3.52	38.8	53.4	0
Aug	1	Late	1.06	3.36	33.6	55.3	0
Aug	2	Late	1	3.14	31.4	56.2	0
Aug	3	Late	0.95	3.12	25	39.7	0
					543.3	625.5	300.1

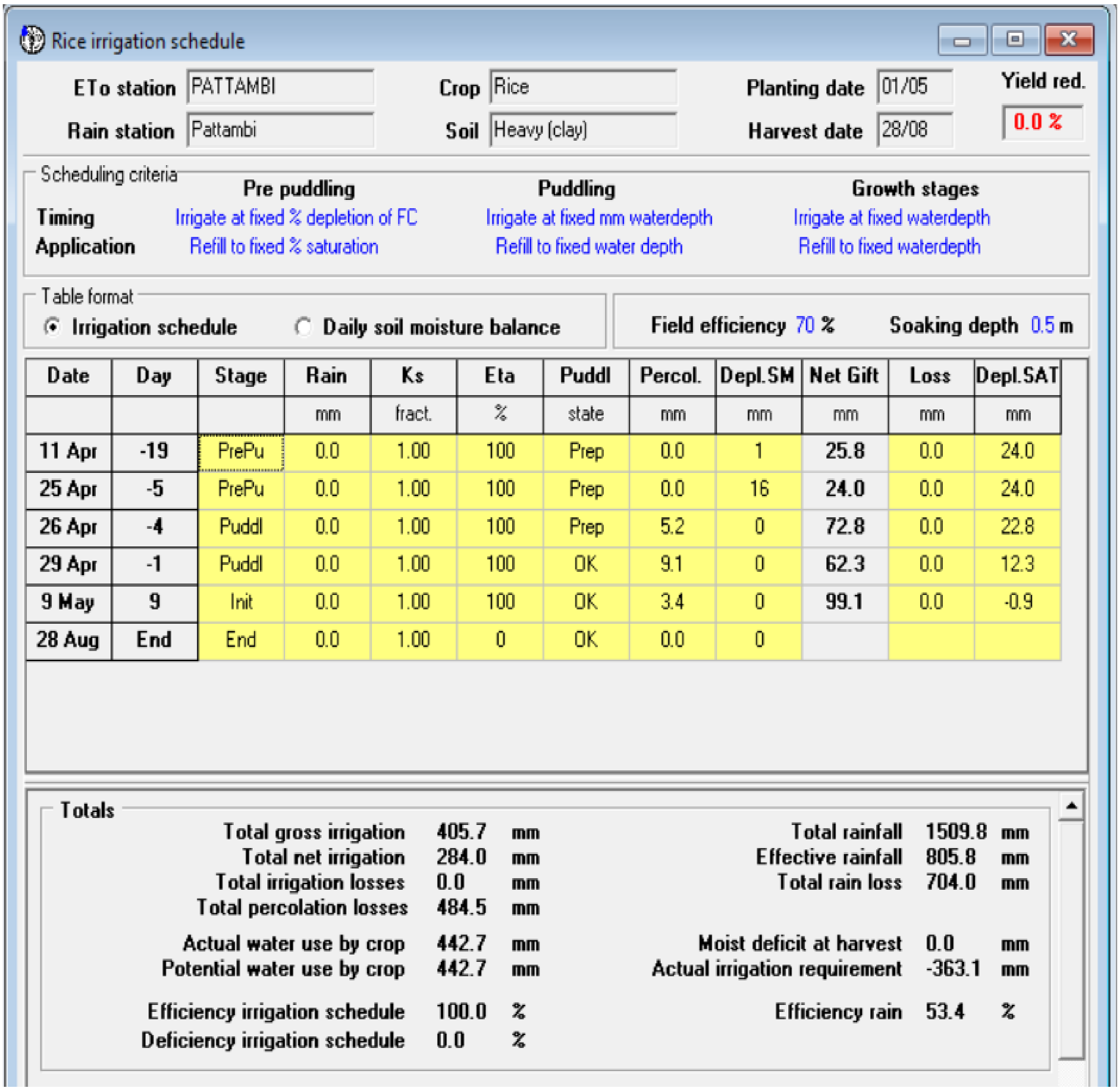
From the Table 4.6, it can be observed that the direct sown rice requires irrigation only on the land preparation stage and all other stages water demand was met from rainfall. The total CWR and IR were found to be 543.3 mm and 300.1 mm respectively.

4.2.10 Irrigation Scheduling of rice (direct sown) during 2017

The results of irrigation scheduling of rice at two different criteria are as follows:

1. Irrigation at fixed water depth

   From the Fig. 4.16, it was observed that the total gross irrigation was 405.7 mm, NIR was 284.0 mm and efficiency of rain was 53.4%.



Rice irrigation schedule

ETo station PATTAMBI | Crop Rice | Planting date 01/05 | Yield red. 0.0 %
Rain station Pattambi | Soil Heavy (clay) | Harvest date 28/08

Scheduling criteria

	Pre puddling	Puddling	Growth stages
Timing	Irrigate at fixed % depletion of FC	Irrigate at fixed mm waterdepth	Irrigate at fixed waterdepth
Application	Refill to fixed % saturation	Refill to fixed water depth	Refill to fixed waterdepth

Table format: Irrigation schedule / Daily soil moisture balance | Field efficiency 70 % | Soaking depth 0.5 m

Date	Day	Stage	Rain	Ks	Eta	Puddl	Percol.	Depl.SM	Net Gift	Loss	Depl.SAT
			mm	fract.	%	state	mm	mm	mm	mm	mm
11 Apr	-19	PrePu	0.0	1.00	100	Prep	0.0	1	25.8	0.0	24.0
25 Apr	-5	PrePu	0.0	1.00	100	Prep	0.0	16	24.0	0.0	24.0
26 Apr	-4	Puddl	0.0	1.00	100	Prep	5.2	0	72.8	0.0	22.8
29 Apr	-1	Puddl	0.0	1.00	100	OK	9.1	0	62.3	0.0	12.3
9 May	9	Init	0.0	1.00	100	OK	3.4	0	99.1	0.0	-0.9
28 Aug	End	End	0.0	1.00	0	OK	0.0	0			

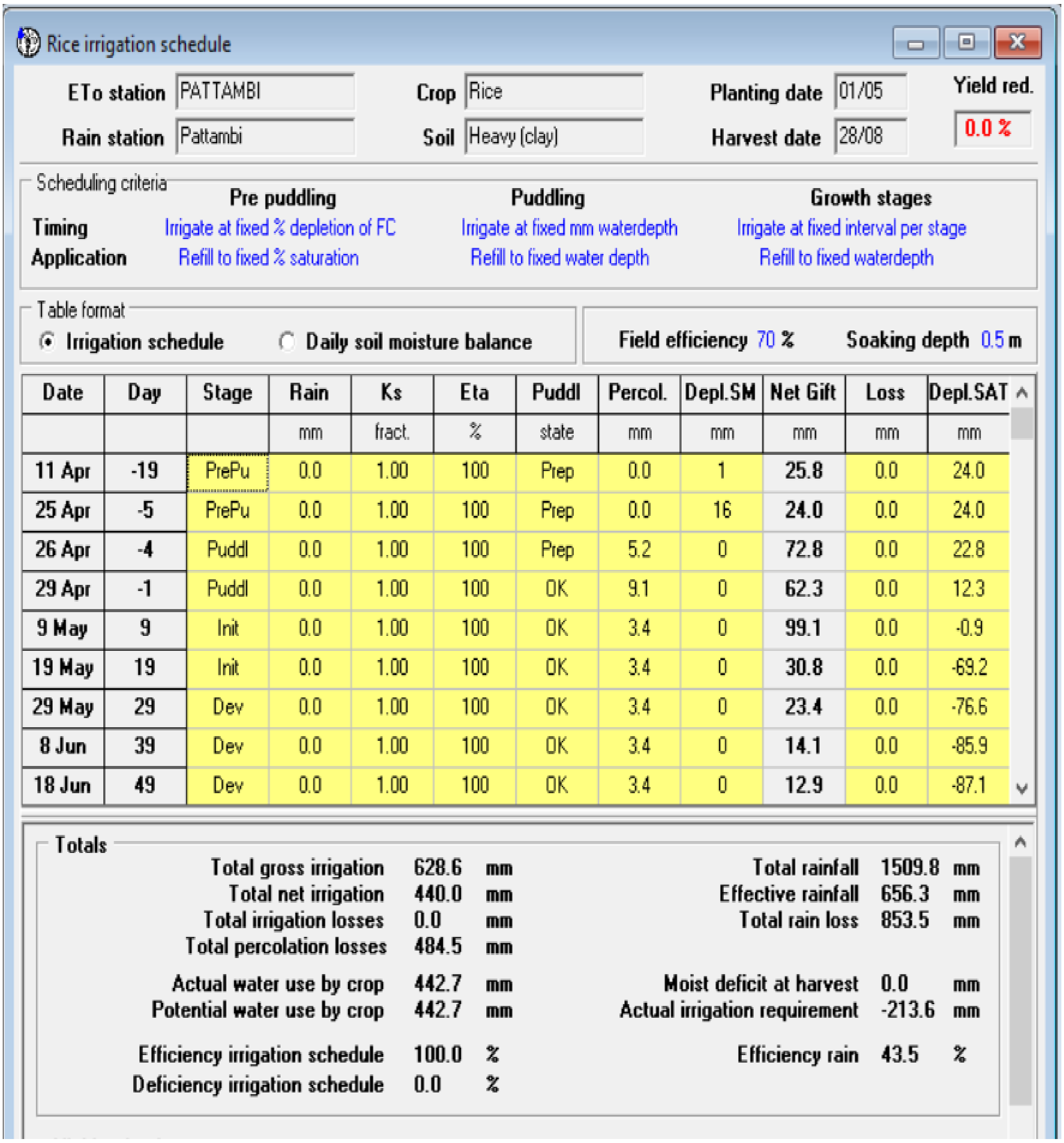
Totals

Total gross irrigation	405.7	mm	Total rainfall	1509.8	mm
Total net irrigation	284.0	mm	Effective rainfall	805.8	mm
Total irrigation losses	0.0	mm	Total rain loss	704.0	mm
Total percolation losses	484.5	mm			
Actual water use by crop	442.7	mm	Moist deficit at harvest	0.0	mm
Potential water use by crop	442.7	mm	Actual irrigation requirement	-363.1	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	53.4	%
Deficiency irrigation schedule	0.0	%			

Fig. 4.16 Output window of irrigation scheduling of rice (direct sown) at fixed water depth

2. Irrigation at fixed interval per stage

   From the Fig. 4.17, the total gross irrigation, NIR and efficiency of rain was found to be 628.6 mm 440.0 mm and43.5% respectively.



