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Determination of Crop Water Requirement for Rice: A Case Study in the Long Xuyen Quadrangle, Vietnam

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Key words: Cropwat, crop water requirement, effective rainfall, irrigation, climate change

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Abstract: This study is focused on water use aspects with the aim of: calculating reference and actual evapo transpiration; determining Crop Water Requirement (CWR) and Crop Irrigation Requirement (CIR) and constructing Efficient Irrigation Schedule (EIS) for three main crops, including winter-spring, summer-autumn and autumn-winter using the Cropwat model based on monthly meteorological data recorded from 1984-2015. The results showed that winter-spring and summer-autumn harvest needed irrigation water approximately 8186 and 5830 m^3 ha^{-1} while autumn-winter harvest needed approximately 2204 m^3 ha^{-1}. The lowest value of the reference Evapotranspiration (ET_C) is approximately 607.8 mm crop occurred autumn-winter crop while the highest value 709.9 mm crop occurred summer-autumn crop. The highest IR of the winter-spring, summer-autumn crops occurred on development stage with net irrigation approximately 499.5 and 397.1 mm, respectively. While the autumn-winter crop occurred on both growth, development and late stage with average net irrigation approximately 307 mm. The results obtained confirm that the Cropwat model with meteorological and soil data as input variables is successfully applied to define actual Evapotranspiration (ET_o), ET_C, CWR and EIS for three major crop seasons of rice in LXQ areas, vietnam with reasonable accuracy.

INTRODUCTION

The Long Xuyen Quadrilateral (LXQ) is one of the important agricultural areas and is a primary source of livelihood in the Mekong Delta. It has an important role in term of food security and socio-economic development of millions of people in Vietnam (Hanington *et al*., 2017). In recent years, the LXQ region has frequently impacted by salinization, drought due to climate change and flow discharge from the upper Mekong river flows down significantly in the dry season (Dinh *et al*., 2012) that it is leading to the Crop Water Deficits (CWD) for agricultural production and this problem has been increasingly threatened the farmer's life. Therefore, accurately estimating CWR is becoming more and more concerned (Surendran *et al*., 2014) and especially in the context of the study area where is considered as one of five river deltas is severely affected by climate change. The rainfall is one of the major factor impacts on crop production. In particular, the rainfall is relatively deficit during the crop growing season. In recent years, due to impact of climate change, the temporal distribution of rainfall is also changing (Poudel and Shaw, 2016). It resulted in the rate of evaporation may change the negative trend and this will lead CWD. According to Surendran *et al*. (2014); Aggarwal and Singh (2010) the total CWR in recent years increased with the rising temperature thereby increasing the irrigation water demand. Improved management and planning of water resources are needed to ensure proper use and distribution of water for crop production of the agricultural areas. Hence, it is the necessary for assessing future water requirement for agricultural production. Presently the impact of climate change requires human to rethink about the CWR for the crops. Feddema and Freire (2001) confirmed that global warming will affect water sources and have a significant impact on river flow regimes. They observed that water lost to runoff may increase deficits during rainy seasons, thus, causing crops to suffer higher water stress during the dry season. Water season, climate condition and it depends on the cropping pattern and climate. The rate of water uptake required to sustain normal plant growth at any time depends on water deficits in crops and the resulting water stress on the plant have an effect on crop Evapotranspiration (ETa) and crop yield. Water stress on the plant can be quantified by the rate of ETa in relation to the rate of maximum evapotranspiration. Each crop has different water requirement, therefore, the CIR is varied according to the status, properties of the soil, plants and the atmospheric conditions (Al-Omran and Shalaby, 1992; Feddema and Freire, 2001; Soltani and Hoogenboom, 2007). The Cropwat model is used in this work to determine the variation of ET_o, ET_C, CWR and EIS of rice grown in three crops continuously per year based on the relation of the climate factors such as the sunshine, temperature, humidity, rainfall, etc. Finally rebuilding sowing calendar that consistent with the status of climate change to provide information necessary in taking decisions on irrigation management under the impacts of climate change on the agro-ecosystem.

