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Water Requirement of Sugarcane Using CROPWAT 8.0 Model: A Case Study of North India

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A B S T R A C T

The global consumption of water is doubling every 20 years, more than twice the rate of human population growth. As per one of the estimate of Food and Agriculture organization (FAO), 70-80 per cent of the increase in food demand between 2000 and 2030 will have to be met by irrigation. Efficient water use can increase crop diversity, produce higher yields, enhance employment and lower food prices. Understanding crop water requirements (CWR) is essential for better irrigation practices, scheduling and efficient use of water, since the water supply through rainfall is limited and erratic in nature. So it has become very important to define appropriate strategies for planning and management of irrigated farm land. One of the major practices adopted by the researchers for estimating water requirement of the crop is modelling. In this paper, Sugarcane crop water requirement in Lakhimpur Kheri district of Uttar Pradesh are forecasted, based on the meteorological data. For determination of crop evapo-transpiration and yield responses to water in the agro-climatic district, CROPWAT 8.0 model is used, which was developed by the Land and Water Development Division of Food Agricultural Organization (FAO). It includes a simple water balance model that allows the simulation of crop water stress conditions and estimation of yield reductions based on well-established methodologies.

Introduction

Severe water shortages are developing in many countries particularly in India and water for agriculture is becoming increasingly scarce, in the light of growing water demands from different sectors (IWMI 2010). Agriculture is the largest (81%) consumer of water in India and hence more efficient use of water in agriculture needs to be top most priority (Surendran *et al.,* 2013). Water is an essential input for crop production. Even though the mean annual rainfall in the Lakhimpur Kheri (UP, India) district is 1068.7mm, available water for crop is becoming increasingly scarce throughout the district. Lakhimpur Kheri (UP, India) district is located in the state of Uttar Pradesh and lies between 27.57N latitude and 80.46E longitude. Aridity and drought are natural causes of scarcity. More recently however man-made desertification and water shortages have aggravated natural scarcity while at the same time population is increasing and there is increased competition for water among water user sectors and regions. In addition, the quality of water is often degraded, so that water resource has become less and less available. Thus, improved management and planning of the water resources are needed to ensure proper use and distribution of the water among competing users. The accurate planning and delivery of the necessary amount of the water in the time and space can conserve water. A scarce water resources and growing competitions for water will reduce its availability for irrigation. Achieving greater efficiency of water use will be a primary challenge for the near future and will include the employment of techniques and practices that deliver a more accurate supply of water to crops. Prediction of the crop water requirement is of vital importance in water resources management. Crop water requirements are normally expressed by the rate of evapotranspiration (ET) in mm day^{-1}. One of the major practices adopted by the researchers for water requirement of crops is modelling. For determination of crop evapotranspiration and yield responses to water, CROPWAT 8.0 model is used which was developed by the FAO Land and Water Development Division (FAO 1992). It also includes a simple water balance model that allows the simulation of crop water stress conditions and estimation of yield reductions based on well-established methodologies. Several researchers have used the CROPWAT 8.0 model for analyzing crop water and requirements in different parts of the world (Kar and Verma, 2005; Martyniak *et al.,* 2006; Dechmi *et al.,* 2003). The irrigation schedule recommendations for various crops should be location-specific, considering the soil types and agro-ecological conditions. The scientific crop water requirements are required for efficient irrigation scheduling, water balance, canal design capacities, regional drainage, water resources planning, reservoir operation studies, and to assess the potential for crop production.

Materials and Methods

Study location

Lakhimpur Kheri district is located in the state of Uttar Pradesh and lies between 27.57N latitude and 80.46E longitude. The district has an area of 7,680 km^2. The normal rainfall of this area is about1068.7 mm annually. Whereas maximum temperature goes up to 38.5 ^{0}C during summer. The location map of Lakhimpur Kheri (UP,India) is also shown in Figure 1 (Table 1 and 2)

Crop data

The major cultivated crops in study area are Sugar cane is the main crop. The salient details (i.e. crop coefficient, length of growing stages, yield response factor and crop height etc.) of crops considered for the study are as per guidelines for estimating irrigation water requirement, Ministry of Irrigation, Govt, of India and FAO - Irrigation and Drainage paper, 24 & 56.

CROPWAT 8.0 Model

CROPWAT for Windows is a decision support system developed by the Land and Water Development Division of FAO, Italy with the assistance of theInstitute of Irrigation and Development Studies of Southampton, UK and National Water Research Center, Egypt. The model carries out calculations for reference evapotranspiration, crop water requirements and irrigation requirements in order to develop irrigation schedules under various management conditions. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules and the assessment of production under rain fed conditions or deficit irrigation (Adriana and Cuculeanu, 1999).

Reference evapotranspiration

This parameter was calculated inCROPWAT8.0 Model which uses the FAO Penman-Monteith method (Allen *et al.,* 1998). In this model, most of the equation parameters are directly measured or can be readily calculated from weather data.

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

Where, ET_o is reference evapotranspiration (mm day^{-1}), R_n is net radiation at the crop surface (MJ m^{-2} day^{-1}),G is soil heat flux density (MJ m^{-2} day^{-1}),T is air temperature at 2 m height (°C),$u_2$is wind speed at 2 m height (m s^{-1}), e_s is saturation vapour pressure (kPa), e_a is actual vapour pressure (kPa), e_s - e_a is saturation vapour pressure deficit (kPa), Δ is slope vapour pressure curve (kPa $°C^{-1}$),Y is psychometric constant (kPa $°C^{-1}$).