Rice irrigation schedule

ETo station: PATTAMBI | Crop: Rice | Planting date: 01/05 | Yield red.
Rain station: Pattambi | Soil: Heavy (clay) | Harvest date: 28/08 | 0.0 %

Scheduling criteria

	Pre puddling	Puddling	Growth stages
Timing	Irrigate at fixed % depletion of FC	Irrigate at fixed mm waterdepth	Irrigate at fixed interval per stage
Application	Refill to fixed % saturation	Refill to fixed water depth	Refill to fixed waterdepth

Table format: Irrigation schedule / Daily soil moisture balance

Field efficiency 70 % Soaking depth 0.5 m

Date	Day	Stage	Rain	Ks	Eta	Puddl	Percol.	Depl.SM	Net Gift	Loss	Depl.SAT
			mm	fract.	%	state	mm	mm	mm	mm	mm
11 Apr	-19	PrePu	0.0	1.00	100	Prep	0.0	1	25.8	0.0	24.0
25 Apr	-5	PrePu	0.0	1.00	100	Prep	0.0	16	24.0	0.0	24.0
26 Apr	-4	Puddl	0.0	1.00	100	Prep	5.2	0	72.8	0.0	22.8
29 Apr	-1	Puddl	0.0	1.00	100	OK	9.1	0	62.3	0.0	12.3
9 May	9	Init	0.0	1.00	100	OK	3.4	0	99.1	0.0	-0.9
19 May	19	Init	0.0	1.00	100	OK	3.4	0	30.8	0.0	-69.2
29 May	29	Dev	0.0	1.00	100	OK	3.4	0	23.4	0.0	-76.6
8 Jun	39	Dev	0.0	1.00	100	OK	3.4	0	14.1	0.0	-85.9
18 Jun	49	Dev	0.0	1.00	100	OK	3.4	0	12.9	0.0	-87.1

Totals

Total gross irrigation	628.6	mm	Total rainfall	1509.8	mm
Total net irrigation	440.0	mm	Effective rainfall	656.3	mm
Total irrigation losses	0.0	mm	Total rain loss	853.5	mm
Total percolation losses	484.5	mm			
Actual water use by crop	442.7	mm	Moist deficit at harvest	0.0	mm
Potential water use by crop	442.7	mm	Actual irrigation requirement	-213.6	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	43.5	%
Deficiency irrigation schedule	0.0	%			

Fig. 4.17 Irrigation scheduling of rice (direct sown) at fixed interval

4.2.11 Water Requirement of rice (transplant) during 2017

The water requirement of rice (transplant) was found for the year 2017 using CROPWAT model. The model calculated the IR for the entire growth period, decade wise. The results obtained from the model are shown in Table 4.7.

Table 4.7 Crop water requirement of rice (transplant) during 2017

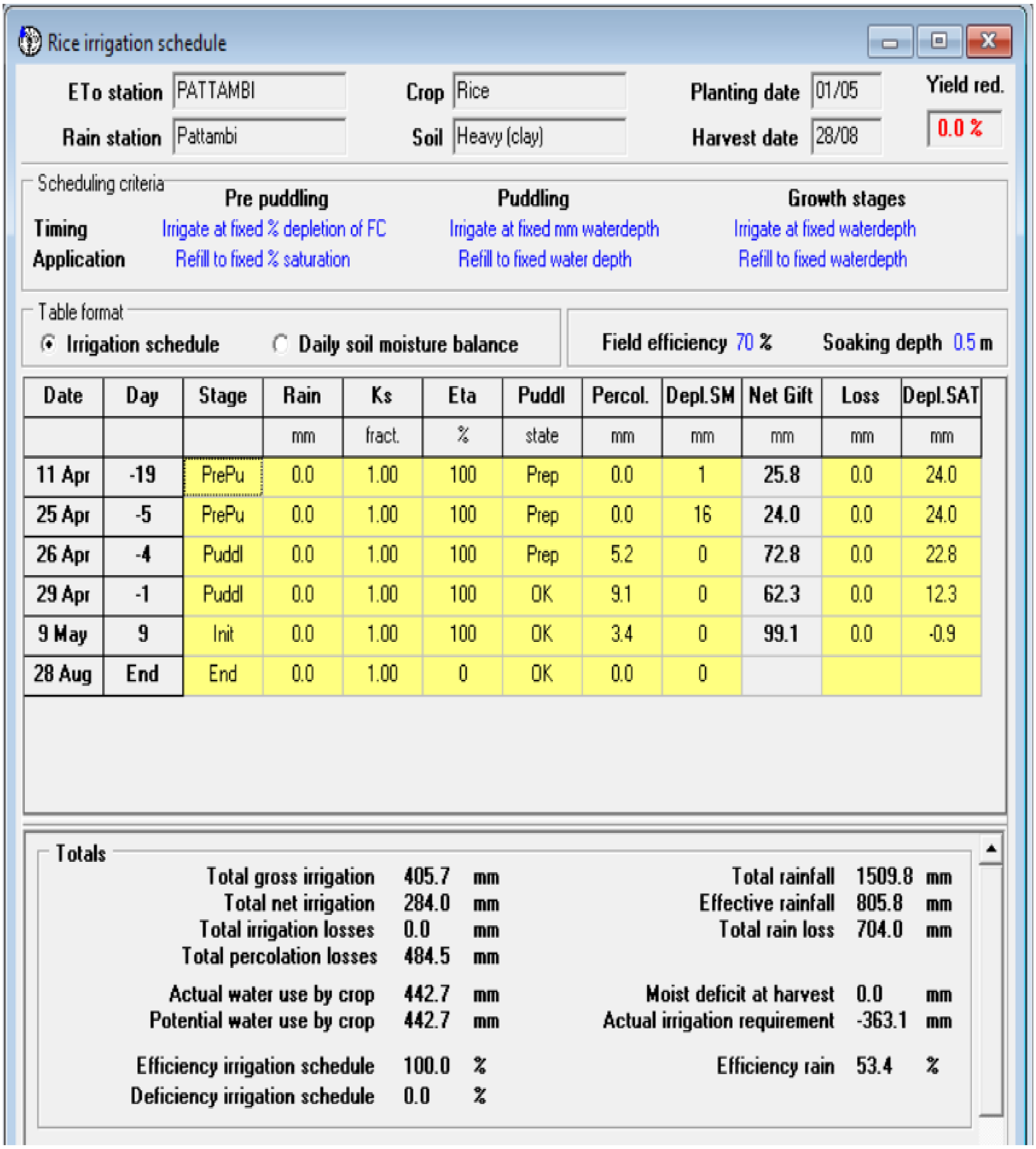
Month	Decade	Stage	Kc	ETc	ETc	ER	IR
	dec		**coefficient**	**mm/day**	**mm/dec**	**mm/dec**	**mm/dec**
Apr	1	Nursery	1.2	0.57	5.7	0.4	5.3
Apr	2	Nursery/LPr	1.06	5	50	0	76
Apr	3	Nursery/LPr	1.06	4.89	48.9	1.3	209.4
May	1	Initial	1.1	5.01	50.1	32.2	17.8
May	2	Initial	1.1	4.93	49.3	48.1	1.2
May	3	Development	1.1	4.38	48.2	52.1	0
Jun	1	Development	1.1	3.64	36.4	56.8	0
Jun	2	Mid	1.1	3.05	30.5	63.2	0
Jun	3	Mid	1.1	3.22	32.2	59.9	0
Jul	1	Mid	1.1	3.47	34.7	54.9	0
Jul	2	Mid	1.1	3.57	35.7	52.3	0
Jul	3	Late	1.1	3.52	38.8	53.4	0
Aug	1	Late	1.06	3.36	33.6	55.3	0
Aug	2	Late	1	3.14	31.4	56.2	0
Aug	3	Late	0.95	3.12	25	39.7	0
					550.4	626	309.7

4.2.12 Irrigation Scheduling of rice (transplant) during 2017

The results of irrigation scheduling are obtained under two different criteria:

1. Irrigation at fixed water depth

   From Fig. 4.18 it can be inferred that the total gross irrigation was 405.7 mm, NIR of transplanted rice was 284 mm and the rainfall efficiency was 53.4%.