MATERIALS AND METHODS

Study area: The LXQ located in the upper Mekong river Delta of Vietnam with a total land area of approximately 498141 ha sbelonging to three provinces: An Giang, KienGiang and Can Tho of Vietnam, a population of approximately 1.6 million and lies from 09º57’-10º42’N latitudes and 104º29’-105º29'E longitudes with topography is relatively low, flat and range from 0.25-2.0 m above average sea level (Fig. 1). Agricultural production is considered the dominant sector in the LXQ

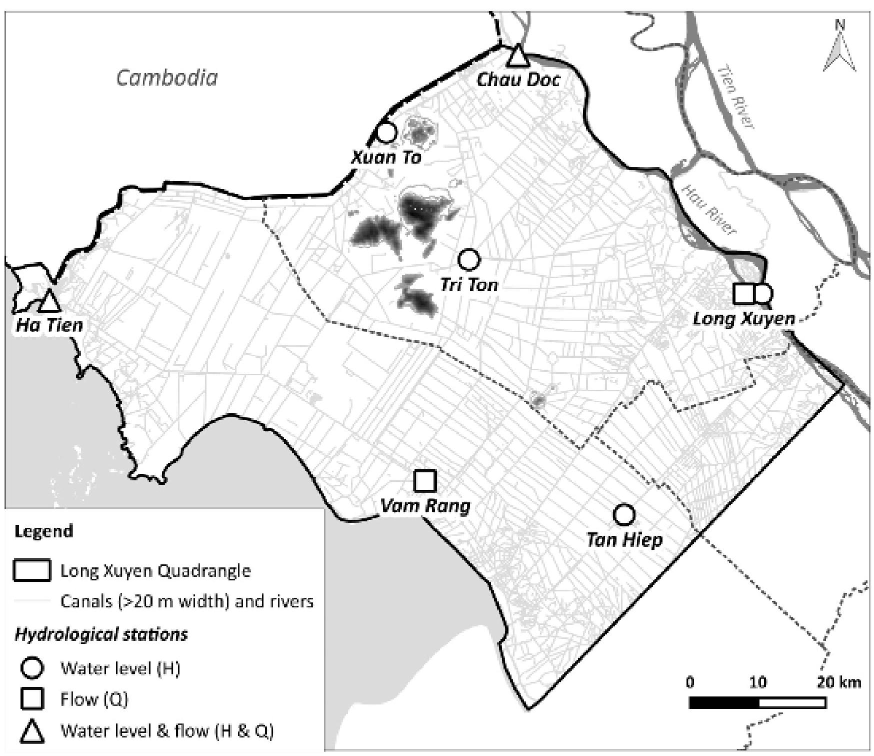

Fig. 1: Location of the study area in the LXQ in the Mekong Delta (Hanington *et al*., 2017)