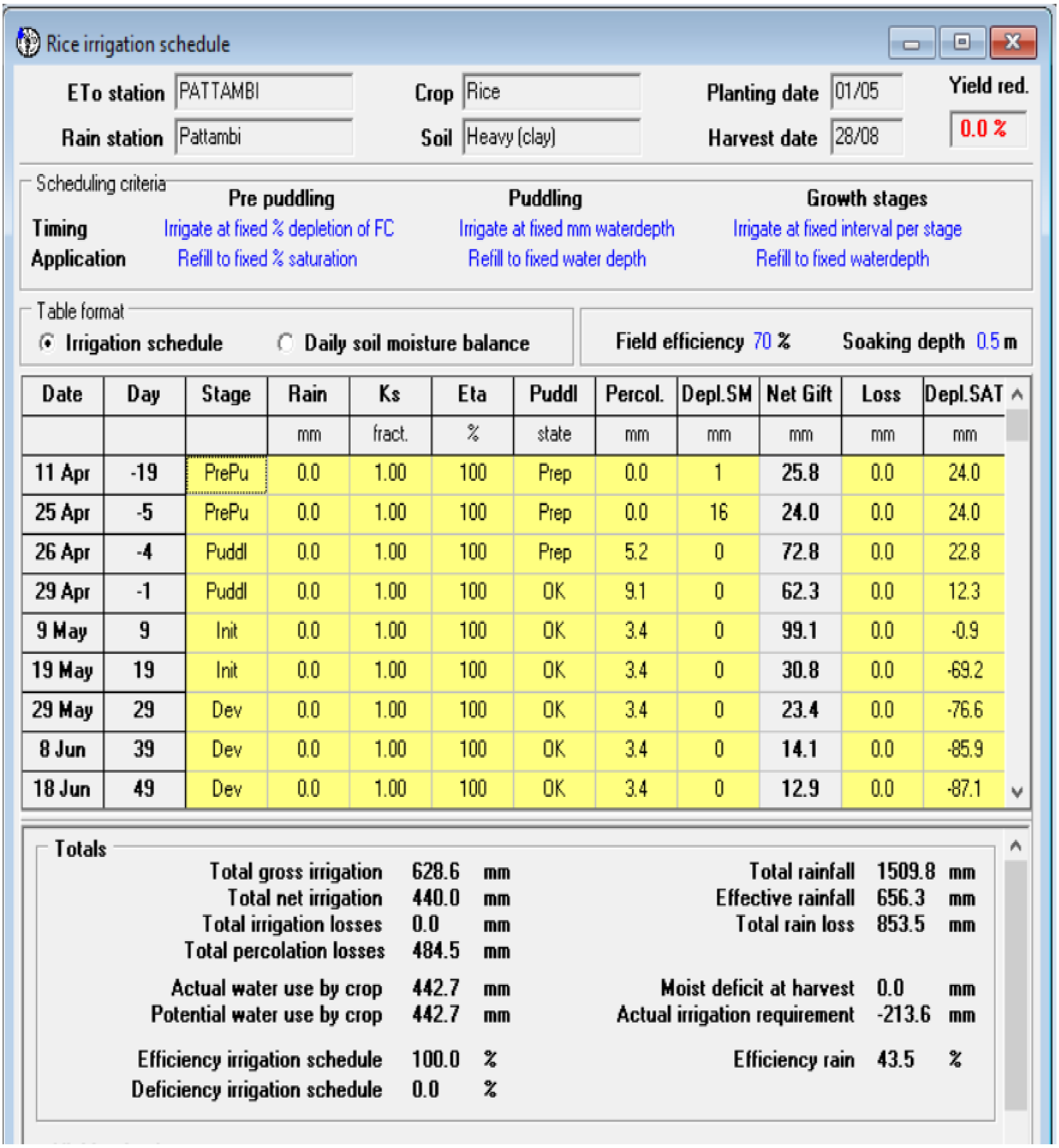


Date	Day	Stage	Rain	Ks	Eta	Puddl	Percol.	Depl.SM	Net Gift	Loss	Depl.SAT
			mm	fract.	%	state	mm	mm	mm	mm	mm
11 Apr	-19	PrePu	0.0	1.00	100	Prep	0.0	1	25.8	0.0	24.0
25 Apr	-5	PrePu	0.0	1.00	100	Prep	0.0	16	24.0	0.0	24.0
26 Apr	-4	Puddl	0.0	1.00	100	Prep	5.2	0	72.8	0.0	22.8
29 Apr	-1	Puddl	0.0	1.00	100	OK	9.1	0	62.3	0.0	12.3
9 May	9	Init	0.0	1.00	100	OK	3.4	0	99.1	0.0	-0.9
28 Aug	End	End	0.0	1.00	0	OK	0.0	0			

Fig. 4.18 Output window of irrigation scheduling at fixed water depth for rice (transplant)

2. Irrigation at fixed interval per stage

From Fig. 4.19, it was found that the NIR when the irrigation was applied at 10 day's intervals was 440 mm while the rainfall efficiency during the same was 43.5%.



Date	Day	Stage	Rain	Ks	Eta	Puddl	Percol.	Depl.SM	Net Gift	Loss	Depl.SAT
			mm	fract.	%	state	mm	mm	mm	mm	mm
11 Apr	-19	PrePu	0.0	1.00	100	Prep	0.0	1	25.8	0.0	24.0
25 Apr	-5	PrePu	0.0	1.00	100	Prep	0.0	16	24.0	0.0	24.0
26 Apr	-4	Puddl	0.0	1.00	100	Prep	5.2	0	72.8	0.0	22.8
29 Apr	-1	Puddl	0.0	1.00	100	OK	9.1	0	62.3	0.0	12.3
9 May	9	Init	0.0	1.00	100	OK	3.4	0	99.1	0.0	-0.9
19 May	19	Init	0.0	1.00	100	OK	3.4	0	30.8	0.0	-69.2
29 May	29	Dev	0.0	1.00	100	OK	3.4	0	23.4	0.0	-76.6
8 Jun	39	Dev	0.0	1.00	100	OK	3.4	0	14.1	0.0	-85.9
18 Jun	49	Dev	0.0	1.00	100	OK	3.4	0	12.9	0.0	-87.1

Fig. 4.19 Output window of irrigation scheduling at fixed interval per stage for rice (transplant)

4.3 ANALYSIS OF GAP BETWEEN RAINFALL AND CROP WATER REQUIREMENT

The analysis of gap between rainfall and water requirement gives an idea about how much excess water need to be supplied through irrigation. If the rainfall could not meet the required water demand of crop, the deficit water is supplied through irrigation. Excellent irrigation practice is a must to ensure judicious use of water and improve productivity. The data pertaining to this was analyzed during the years 1983-2017.

4.3.1 Gap between ER and IR for banana

The Fig. 4.20 represents the variation of ETc, ER and IR of banana. It can be inferred that rainfall alone could not meet the water demands of banana during all the years. Hence the rest must be supplied through irrigation. This study revealed a comparatively higher water requirement of 4.425 mm/day during the year 1988-1992. This required an increased irrigation of 2.556 mm/day during the same year.

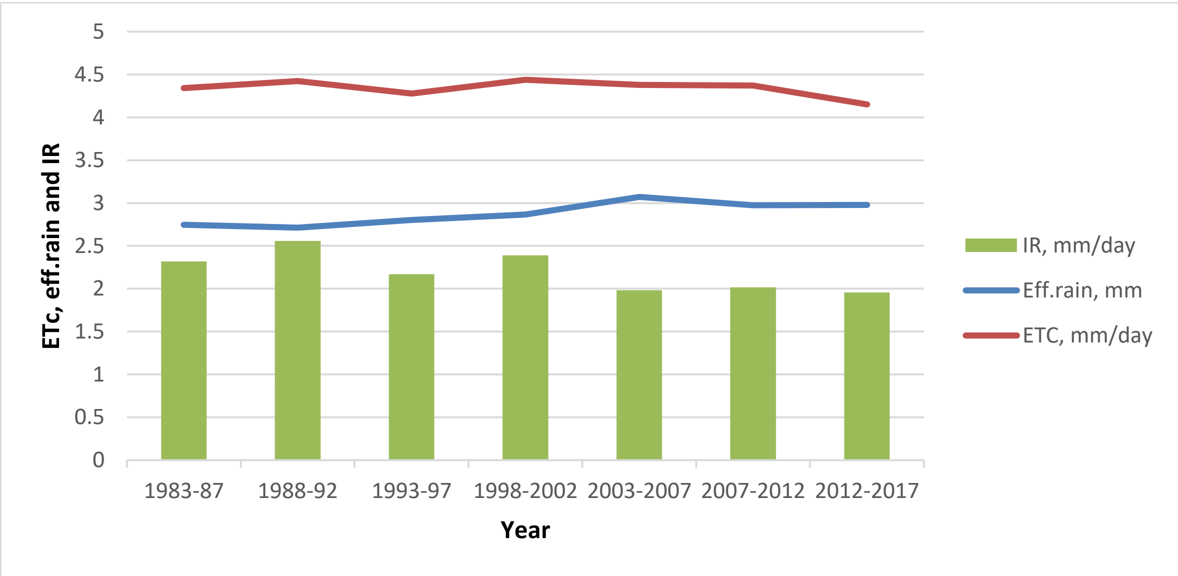


Fig 4.20 Variation of effective rainfall and irrigation requirement of banana (1983-2017)

4.3.2 Gap between ER and IR of pepper

The Fig 4.20 represents the variation of ETc, ER and IR of pepper. The Fig 4.21 indicated that the variation of ER and ETc followed the same trend during the years 1983-2017. The ER varied only from 2.74 mm to 3.1 mm whereas ETc varied from 4.14 to 3.85

mm/day. A comparatively higher water requirement of 4.29 mm/day during the year 1988-1992 required an increased irrigation of 2.95 mm/day during the year 1988-1992.

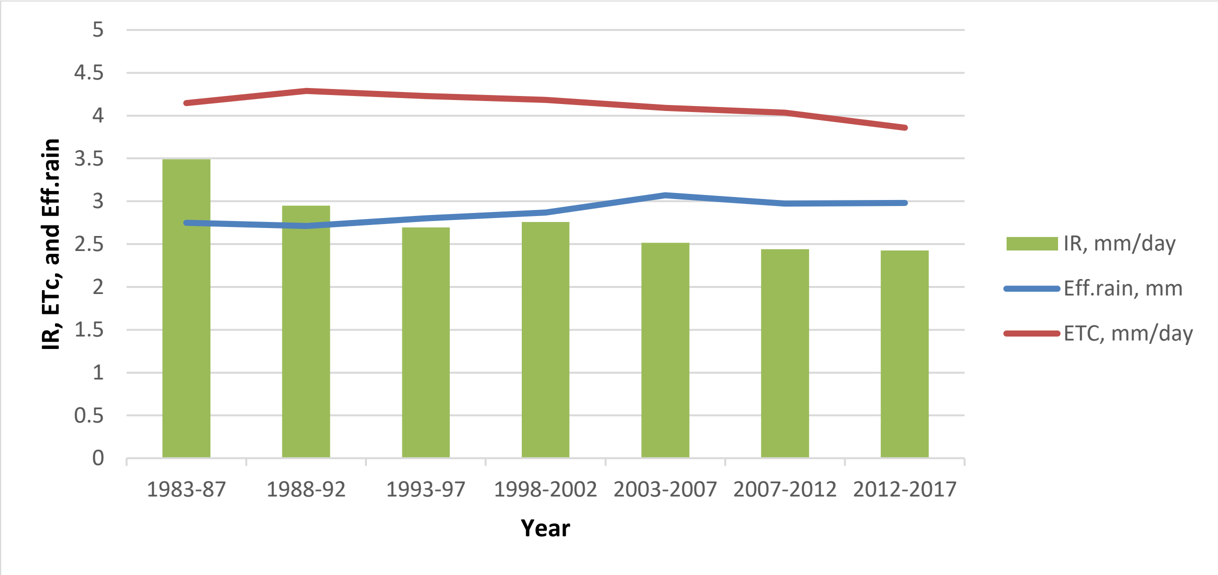


Fig. 4.21 Variation of effective rainfall and irrigation requirement of pepper

4.3.3 Gap between ER and IR of vegetables

The variation of ETc, ER and IR of vegetables are represented in the Fig. 4.22. From Fig. 4.22 it is observed that a highest irrigation requirement of 3.6 mm/day was required for vegetables during the year 1983-1987 when the effective rainfall was only 2.71 mm. The lowest irrigation requirement of 2.38 mm/day was observed during the year 2003-2007 when the effective rainfall was 3.07 mm and the crop water demand was 4.26 mm/day.

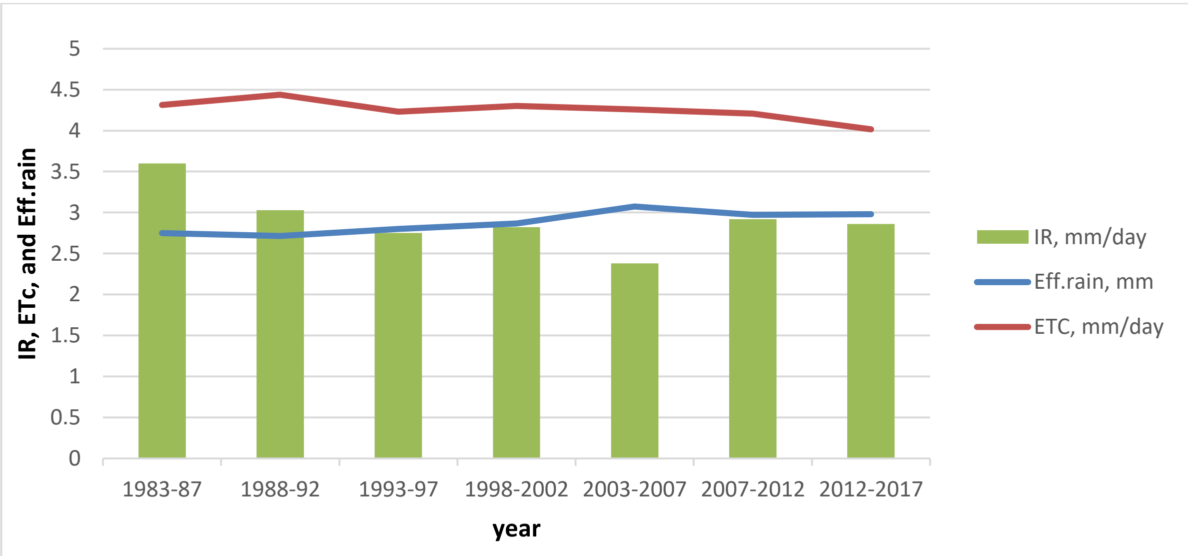


Fig. 4.22 Variation of effective rainfall and irrigation requirement of vegetables

4.3.4 Gap between ER and IR of pulses

The variation of ETc, ER and IR of pulses are represented in the Fig. 4.23. From this it could be inferred that the IR of pulses was higher during the period 1983-1987 (3.46 mm/day) even though the water requirement was not so high. The increase in IR could be attributed to the less rainfall availability during that period. The less IR of 2.29 mm/day during 2007-2012 can be attributed to the low CWR of 3.619 mm/day and comparatively high rainfall (2.97 mm).

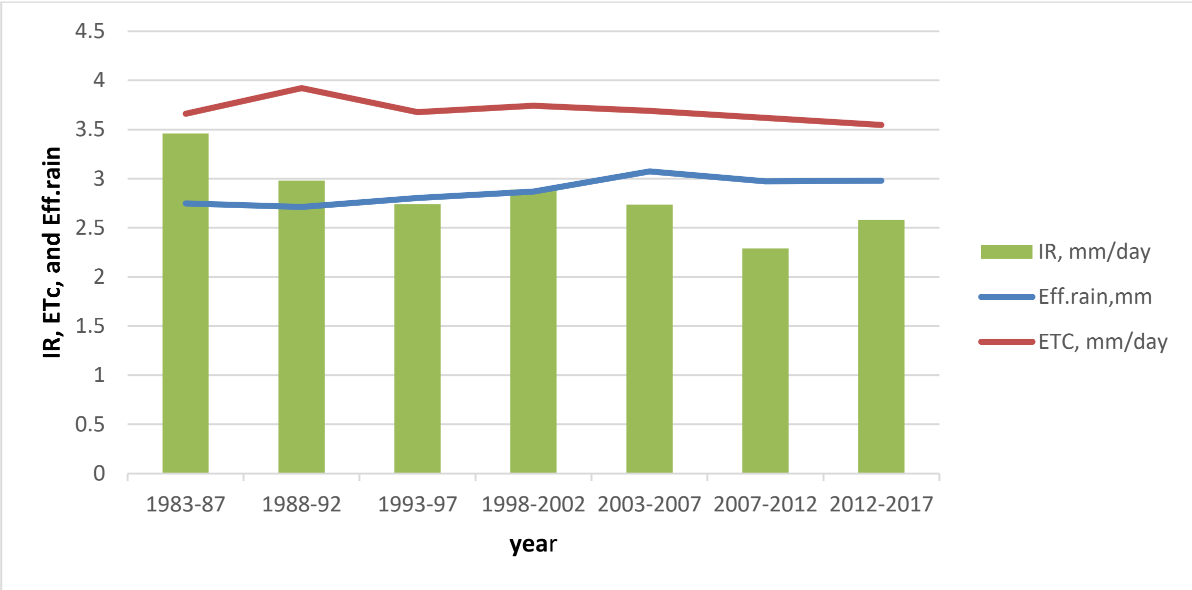


Fig. 4.23 Variation of effective rainfall and irrigation requirement for pulses

4.3.5 Gap between ER and IR of rice (direct sowing)

Fig. 4.24 shows the gap between ER and IR for direct sowing rice. A high IR of 3.6 mm/day was observed during the period 1983-1987 where the CWR was high (6.273 mm/day). The rest of the period almost showed same values without much fluctuation.