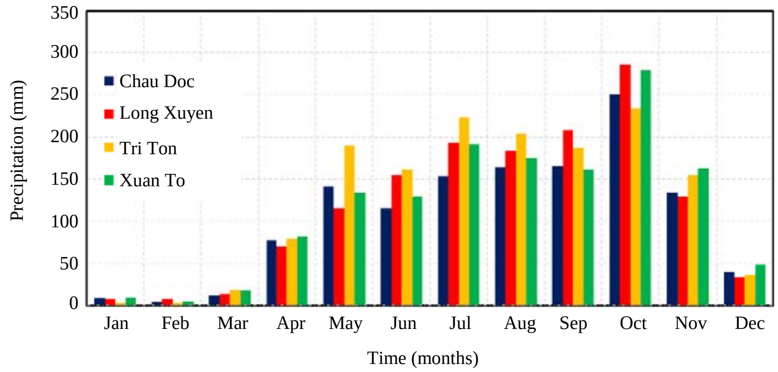

Fig. 2: Average monthly precipitation in the study area from 1984-2015

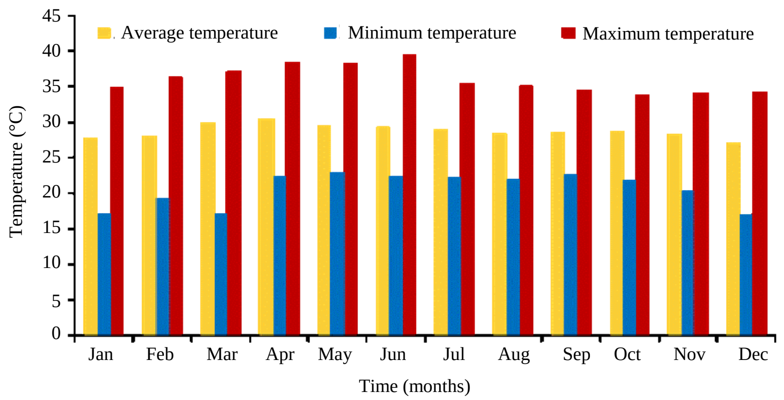

Fig. 3: Average, maximum and minimum temperature in the study area from 1984-2015

and it is one of Vietnam's most productive regions for rice beside the Dong Thap Muoi zone in the upper Vietnamese Mekong delta. Farmers grow two or three rice crops per year based on fresh water come from the upstream of the Mekong river and local rainfall. Annually, this area receives average rainfall approximately 1500-1620 mm (Fig. 2). A seven-month rainy season is from May to November and following by a dry season of five month (December to April next year). The average monthly temperature about 28.7°C while the average maximum temperature >35°C and it usually occurs in May (Fig. 3). Most plant processes related to growth and yield are highly temperature dependent. Temperature increases, however, have also been found to reduce the yields and quality of many crops. Adams *et al*. (1998) found that higher shorten the life cycle of grain crops, resulting in a shorter grain filling period, so, the plants produce smaller and lighter grains (Kahlown *et al*., 2003; Tantawy *et al*., 2007).

In agricultural production, irrigation water is considered as the main factor determining yield, therefore, rainfall is considered as an important source to supply soil moisture. The effects of the CWD on crop production maybe depends on the particular crop. According to Adeniran *et al*. (2010), Arku *et al*. (2012), Kahlown *et al*. (2003) and Rajan (2007) the critical phases of plant development in the tropical area depend on rainfall factor. They concluded that CWR depends on not only crop area, soil type, growing seasons and crop production frequencies but also climatic conditions. About 90% the average rainfall in the study area is taking place during the rainy season and it frequently suffers from droughts and water scarcity during the dry season (Fig. 2). Daily sunshine length varies between 5.2-7.2 h and average sunshine length 6.2 h/day. The average monthly humidity varies from 76-84% and average 80%. The study area is characterized by tropical monsoon climate with two main wind directions including the Northeast Monsoon (NE) and Southwest Monsoon (SW). The NE monsoon wind blows from December to April next year with an average velocity varies between 2.5-3.2 m sec^{-1} and SW monsoon wind blows from May to November with an average velocity varies between 2.7-4.7 m sec^{-1}. These have three crop seasons in the study area, including winter-spring (from June to September), summer-autumn (from October to January), and autumn-winter (from February to May).

Model description: The Cropwat model is developed by the Land and Water Development Division of Food and Agriculture Organization (FAO), Italy with the assistance of the Institute of Irrigation and Development Studies of Southampton, United Kingdom and National Water Research Center, Egypt for planning and management of irrigation (FAO, 1992; Hess, 2005; Lee *et al*., 2004; Muhammad, 2009). The model is considered as a useful tool to carry out standard calculations ET_o, CWR, Crop Irrigation Requirements (CIR) and specifically the design planning schedules and management of irrigation schedules. Beside the Cropwat also allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions and the assessment of CWR for the crops varies under different weather conditions (Allen *et al*., 1998; Arulkar and Hiwase, 2008; Banik *et al*., 2014; Rajan, 2007). Evapotranspiration isan important parameter for irrigation scheduling and regional water allocation.