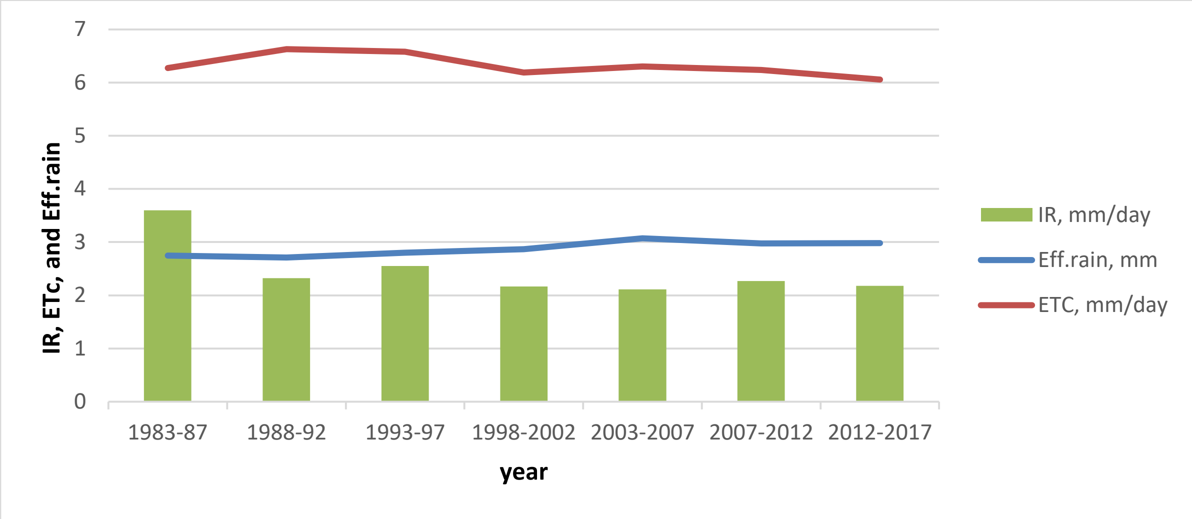


Fig. 4.24 Variations of effective rainfall and irrigation requirement for rice (direct sown) during 1983-2017

4.3.6 Gap between ER and IR of rice (transplant)

The variation of ETc, ER and IR of rice (transplant) are represented in the Fig. 4.25. From this, it can be observed that in the case of transplanted rice, the highest IR of 2.903 mm/day was observed during the period 1983-1987 with a comparatively high CWR of 3.965 mm/day and an effective rainfall of 2.75 mm.

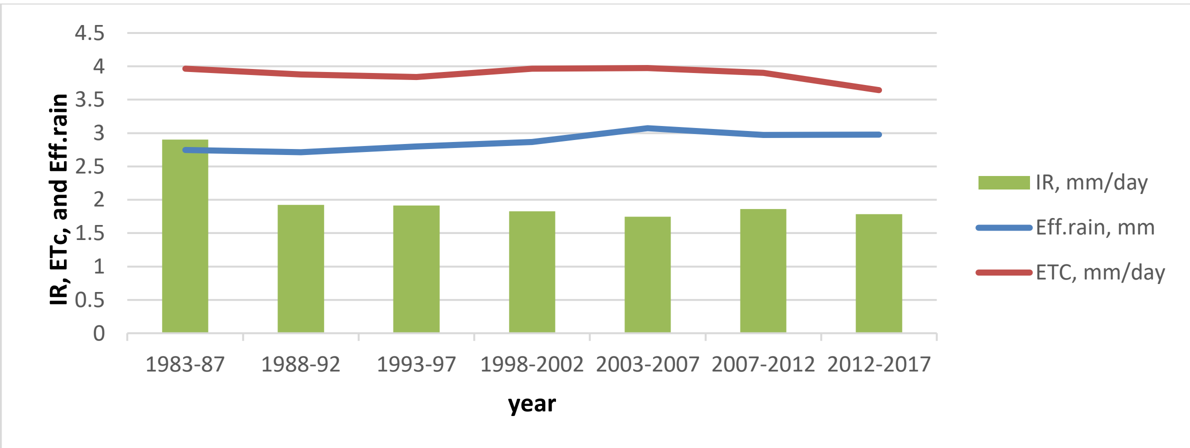


Fig. 4.25 Variation of Effective rainfall and irrigation requirement for rice (transplant) during 1983-2017

SUMMARY AND CONCLUSION

CHAPTER-V

SUMMARY AND CONCLUSION

Water is an important input in agricultural sector and its judicious use is necessary for the efficient allocation of water in agricultural sector. This study mainly concentrated on determining the crop water requirement and irrigation scheduling of major crops such as banana, pulses, pepper, vegetables, rice (direct sown and transplanted) in the Pattambi region. The study also analyzed the changes in water requirement of these crops during the past 35 years (1983-2017).

The weather parameters such as temperature, sunshine hours did not show much variations during the past 35 years while variations can be seen in rainfall and humidity. The ET_o is found to vary with these parameters. It was found that ETo values were highest when humidity was less and wind speed was more. During 1998-2002, highest value of ET_O was found (4.2 mm/day) while a lowest value of 3.94 mm/day was observed during 2012-2017. Only a limited portion of rainfall was available to the crops during these years. About 1000 mm of rainfall was lost not being available to the crops.

The variation of CWR and IR was found to show the same trend as that of ET_O. The CWR and IR were found to be higher when ET_o values were higher and was found to be low when ET_o was low.

Water requirement for banana, pepper, rice, pepper, rice (transplant), rice (direct sown), pulses and vegetables were found as 1546.2 mm, 327.7 mm, 550.4 mm, 543.3 mm, 351 mm and 564.3 mm respectively for the year 2017. IR for banana, pepper, rice (transplant), rice (direct sown), pulses and vegetables were found as 807.2 mm, 0.0 mm, 309.7 mm, 300.1 mm, 311 mm and 473.2 mm respectively for the same year. The water requirement of crops was found to be dependent on the ET_o values while the IR was found to vary with rainfall. The crops should be irrigated with that amount of water which is not provided by rainfall.

It was found that for all crops, the water requirement was high during mid-stages. Even though the CWR is high during mid-stages, irrigation needs to be provided only when the rainfall could not meet the demands. In the case of rice, a high water requirement was found during the initial stages since a large amount of water was needed for land preparation and puddling.

The irrigation scheduling of major crops of Pattambi region were done under two different criteria. For both dry crops and wet crops, a lesser rainfall efficiency was found when irrigation was scheduled at fixed interval per stage while a higher rainfall efficiency was found when irrigation was scheduled at critical depletion for dry crops and up to a fixed water depth for rice.

Among the various crops taken for the study, IR for pepper was found to be the least. This was because of the fact that it was grown during the monsoon period. Among the various crops taken for the study, the rainfall efficiency of pulses was found to be the highest. About 95.2 % of rainfall was effectively used by the crops.

The study estimated the CWR and determined an irrigation schedule for the selected crops of Pattambi region. The study was also helpful in determining whether rainfall could meet the ET demand of crops. The results of the study could be used as a guide for the farmers in scheduling their irrigation and choosing a good irrigation method and practice. The study results can be extrapolated to future and by using probability analysis, the future water demand of crops can be determined. Further, it can be assessed whether the future rainfall could meet the future water demand of crops.

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APPENDICES

APPENDIX-I

Monthly rainfall data of Pattambi region from 1983-2017 (mm)

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	0.00	0.00	0.00	0.00	128.5	282.1	712.9	556.6	470.8	198.4	108.0	43.5
1984	0.00	0.00	0.00	0.00	128.5	282.1	712.9	556.6	470.8	198.4	108.0	43.5
1985	0.00	0.00	0.00	0.00	128.5	282.1	712.9	556.6	470.8	198.4	108.0	43.5
1986	22.10	0.00	14.5	0.00	19.30	847.4	318.3	426.9	233.8	192.3	244.8	0.00
1987	0.00	0.00	0.00	7.10	84.00	577.3	363.4	310.7	166.7	236.6	228.1	86.0
1988	0.00	0.00	0.00	137.1	137.1	569.7	594.6	339.4	466.3	0.00	2.60	0.00
1989	0.00	0.00	0.00	87.80	92.60	19.50	437.6	244.6	239.8	295.3	46.80	0.00
1990	1.00	0.00	0.00	78.20	433.2	530.0	730.0	310.3	38.20	446.0	99.30	0.00
1991	35.60	0.00	0.00	136.8	75.00	878.8	995.7	497.4	0.00	494.2	33.50	0.00
1992	0.00	0.00	0.00	37.20	90.40	836.8	788.9	469.9	273.2	218.5	172.5	0.00
1993	0.00	54.7	1.00	8.70	163.6	734.8	699.4	314.1	47.00	297.2	117.5	7.20
1994	0.00	0.00	32.10	124.8	74.10	825.5	1014	386.4	182.4	0.00	0.00	0.00
1995	15.66	2.96	6.50	12.02	77.51	671.1	562.4	371.7	199.4	220.4	143.4	29.6
1996	7.32	10.94	0.20	69.74	176.0	602.9	732.1	373.2	119.9	350.3	97.47	1.44
1997	34.10	20.12	1.13	102.2	148.2	557.3	388.9	371.1	248.1	271.3	87.75	16.5
1998	0.00	0.00	0.00	40.20	134.2	678.7	590.7	397.3	448.3	316.8	44.10	37.3

1999	0.00	8.40	0.40	37.80	433.5	659.8	708.1	150.6	39.80	278.3	42.70	0.80
2000	0.00	10.50	0.00	56.40	47.70	592.9	327.9	518.2	179.1	194.9	70.10	42.0
2001	0.00	51.60	0.00	155.3	142.0	790.7	466.2	215.6	449.1	279.3	144.6	0.00
2002	0.00	0.00	2.70	57.90	222.9	472.0	376.4	420.9	51.10	421.3	70.80	12.0
2003	183.6	13.60	0.00	0.00	174.9	151.6	79.40	313.6	233.5	298.1	74.64	34.9
2004	0.00	0.00	4.10	105.0	195.6	743.5	347.1	486.7	122.2	313.3	40.20	0.00
2005	21.00	45.0	0.00	238.3	101.4	567.6	736.6	271.8	453.7	121.1	126.2	10.1
2006	0.00	0.00	36.10	16.70	396.6	688.4	470.4	426.7	500.6	352.9	127.1	0.00
2007	0.00	0.00	0.00	53.90	184.8	728.4	1308	483.0	619.0	297.4	34.40	6.00
2008	0.00	0.00	117.5	13.60	73.2	535.1	322.7	174.8	302.0	345.7	7.60	0.00
2009	0.00	0.00	141.9	52.50	158.6	358.9	693.9	296.9	275.8	160.0	53.22	122
2010	0.00	0.00	0.00	114.5	130.3	569.1	521.7	233.4	174.1	430.9	87.24	21.2
2011	0.00	20.00	0.00	172.2	108.4	759.0	456.9	339.8	296.0	229.7	147.0	10.5
2012	0.00	0.00	0.00	104.4	42.50	459.7	297.8	489.3	220.2	234.9	74.60	6.20
2013	0.00	51.50	18.55	81.25	171.1	903.5	896.9	253.9	242.6	155.2	93.60	0.20
2014	0.00	0.00	0.00	23.80	169.0	415.8	833.6	466.1	180	356.9	78.3	16
2015	0.00	0.0	19	46	66	145	139	65	76	103	65	33
2016	0.0	0.0	0.0	0.0	62	160	111	39	31	19	1	11
2017	0.0	0.0	42.3	1.6	190.6	550.5	354.4	412.9	291.2	64.2	101.7	35.4

APPENDIX-II

Monthly relative humidity data of Pattambi region from 1983-2017 (%)

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	82.5	81.00	84.59	85.90	86.24	91.93	96.61	97.32	98.30	96.48	91.53	84.48
1984	80.81	83.34	86.61	92.83	90.22	94.16	93.08	94.48	93.90	92.03	90.36	84.09
1985	84.90	89.96	91.35	53.76	84.06	95.83	95.35	95.96	94.60	93.41	87.43	82.38
1986	80.70	83.42	86.83	90.36	88.87	90.96	94.67	91.54	95.31	97.00	92.36	84.00
1987	77.70	77.96	87.38	86.73	90.38	94.86	96.58	96.77	95.60	95.35	95.80	92.90
1988	87.93	93.27	93.48	92.40	94.32	96.76	96.32	96.74	96.13	94.63	91.53	91.38
1989	83.51	86.60	85.64	84.70	91.03	93.86	93.35	92.74	94.23	93.54	88.06	82.36
1990	85.96	84.89	89.38	88.06	92.61	93.70	93.90	93.67	93.83	93.48	92.76	83.54
1991	84.74	86.10	89.90	88.13	88.22	93.26	94.06	93.87	93.16	93.74	89.23	83.58
1992	76.09	90.82	90.32	88.63	91.12	92.43	93.87	93.96	93.33	93.35	91.20	78.41
1993	79.87	83.00	88.74	86.10	89.16	92.90	92.80	93.35	93.60	92.16	87.93	82.70
1994	80.32	84.53	85.45	89.83	87.83	93.20	93.77	92.29	93.20	93.56	90.54	83.54
1995	85	86	91	88	90	95	97	97	96	97	95	95
1996	86	86	90	86	94	97	96	95	97	94	93	88
1997	84.90	91.75	90	86	94	97	96	95	97	95	94	88
1998	82.06	83.35	89.64	85.46	89.77	95.16	94.77	94.74	95.40	94.93	93.30	87.00

1999	82.90	83.92	88.51	88.23	91.64	94.16	94.48	92.48	92.20	92.16	87.06	79.58
2000	75.22	83.79	84.68	87.50	87.45	93.83	93.38	95.00	95.00	93.77	88.40	83.67
2001	80.61	93.03	90.32	90.33	90.22	94.26	94.16	93.87	95.00	93.50	91.46	83.06
2002	85.61	81.07	88.32	87.53	89.48	94.26	94.48	95.22	93.76	93.74	89.23	88.00
2003	82.35	84.65	89.5	90.37	90.83	93.81	95.54	95.20	91.00	91.50	86.56	86.24
2004	80.29	79.89	88.64	90.23	92.50	95.25	94.19	94.48	94.20	91.58	86.56	81.19
2005	82.87	88.46	93.00	90.96	91.80	95.13	95.45	94.96	95.26	94.32	92.46	93.50
2006	83.03	80.10	90.48	89.03	89.38	94.73	95.25	94.96	94.76	94.45	90.36	81.45
2007	82.38	86.53	90.41	88.36	89.19	93.46	96.00	95.38	95.30	94.45	89.86	83.03
2008	86.77	92.75	89.00	85.83	86.90	93.46	93.29	93.00	93.40	91.67	92.16	83.25
2009	80.19	86.92	89.93	90.30	89.87	93.50	95.00	93.84	94.16	94.09	87.25	82.13
2010	80	88	91	85.89	89.22	86.66	93	92.88	93.50	93.64	93.00	87
2011	87.96	87.42	74.75	88.37	89.45	95.60	94.38	95.20	95.40	93.51	89.53	91.50
2012	83.16	86.48	89.12	87.53	89.29	93.23	94.16	94.64	94.20	92.19	92.63	85.06
2013	84.77	81.28	89.25	86.54	90.24	94.48	94.87	92.87	92.63	93.41	89.93	84.12
2014	85.32	80.34	92.56	88.98	89.54	94.36	94.56	93.67	95.67	94.08	92.00	86.05
2015	86	83	91	92	92	92	94	93	93	92	89	86
2016	84.19	87.39	90.94	87.95	91.48	94.58	93.57	93.56	93.43	92.29	91.00	87.56
2017	84	79.87	90.67	89.06	91	93.32	93.69	91.65	96.01	95.45	91.67	88

APPENDIX-III

Monthly sunshine hour data of Pattambi region from 1983-2017 (h)

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	8.694	9.408	9.119	8.338	8.274	4.447	3.716	2.361	3.596	6.825	8.356	7.700
1984	7.980	6.276	7.548	7.273	9.290	2.073	3.065	5.348	6.413	5.916	7.133	8.803
1985	8.696	9.132	9.032	8.663	6.971	2.797	3.153	4.522	6.150	6.303	7.216	8.387
1986	7.616	8.875	7.800	9.026	7.938	3.758	5.074	6.103	5.979	6.435	7.343	9.100
1987	9.445	9.860	12.364	8.323	8.706	4.237	5.309	4.706	7.296	6.867	7.120	8.312
1988	9.906	9.944	8.648	8.593	7.177	4.033	3.377	4.022	5.343	6.469	7.454	5.138
1989	8.032	9.021	9.921	8.030	8.006	28.193	4.171	6.083	5.316	6.171	8.423	9.377
1990	8.729	9.971	8.929	8.080	4.835	2.803	2.329	3.703	5.506	6.158	4.996	8.025
1991	8.335	9.835	8.645	8.010	7.958	2.163	2.151	2.606	7.650	5.419	6.740	8.338
1992	9.032	8.858	8.874	8.473	7.638	3.290	1.996	3.458	4.606	5.446	5.993	9.229
1993	8.419	9.450	8.435	9.053	6.748	3.576	2.554	5.083	6.290	4.922	6.133	7.280
1994	8.735	8.825	8.458	7.453	7.938	2.720	1.406	6.478	8.630	5.943	6.725	8.021
1995	8.626	9.142	9.029	8.351	7.595	5.579	3.355	4.367	5.834	6.090	6.999	8.154
1996	8.544	8.113	8.531	7.621	7.072	4.034	4.674	3.785	7.155	4.886	7.218	7.948
1997	9.371	9.087	9.019	8.352	7.527	5.695	3.318	4.563	6.057	6.016	6.855	8.199
1998	9.051	9.214	9.370	8.747	7.664	3.170	3.448	4.261	3.983	4.535	6.776	6.464

1999	8.858	8.792	8.458	6.663	5.151	4.897	2.261	5.583	6.810	4.593	7.903	8.645
2000	8.932	8.106	8.406	6.883	8.680	3.467	5.893	3.912	5.511	5.048	7.178	7.769
2001	8.193	7.939	8.632	8.470	7.232	3.886	5.277	2.822	8.130	4.951	6.896	7.876
2002	8.193	7.939	8.632	8.470	7.232	3.886	5.277	2.822	8.130	4.951	6.896	7.502
2003	8.787	9.430	8.214	7.615	7.440	4.859	2.561	5.134	4.559	5.472	6.470	8.915
2004	9.312	9.020	8.554	8.093	6.362	3.775	3.998	5.477	5.943	6.225	6.866	8.870
2005	8.354	9.717	8.230	7.925	8.261	3.713	2.274	7.103	5.053	4.935	4.930	7.846
2006	9.261	9.514	8.677	8.060	6.741	4.543	3.974	5.590	4.227	5.358	6.676	7.930
2007	8.138	9.364	8.519	7.983	7.638	4.150	1.493	3.906	2.817	5.089	7.730	7.248
2008	9.203	9.324	7.341	7.550	7.690	3.453	3.929	4.593	6.253	5.977	6.310	7.587
2009	8.977	9.221	8.303	9.593	6.667	4.913	3.478	5.137	4.433	6.009	6.707	7.638
2010	8.874	9.362	8.271	7.851	6.758	4.220	3.190	3.168	5.140	4.371	6.412	7.972
2011	8.135	8.235	8.423	7.060	7.435	3.043	2.326	4.418	4.573	6.141	6.143	7.272
2012	8.683	8.282	7.261	6.763	7.238	3.620	3.674	3.525	5.440	6.483	6.826	7.996
2013	8.377	8.192	7.987	7.763	7.158	2.527	0.941	4.054	4.133	5.203	5.526	7.600
2014	8.264	8.023	8.542	6.53	6.6	4.34	2.609	3.312	6.637	5.287	5.2933	6.123
2015	8.157	8.6	6.2	6.6	5.8	4.9	3.7	4.1	6.9	5.8	4.6	7.1
2016	7.6	7.7	7.3	7.4	6.4	2.9	3.8	5.9	6.2	5.5	5.8	7
2017	7.9	8.4	7.8	6.8	6	2.7	3.6	3.4	4.9	4.8	6	7.4