The ET_o was calculatedby Penman-Monteith method, which represents evaporation from the surface of a wide range of high standard green grass with enough water and active growth can be presented by Lee *et al*. (2004) and Serban (2013). According to Bouraima *et al*. (2015), FAO Irrigation and Drainage Paper 56 namedadopted the Penman-Montiethmethod as global standard to estimate ET_o frommeteorological data. The Penman-Monteith equation integrated in the Cropwat model is expressed:

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

Where:

ET_o = Reference evapotranspiration (mm day^{-1})
R_n = The net radiation at the crop surface (MJ $daym^{-2}$)
G = Soil heat flux density (MJ $daym^{-2}$)
T = Average daily air temperature at 2.0 m height (°C)
u_2 = Wind speed at 2.0 m height (ms^{-1})
e_s = The saturation vapor pressure (kPa)
e_a = Actual vapor pressure (kPa)
Δ = The slope of the vapor pressure curve (kPa°C^{-1})
c = Psychrometric constant (kPa°C^{-1})

The Penman-Monteith method is often applied to the Cropwat model to predict CWR, irrigation water management and crop scheduling, etc. It is to be noted that while ET_C represents the amount of water that crop losses due to evapotranspiration, CWR represents the amount of water to be supplied (FAO, 1992, Kahlown *et al*., 2003). The CWR was often estimated for each crop and then added through the irrigation scheme planning to predict the total of the CWR (Adeniran *et al*., 2010; Aghdasi, 2010; Kang *et al*., 2003).

ET_C is known as the CWR and defined as the depth of water needed to meetthe water loss through evapotranspiration of a diseasecrop, growing in fields. While ET_o is multiplied by an empirical crop coefficient (Kc) to produce an estimate of ET_C. In the Cropwat model, calculates ET_C on a 10-days basis as:

$$ET_C = ET_O \times K_C \quad (2)$$

Where:

ET_C = Actual evapotranspiration by the crop (mm day^{-1})
ET_o = Reference evapotranspiration (mm day^{-1})
K_C = The crop coefficient at a specific growth stage
K_C = Depends on the type of crop

The parameter K_C varies on the type of the crop and the growing stage of a crop. The CIR represents the fraction of the CWR that needs to be satisfied through irrigation contributions to ensure that the plants will best development. The amount of water required to compensate the evapotranspiration loss from the crop fields is considered as a crop water requirement. To calculate CWR for a crop, it is essential to know the Eff. Rain over the cultivated area (Arku *et al*., 2012; Bhat *et al*., 2012; Shah *et al*., 2015; Feng *et al*., 2007). The Eff. Rain can be calculated following as:

$$P_{eff} = P_{month}\frac{125 - 0,2*P_{month}}{125} \quad (3)$$

Where:

P_{eff} = Effective rainfall (mm)
P_{month} = The total rainfall (mm)

Equation 3 is valid for a rainfall of P_{month} <250 mm. In the study area, meteorological stations had record average monthly rainfall during 34 last year (1984-2015) is less than 250 mm/month. Therefore, Eq. 3 is valid for the prediction of CWR for each crop, the monthly water requirements can be calculated as:

$$Q = \sum_{i=0}^{n} A_i (ET_{ci} - P_{eff})*10 \quad (4)$$

Where:

Q = Monthly water requirement of irrigation scheme (m^3day^{-1})
I = Crop index
A_i = Crop planted area (hectare)
ET_{Ci} = Crop evapotranspiration (mm day^{-1})
P_{eff} = The effective rainfall (mm day^{-1}) and 10 represents the conversion factor

Input data: The Cropwat model requires climate data for estimating CWR including temperature (maximum,

Table 1: Monthly values of climatic parameters for the study area

Months	Tempetature (°C) Min.	Max.	Humidity (%) (MJ/m^2/day)	Wind (msec^{-1})	Sun shines (h)	Net radiation	Rainfall (mm)
Jan.	17.1	34.9	78	2.5	6.8	17.4	5.6
Feb.	19.3	36.4	77	3.3	7.2	19.2	0.7
Mar.	17.1	37.2	76	3.2	6.9	19.8	19.4
Apr.	22.3	38.3	78	3.1	7.1	20.5	75.2
May	22.9	38.2	80	3.0	6.4	19.0	185
Jun.	22.3	39.4	84	4.7	6.1	18.2	105
Jul.	22.2	35.4	84	4.3	5.2	17.0	175
Aug.	21.9	35.1	84	4.7	5.2	17.3	210
Sep.	22.5	34.6	84	4.2	5.4	17.5	260
Oct.	21.8	33.8	83	2.7	5.8	17.3	228
Nov.	20.3	34.0	80	2.4	6.8	17.6	143
Dec.	17.0	34.2	79	2.5	6.4	16.4	29.5

Table 2: Crop calendar for rice crops planted in the study area

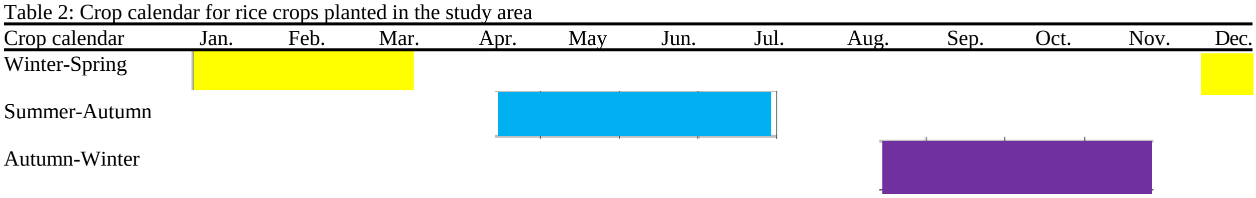

Table 3: Planting and harvesting dates, growing and crop growth stage coefficient (K_C)

Crops	Crop coefficient (K_C) LP	I	D	L	Growth stages (day) LP	I	D	L	Crop length (day)	Sowing date	Harvesting date
Winter-spring	0.3	0.5	1.05	0.7	10	10	65	30	115	15-Dec.	29-Mar.
Summer-autumn	1.05	1.2	1.73	1.15	10	10	65	30	115	15-Apr.	28-Jul.
Autumn-winter	1.05	1.15	1.69	1.1	10	10	65	30	115	15-Aug.	27-Nov.

minimum), relative humidity, wind speed, solar radiation, sunshine duration, rainfall. The database was collected from the Southern Regional Hydro-meteorological Center of the Vietnam during for a period of 34 years (1984-2015) (Table 1). The average annual rainfall varies from 1500-1800 mm with monthly peaks in June and October. Total of rainy season approximately 85-90% of annual rainfall. Sunshine duration is approximately 6.9 h from January to May while it decreases gradually 5.2-5.8 h from June to December. Net radiation is 19.0 MJm^2 day^{-1} from January to June while the lowest radiation is 16.9 MJm^2 day^{-1} from July to December. The average maximum temperature varies from 34-39.42°C, the average minimum temperature varies from 17-22.9°C.

Three main crop calendars, including winter-spring, summer-autumn and autumn-winter corresponding with December-March, April-July and August-November, respectively is shown in Table 2.

In addition, to calculate CWR, besides the climate data, other inputs of the model are cultivation pattern, plant coefficient, area under cultivation, irrigation scheduling, soil type, available soil moisture, root depth and water content in the soil are also required. The planting dates of the crops obtained from Department of Agriculture and Rural Development of the provinces where located in the study area. The details of crop growth stage coefficient (K_C) for various crops, crop length, sowing and harvesting dates are shown in Table 3.

Table 4: Relevant soil characteristics

Soil description	Medium
Maximum rain infiltration rate (mm day^{-1})	105
Plowing depth (cm)	20
Maximum water depth (cm)	70
Water availability at planting (mm WD)	5
Maximum rooting depth (cm)	90
Maximum percolation rate after puddling (mm day^{-1})	407
Critical depletion for puddle cracking (fraction)	104
Drainable porosity (SAT-FC)	13
Initial soil moisture depletion (%)	50
Initial available soil moisture (mm m^{-1})	140
Total available soil moisture (mm m^{-1})	140

where LP is land preparation stage, I is initial stage, D is development stage, L is late season stage, K_C is crop coefficient.