APPENDIX-IV

Monthly wind speed data of Pattambi region from 1983-2017 (km/h)

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
1983	4.400	6.121	4.466	3.525	3.808	3.436	1.883	2.009	2.346	2.248	1.690	4.235
1984	4.319	6.093	3.980	3.153	3.861	3.086	2.848	4.532	2.726	1.593	1.846	2.287
1985	4.274	3.210	3.912	3.460	3.716	2.330	2.545	3.738	2.926	2.119	2.150	3.709
1986	3.712	3.167	4.712	3.633	3.771	2.577	3.645	4.700	3.280	2.329	2.460	4.290
1987	5.257	4.322	4.293	4.430	3.987	3.203	3.622	3.429	3.316	2.186	1.920	4.419
1988	4.851	3.648	3.829	3.730	3.638	2.543	2.974	4.138	3.816	3.547	2.915	4.471
1989	4.987	4.192	5.147	5.433	5.012	3.916	5.561	5.287	3.603	2.780	4.466	7.951
1990	6.280	6.282	4.945	5.043	4.209	3.700	3.419	5.277	4.306	3.129	2.850	7.206
1991	5.838	5.282	4.645	4.293	3.671	3.660	4.216	4.074	4.336	2.803	4.066	5.792
1992	8.193	4.106	4.364	4.693	4.148	4.383	3.967	3.625	3.296	1.771	2.973	8.546
1993	5.938	6.471	4.538	4.160	4.438	3.366	3.951	4.790	3.716	2.387	3.266	5.696
1994	7.490	4.289	4.858	3.613	4.541	4.050	3.622	4.196	3.736	2.704	3.839	5.947
1995	6.987	4.976	5.012	4.401	5.001	4.998	3.965	3.975	4.001	3.012	3.998	7.998
1996	7.998	5.001	4.965	4.101	5.023	5.989	5.122	5.254	4.321	3.234	4.998	7.213
1997	5.438	3.450	6.014	4.212	5.989	4.789	5.341	5.234	4.134	4.241	5.423	6.897
1998	6.574	5.607	4.235	4.423	3.974	3.353	4.245	5.254	2.973	2.454	2.333	4.648

1999	5.693	5.192	3.874	5.186	3.709	3.466	4.048	4.248	3.753	2.141	3.513	6.774
2000	7.467	4.162	4.343	5.016	5.500	2.020	2.733	3.122	3.450	1.406	2.606	4.051
2001	4.938	2.782	3.651	2.883	3.522	2.763	3.548	4.222	6.950	3.327	3.403	6.964
2002	6.171	6.775	4.954	4.533	4.603	4.210	3.848	2.967	3.103	2.132	3.106	2.800
2003	5.245	5.234	4.789	3.000	3.183	2.785	2.513	2.480	2.701	3.176	3.453	4.600
2004	5.845	4.648	4.455	4.007	5.517	4.315	3.755	5.181	3.473	3.113	4.730	6.148
2005	4.842	4.818	4.275	3.452	3.635	3.003	3.809	3.571	3.220	2.080	2.966	2.200
2006	6.671	6.482	4.419	4.613	5.132	3.337	4.180	3.771	3.190	2.948	3.780	8.513
2007	7.194	5.646	4.468	4.500	4.290	3.820	3.332	4.732	2.963	3.106	3.280	6.397
2008	6.187	3.975	4.782	3.867	4.694	3.367	3.884	4.071	3.157	3.171	2.903	6.294
2009	10.03	4.764	4.397	3.000	3.848	2.783	3.300	2.281	2.187	2.413	5.275	6.328
2010	10.98	4.378	5.216	3.531	3.242	4.000	3.769	3.812	2.910	2.035	2.000	6.359
2011	4.926	4.250	5.525	3.624	3.445	2.273	1.923	1.220	2.790	1.697	2.573	1.650
2012	4.368	4.407	3.487	3.397	3.419	1.877	2.777	2.071	1.740	1.987	2.011	4.587
2013	4.187	4.836	3.175	3.970	3.357	2.644	2.535	3.735	2.673	2.423	2.783	4.148
2014	5.980	5.198	4.790	3.245	2.908	3.290	3.209	2.103	3.342	2.312	2.990	4.245
2015	7.851	4.701	3.585	3.148	2.769	3.275	2.750	3.514	2.945	1.908	3.137	2.907
2016	6.194	4.301	3.100	3.341	2.980	2.159	3.123	3.270	2.309	1.990	2.123	4.354
2017	6.041	3.958	3.250	3.324	3.432	1.875	2.916	1.875	2.083	2.291	1.875	3.750

APPENDIX-V

Monthly maximum temperature data of Pattambi region from 1983-2017 (^{0}C)

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	33.32	36.24	36.43	35.93	35.19	32.21	29.91	29.16	29.39	31.75	32.42	32.51
1984	33.18	35.03	36.14	34.73	35.72	29.12	28.29	28.94	30.14	29.86	32.27	32.63
1985	32.82	34.79	36.00	35.69	34.54	27.58	28.47	29.21	30.50	31.03	32.04	32.68
1986	32.65	34.20	36.46	36.04	34.63	30.68	29.75	28.98	30.64	31.75	31.73	33.59
1987	33.98	35.23	36.65	36.81	35.64	30.81	30.50	29.82	31.61	32.23	31.82	32.38
1988	33.11	35.64	35.61	35.66	34.08	30.13	29.28	28.96	29.88	31.32	33.31	33.89
1989	34.33	46.71	36.73	35.75	34.18	29.88	29.76	29.76	30.14	30.93	32.45	33.03
1990	33.48	35.04	36.17	36.13	32.49	30.06	29.01	29.35	31.38	32.43	30.72	32.54
1991	33.54	35.64	36.82	35.57	34.77	29.89	29.46	29.25	31.75	31.07	31.70	32.19
1992	32.76	34.58	37.03	36.56	34.05	30.57	29.03	29.04	30.36	30.79	31.65	31.51
1993	32.76	34.51	35.53	36.41	34.84	30.46	29.12	29.72	31.08	31.23	31.60	31.56
1994	33.31	34.90	36.84	34.43	34.47	29.43	28.64	29.67	31.27	31.31	31.97	32.59
1995	33.26	36.02	36.36	35.80	34.49	29.87	29.21	29.34	30.79	31.27	31.93	32.60
1996	33.15	34.54	36.11	35.02	33.05	30.00	29.38	29.48	30.65	30.84	31.77	32.13
1997	32.83	34.72	36.12	35.03	33.29	30.18	29.31	29.65	30.45	30.91	31.76	32.28
1998	33.54	34.41	36.34	36.43	32.84	30.64	29.30	29.95	29.38	29.64	31.57	31.18
1999	32.62	35.03	35.83	33.94	31.07	29.77	28.60	29.87	31.66	30.76	31.64	32.17

2000	33.72	34.11	36.09	34.69	34.52	29.83	29.71	29.06	30.70	31.31	31.97	32.59
2001	33.09	34.18	35.25	34.45	33.02	29.44	29.15	29.50	30.22	31.22	31.77	31.85
2002	33.11	34.76	37.04	35.58	33.58	30.11	30.20	28.84	31.49	31.20	31.88	32.72
2003	33.22	34.51	36.11	34.77	32.81	30.98	29.49	29.77	30.69	30.83	31.77	32.57
2004	33.62	35.47	36.63	34.82	33.51	29.88	29.51	29.49	30.87	31.34	31.97	32.87
2005	33.92	35.08	36.19	34.08	34.15	30.57	29.04	30.01	29.80	31.26	31.51	32.62
2006	33.47	34.83	35.30	35.18	33.40	30.30	29.53	30.10	29.94	31.04	31.44	32.11
2007	33.07	34.54	36.45	36.39	34.00	30.29	28.55	29.90	29.73	30.48	32.13	32.07
2008	32.75	34.71	33.95	34.14	33.88	30.30	29.61	29.22	30.44	31.75	32.51	32.33
2009	33.31	35.70	35.59	34.57	33.41	31.01	29.29	30.53	30.41	32.23	32.24	32.76
2010	33.36	34.93	35.70	35.36	33.95	30.33	29.34	29.40	30.66	30.47	31.78	32.32
2011	33.15	34.30	35.40	34.59	33.66	29.84	29.42	29.59	30.45	32.10	40.91	32.26
2012	32.95	35.41	35.60	35.28	33.56	30.61	29.95	29.25	30.59	32.40	32.01	33.19
2013	34.34	35.10	35.67	32.70	28.64	29.69	30.42	30.83	32.42	31.99	32.11	31.38
2014	33.25	34.50	37.23	36.05	34.06	31.34	29.84	29.60	31.39	28.05	31.54	32.74
2015	33.18	34.79	35.88	33.40	32.95	31.20	30.50	31.00	27.77	32.45	32.04	27.53
2016	33.13	34.95	36.92	36.99	34.17	30.14	29.78	30.51	26.91	31.46	33.04	27.07
2017	34.10	35.80	35.80	35.70	34.50	29.70	30.20	29.70	30.90	31.20	32.20	31.90