The soil characteristics in the study are obtained and classified using the Soil Water Characteristics Program Software (Saxton *et al*., 1986; Oyeogbe and Oluwasemire, 2012). Soil type is predominantly silly-clay mix clay (Table 4). The soil pH about 4.0 showing the soil is mostly acidic which means that the soils available have high potentials for retaining plant nutrients.

RESULTS AND DISCUSSION

Actual Evapotranspiration (ET_o): The calculated results of three rice crops as shown in Fig. 4 showed that the ET_o varies in the range of 3.72-5.13 mm day^{-1}. The ET_o

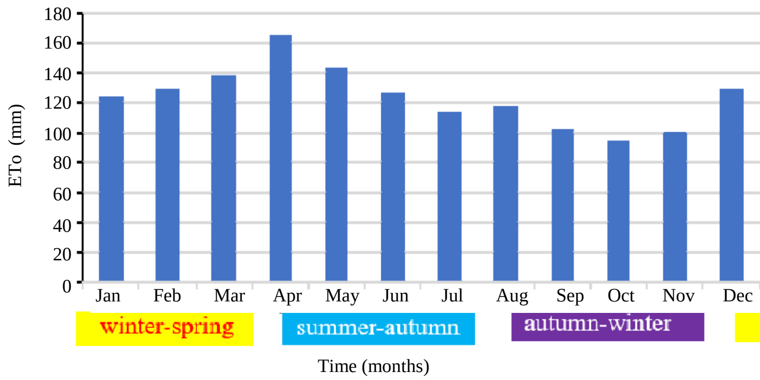

Fig. 4: Simulation results of ETO with time

increases gradually from 3.99 mm per day in January to the peak value of about 5.36 mm day in April. Then it decreases gradually to 3.67 mm day^{-1} in October. The high ETo occurred in March, April and May as show in Fig. 4. The monthly variation of ETo indicates that sowing time can affect CWR significantly for a particular type of crop. The summer-autumn crop is grown during the summer months, this period might consume proportionately more water, therefore, the values of K_C are high and this will lead to higher values of CWR. The ETo values varied greatly through three crops and the Eto was recorded approximately 128.71 mm month^{-1} in the autumn-winter crop. While the highest ETo value was recorded approximately 139.89 mm month^{-1} of the summer-autumn crop. This can be explained by the change in air temperature because of the high air temperature and the resulting low relative humidity combined with high air temperatures led to increased evapotranspiration over this period. The lowest ETo value was recorded 105.67 mm month^{-1} of the winter-spring crop. According to Adeniran *et al*. (2010), the lowest value of the ETo was often occurred during the peak of the rainy season and highest during the peak of the dry season. The calculated values of ETo at the peak is 6.08 mm day^{-1} at the beginning stage, slightly reduced at growing stage, 5.20 mm day^{-1}, at mid-stage reaches 3.58 mm day^{-1} and at the late stage reaches 1.36 mm day^{-1}. The main cause of this decrease is due to an increase of rainfall.

Reference Evapotranspiration (ET_C): The calculated results of the ET_C for three rice crops as shown in Fig. 5. The ET_C value of winter-spring crop was calculated 662.9mm/crop. The highest value of ET_C was calculated approximately 722.4 mm/crop of the summer-autumn crop. This also can be explained by the increase of the air temperature on dry season and it lead to an increase evapotranspiration. While the lowest ET_C value was calculated 574.9 mm/crop of autumn-winter crop. This result is similar to the FAO (1998) report, in that crops grown in the wet season needs less water than those grown during the dry season.