APPENDIX-VI

Monthly minimum temperature data of Pattambi region from 1983-2017 (^{0}C)

Year	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1983	19.42	20.04	22.22	23.73	25.33	24.67	23.53	23.80	23.25	23.03	21.82	22.98
1984	22.04	26.05	23.75	25.00	25.63	23.27	23.02	23.23	23.13	22.05	22.42	19.30
1985	21.87	21.36	23.80	25.30	24.96	24.32	22.70	23.14	23.07	22.75	22.06	21.51
1986	20.90	20.99	23.75	24.91	24.83	23.25	23.29	22.67	22.80	23.03	20.70	21.64
1987	20.75	20.94	21.43	24.92	23.54	22.95	22.77	22.57	39.34	23.08	21.43	21.35
1988	19.14	20.54	22.84	23.15	23.84	21.36	19.75	20.41	20.34	22.79	19.48	17.85
1989	19.20	18.69	22.70	24.98	24.61	22.41	23.24	22.82	22.83	23.07	21.78	20.92
1990	17.03	17.51	19.01	20.97	20.37	19.17	20.00	22.70	23.44	23.34	22.18	23.60
1991	20.66	20.15	24.33	24.76	25.35	23.36	22.46	22.34	23.12	22.90	21.78	19.58
1992	18.64	20.84	21.86	23.73	30.62	22.59	22.17	22.38	22.35	21.84	21.54	19.47
1993	18.70	20.49	22.76	24.03	23.93	22.93	22.03	22.45	22.00	22.26	21.27	19.95
1994	19.77	19.90	21.27	22.13	22.91	21.20	20.58	20.87	20.47	22.73	21.82	20.89
1995	19.84	20.62	22.48	23.97	24.66	22.62	22.13	22.45	23.84	22.74	21.52	20.75
1996	21.40	21.79	23.46	24.60	24.25	25.05	22.85	23.06	23.28	23.42	22.77	20.91
1997	18.92	20.36	23.49	24.65	24.81	23.87	23.44	23.30	23.49	23.37	22.40	21.08
1998	21.87	22.36	23.20	26.07	28.07	23.73	23.42	23.84	23.40	23.04	22.77	21.25
1999	19.79	21.51	23.28	24.59	23.81	23.10	22.80	23.30	23.30	23.49	22.19	21.44

2000	21.90	21.73	23.40	24.85	24.77	29.76	22.65	22.61	23.31	23.30	22.61	20.66
2001	21.13	22.10	23.21	24.10	23.70	22.82	22.50	23.32	23.31	23.27	22.52	21.12
2002	21.18	21.56	23.78	24.85	24.26	22.58	23.40	23.26	23.21	23.70	23.16	20.94
2003	21.00	21.70	23.42	24.54	24.98	23.75	23.41	23.35	23.31	23.36	22.65	20.32
2004	20.81	21.26	23.67	25.09	25.04	23.64	23.55	23.21	23.55	23.24	22.27	20.89
2005	20.71	20.86	23.15	24.32	24.65	23.70	23.31	23.15	23.40	23.53	22.53	20.99
2006	20.96	20.53	23.30	24.55	24.83	24.02	23.50	23.44	23.42	23.46	23.20	21.33
2007	20.21	20.80	23.85	24.65	24.72	24.12	23.42	23.42	23.58	23.23	21.59	21.11
2008	22.85	20.81	28.49	24.79	24.20	23.77	23.69	23.93	23.26	23.37	22.85	20.50
2009	19.92	20.80	23.71	24.82	24.53	23.65	23.47	23.61	23.80	23.81	22.53	22.69
2010	20.93	20.75	24.50	25.28	25.66	24.00	23.48	23.70	23.66	23.45	22.78	20.89
2011	20.72	19.81	24.47	24.27	24.75	23.77	23.35	23.59	23.55	23.58	21.98	21.09
2012	20.01	21.14	23.89	25.01	25.48	24.13	23.87	23.78	23.66	23.65	22.30	21.70
2013	20.67	22.65	24.09	24.75	24.87	23.58	23.30	23.68	23.70	23.44	23.39	20.89
2014	21.31	21.18	23.07	25.36	24.98	24.28	23.24	23.28	23.23	26.39	22.80	21.87
2015	20.20	20.94	23.50	23.80	21.87	20.95	23.49	23.70	23.74	23.99	23.40	22.52
2016	21.41	22.30	24.97	26.50	25.18	23.88	23.83	23.88	23.56	23.14	22.58	21.47
2017	20.90	21.60	23.50	25.50	24.70	23.70	23.10	23.80	23.60	23.40	22.70	21.00

APPENDIX-VII

Crop data for Non rice crops

Crop		Crop Parameters	Kc	Length, days	Rooting Depth, m	Critical depletion factor	Yield response factor	Crop height, m
Banana	Date of planting:01/06	Initial	1	120	0.9	0.55	1	
		Development	1.2	60			1	
	Date of harvesting:31/05	Mid	1.2	180	0.9	0.45	1	4
		Late	1.1	5		0.45	1	
Pepper	Date of planting:01/06	Initial	0.6	30	0.25	0.2	1.4	
		Development		35			0.6	
	Date of harvesting:03/10	Mid	1.05	40	0.8	0.3	1.2	0.7
		Late	0.9	20		0.5	0.6	
Pulses	Date of planting:01/01	Initial	0.4	20	0.6	0.45	0.8	
		Development		30			0.4	
	Date of harvesting:10/04	Mid	1.05	30	1	0.45	1.2	0.4
		Late	0.35	20		0.45	1	
Vegetables	Date of planting:26/01	Initial	0.6	30	0.7	0.4	1.05	
		Development		40		0.4	1.05	
	Date of harvesting:09/06	Mid	1.15	40	1.5	0.4	1.05	0.4
		Late	0.8	25		0.4	1.05	

APPENDIX-VIII

Crop data for Rice (Transplant)

Date of planting: 01/05				Date of harvesting: 28/08				
Crop Parameter	Kc (dry)	Kc (wet)	Length, days	Puddling depth	Rooting depth	Critical depletion factor	Yield response factor	Crop height, m
Initial	0.5	1.1	20		0.1	0.2	1	
Development	1.05	1.2	30	0.4		0.2	1.09	
Mid- season	1.05	1.2	40		0.6	0.2	1.32	1
Late	0.7	1.05	30		0.6	0.2	0.5	

APPENDIX-IX

Crop data for Rice (Direct sown)

Date of planting: 01/05				Date of harvesting: 28/08				
Crop Parameter	Kc (dry)	Kc (wet)	Length, days	Puddling depth	Rooting depth	Critical depletion factor	Yield response factor	Crop height, m
Nursery	0.7	1.2	30			0.2		
Initial	0.3	1.05	20		0.1	0.2	1	
Development	0.5	1.1	30	0.4		0.2	1.09	
Mid- season	1.05	1.2	40		0.6	0.2	1.32	1
Late	0.7	1.05	30		0.6	0.2	0.5	

CROP WATER REQUIREMENT AND IRRIGATION SCHEDULING OF SELECTED CROPS USING CROPWAT: A CASE STUDY OF PATTAMBI REGION

By

AISWARYA JOHNSON (2015-02-002)

ASHIKA NP (2015-02-011)

PARVATHY NAYANA N (2015-02-027)

ABSTRACT OF THESIS

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DEPARTMENT OF IRRIGATION AND DRAINAGE ENGINEERING

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

TAVANUR-679 573, MALAPPURAM

KERALA, INDIA

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ABSTRACT

The study entitled "Crop water requirement and irrigation scheduling of selected crops using CROPWAT: A case study of Pattambi region" was taken up to compute the crop water requirement and irrigation schedule of major crops in Pattambi region. The study also focused on analysing whether rain water could meet the evapotranspiration demand of crops. The CROPWAT 8.0 model developed by FAO was used for the determination of crop water requirement and irrigation scheduling. Climatological data including temperature, sunshine hours, wind speed, relative humidity and rainfall were collected from RARS Pattambi for the last 35 years (1983-2017). The details of major crops of Pattambi region, viz, banana, pepper, pulses, rice (direct sown), rice (transplant) and vegetables were also collected from RARS Pattambi. The required soil, crop and climate data inputs were given to the model and the crop water demand and irrigation schedule for each crop was obtained. The best criteria for scheduling irrigation was also determined.

Water requirement for banana, pepper, rice, pepper, rice (transplant), rice (direct sown), pulses and vegetables were found as 1546.2 mm, 327.7 mm, 550.4 mm, 543.3 mm, 351 mm and 564.3 mm respectively for the year 2017. The irrigation requirement for banana, pepper, rice (transplant), rice (direct sown), pulses and vegetables were found as 807.2 mm, 0.0 mm, 309.7 mm, 300.1 mm, 311 mm and 473.2 mm respectively for the same year. The water requirement of crops were found to be dependent on the ET_o values while the IR was found to vary with rainfall. The crops should be irrigated with that amount of water which is not provided by rainfall. For both dry crops and wet crops, a lesser rainfall efficiency was found when irrigation was scheduled at fixed interval per stage while a higher rainfall efficiency was found when irrigation was scheduled at critical depletion for dry crops and up to a fixed water depth for rice.

The results of the study can be used as a guide for the farmers to plan their irrigation and cropping pattern. Also the results can be extrapolated to the future to analyze the trends in future crop water demands.