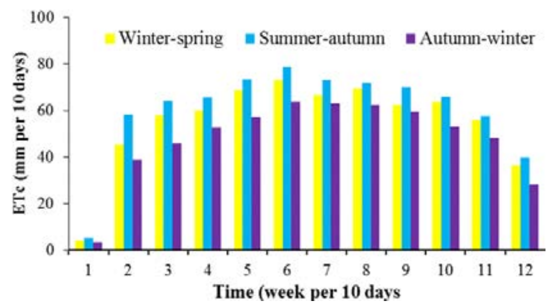

Fig. 5: Calculation results of ET_C from three rice crops

The analysis the cumulative ET_C ($\sum ET_C$) for the development stages of the crops is shown in. Figure 5. During the land preparation and initial stage of crop growth which is the period from sowing through 20 days, the $\sum ET_C$ values is increased from 4.2-40.6 mm/decade for both three crops. $\sum ET_C$ values increase during the development stage which is the period from the twenty-first day to the eighth-five day and its peak were calculated approximately 63.6, 72.9, 78.6 mm/decade, respectively on the 60 days of autumn-winter, winter-spring and summer-autumn crops. Then, the $\sum ET_C$ values decreases slowly during the late season stage from 86 days to one hundred fifteen. The values of ET_C decreases slowly from 63.2, 66.6 and 73.1 mm/decade, respectively in the beginning the late season stage down 28.2, 36.6 and 39.7 mm/decade in the ending the late season stage.

According to FAO (1992), Eff. Rain is defined as that part of the rainfall which is effectively used by the crop after rainfall losses due to runoff surface run off and deep percolation have been accounted and it is the rainfall ultimately used to determine the CIR. The calculated results of the Eff. Rain showed considerable monthly variation (Fig. 6). The calculated results of the Eff. Rain in the study area varied from 0.0-184 mm month^{-1}. The

Table 5: Reference evapotranspiration, effective rainfall, irrigation requirement for three crops

		ET_C (mm)			ER (mm)			CWR (mm)		
Day	Stage	WS	SA	AW	WS	SA	AW	WS	SA	AW
10	LP	4.0	5.3	3.3	0.8	0.7	4.5	80.0	81.3	80.3
10	I	45.3	58.2	38.9	0	9.6	47.5	153.9	174.1	62.3
65	D	395.2	425.8	344.4	0.2	181.6	347.8	360.1	241.1	18.3
30	L	218.4	233.1	188.3	1.5	126.8	130.3	228.6	90.5	63.5
Total		662.9	722.4	574.9	2.5	318.7	530.1	822.6	587.0	224.4

LP: Land Preparation stage, I: Initial stage, D: Development stage, L: Late season stage, K_C: crop coefficient, ET_C: crop Evapotranspiration, IR: Irrigation Requirement, WS: Winter-Spring, SA: Summer-Autumn, AW: Autumn-Winter

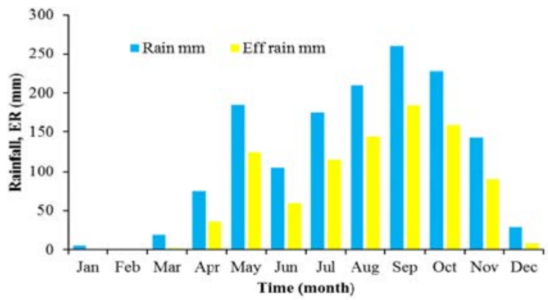

Fig. 6: Simulation results of effective rainfall and rainfall with time

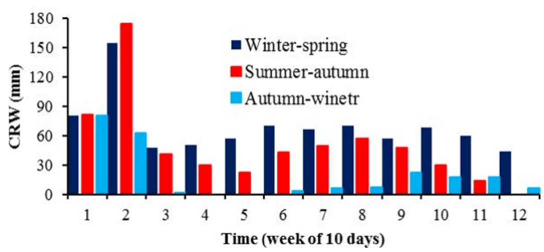

Fig. 7: Crop water requirements for three crops

maximum Eff. Rain was 184 mm month^{-1} in October of the summer-autumn crop. The main reason can be explained by low air temperature and the high rainfall in this period. Whereas the Eff. Rain values were close to zero from December to April. The reduction of the Eff. Rain in the winter-spring crop because of the high air temperature.

Crop Water Requirements (CWR): Calculated results shown that the CWR varied from 0.0-174.1 mm decade $^{-1}$ (Fig. 7). The CWR for the winter-spring, summer-autumn crops were more than for the autumn-winter crop. The total of the CWR for the winter-spring, summer-autumn and autumn-winter were approximately 822.6, 587 and 224.4 mm, respectively. The average CWR of the winter-spring, summer-autumn and autumn-winter crops were approximately 68.55, 48.92 and 18.69 mm decade^{-1}, respectively. The highest CWR of the winter-spring and summer-autumn crop was predicted on the second decade and was recorded 153.9, 174.1 mm decade^{-1},

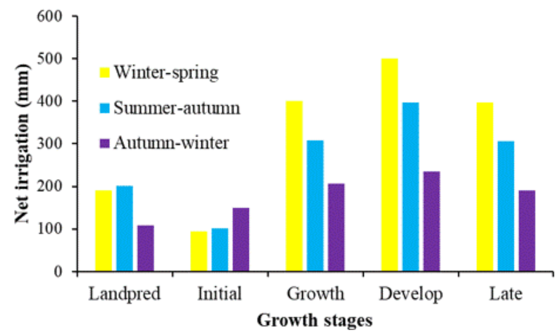

Fig. 8: Irrigation requirement for growth stages of the three rice crops

respectively. According to Zhong etc., reported when the hottest period with highest temperature, high evaporation occur and soil moisture decrease rapidly implying highest CWR. The CWR of the winter-spring crop is increasing with the passage of time and required peak amount of water in the growing and developmental stage. The lowest CWR was close to zero (from the third decade to the sixth decade) of the autumn-winter crop and it is explained by the rainy season in this period. In general, accurate estimation of the CWR is a key requirement for the implementation of proper water management strategies.

Irrigation Requirements (IR): The predicted results of IR for each stage of the three rice crops were shown in Fig. 8. The high IR of the three crops occurred on growth, development, and late stage. The highest IR of the winter-spring, summer-autumn crops occurred on development stage with the irrigation requirement approximately 499.5 and 397.1 mm, respectively. While the highest IR of the autumn-winter crop occurred on both growth, development and late stage with average net irrigation approximately 234.6 mm. The IR for the winter-spring, summer-autumn crops were more than the autumn-winter crops. This implies that rice production of the autumn-winter crop (from August to November, this period coincides with the peak of the wet season) does not require much irrigation water. Because the Eff. Rain was sufficient to irrigate for the entire area. While the ER was not sufficient to irrigate for the entire area in the winter-spring, summer-autumn crops (Table 5).

CONCLUSION

Calculation results showed that ET_C is higher than ETo for the development stage and mid-season stage of three rice crops and this lead to increasing CWR with the development and mid-season stages.

The winter-spring harvest needed largest irrigation water approximately 8186 m^3 ha^{-1}, then summer-autumn harvest approximately 5830 m^3 ha^{-1} and the smallest was autumn-winter harvest approximately 2204 m^3 ha^{-1}.

On the 2nd week of winter-spring and summer-autumn harvest have the highest CWR. While autumn-winter harvest lies entirely in the rainy season therefore CWR is not high. The CWR was lower during the rainy season and higher during the summer season. The study results are consistent with other studies which have been previously published by Adeniran *et al*. (2010), Bouraima *et al*. (2015), FAO (1992).

The results obtained can be used as a guide to farmers whom can apply the amount and frequency of irrigation water for the crops. Enable farmers to schedule watering to minimize crop water stress and maximize yields and contributing to reduced farmer's costs of water and labour through less irrigation.

The results will enhance understanding of CWR which will consequently help improve the productivity. The much longed for the attainment of stability in food security, reduction in poverty.

Simulation model is a useful tool to predict ET_C, ETo, CWR, EIS caused by crop water deficit. The model Cropwat can be used in planning, management and operation of an irrigation project for judicious use of water with the limited inputs, especially, suitable for countries where facing freshwater scarcity.

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