Effective rainfall

It is the part of rainfall which is stored in the soil profile and helps in the growing of crops. Rainfall of Lakhimpur Kheri (UP, India) district of Uttar Pradesh in Table 4.To calculate the effective rainfall the USDA Soil Conservation Service method was used (Smith, 1991). Where, P_{eff} represents effective rainfall (mm) and P_{tot} represents total rainfall (mm)

Crop evapotranspiration

For calculation of crop evapotranspiration CROPWAT 8.0 model uses crop coefficient approach and Crop water requirements of different crops have been estimated by summing up the crop evapotranspiration in all growth stages.

$$ET_{crop} = K_c \times ET_o$$

Where, ET_c represents crop evapotranspiration, K_c represents crop coefficient and ET_o represents reference evapotranspiration.

Results and Discussion

Reference evapotranspiration

The simulated values of reference evapotranspiration (ETo) through CROPWAT 8.0 model using Penman-Monteith equation, for the Lakhimpur Kheri district along with the meteorological parameters is presented in the Table 3 and monthly distribution of reference evapotranspiration is shown in the Figure 2. From the result, it is revealed that the maximum ET_0 was found in May month (6.53 mm/day), which was mainly due to high temperature and wind velocity, whereas it was minimum in December (1.85 mm/day).

The reference evapotranspiration is the function of temperature & also affected by relative humidity (RH).

Effective rainfall

The effective rainfall was calculated for the study area with the help of USDA SCS method which is presented in Table 4 and Figure 3. This will help for the estimation of irrigation water requirement of Sugarcane crops for the same area.

From the analysis, it was found that the effective rainfall was maximum in August month (158.6 mm) followed by July month (156 mm), although it was minimum in November (1.0 mm).

Table.1 Soil data

S.No.	Major Soils	Area ('000 ha)	Percent (%) of total
1.	Deep loamy soil	157.0	30 %
2.	Deep, silty soils	183.7	35%
3.	Deep, silty soils associated with loamy soils slightly eroded	94.5	18%
Source – Agriculture Contingency Plan for District: Lakhimpur kheri			

Table.2 Rainfall pattern of Lakhimpur Kheri (UP,India) District of Uttar Pradesh

Average Rainfall (mm)					
District	SW monsoon (June-sep)	Post monsoon (Oct-Dec)	Winter (Jan-March)	Pre (Apr-May)	Annual
Lakhimpur Kheri	921.8	55.5	57.4	34.0	1068.7

$P_{eff} = P_{tot} \times (125 - 0.2P_{tot})/125$ for $P_{tot} < 250^{mm}$

$P_{eff} = 125 + 0.1 \times P_{tot}$ for $P_{tot} > 250^{mm}$

Table.3 Reference evapotranspiration along with meteorological parameters of the study area

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
Jan	9.1	22.3	74	86	6.9	13.1	1.93
Feb	10.5	25.6	70	104	7.7	16	2.69
Mar	15.3	31.6	63	112	8.4	19.5	3.98
April	20.6	37.5	49	147	9.3	22.9	5.97
May	23.8	38.5	51	147	9.4	24	6.53
Jun	25.2	36.4	72	130	6.6	20	5.18
Jul	25.1	32.7	88	112	6.7	20	4.44
Aug	25	32.5	88	104	5.9	18.1	4.01
Sept	23.7	32.2	88	95	5.7	16.4	3.58
Oct	20.7	31	74	86	7.1	16	3.44
Nov	13.6	26.8	75	69	7.5	14.1	2.49
Dec	9.3	22.7	75	69	7.2	12.7	1.85
Average	**18.5**	**30.8**	**72**	**105**	**7.4**	**17.7**	**3.84**

Source: New_Loc Clim 1.10 Software

Table.4 District-wise effective rainfall of Lakhimpur Kheri (UP,India) district

Month	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Total
Rain (mm)	33	13	16	5	21	121	310	336	185	72	1	4	1117
Eff rain (mm)	31.3	12.7	15.6	5	20.3	97.6	156	158.6	130.2	63.7	1	4	695.9

Source: New_Loc Clim 1.10 Software

Table.5 Crop water requirement of Sugarcane crop in Lakhimpur Kheri (UP,India) District

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sugarcane	29.3	50.6	44.9	85.6	156.9	85.1	8.8	0	4.1	57.2	87.3	62.5

Table.6 Net Scheme Irrigation Required

Net scheme irr.req.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
in mm/day	0.9	1.8	1.4	2.9	5.1	2.8	0.3	0	0.1	1.8	2.9	2
in mm/month	29.3	50.6	44.9	85.6	156.9	85.1	8.8	0	4.1	57.2	87.3	62.5
in l/s/h	0.11	0.21	0.17	0.33	0.59	0.33	0.03	0	0.02	0.21	0.34	0.23

Table.7 Net Scheme Irrigation Required

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Irrigated Area (%)	35.08	35.08	35.08	35.08	35.08	35.08	35.08	35.08	35.08	35.08	35.08	35.08
Actual Area (000Ha)	82.08	82.08	82.08	82.08	82.08	82.08	82.08	82.08	82.08	82.08	82.08	82.08
MCM	24.05	41.53	36.85	70.26	128.78	69.85	7.22	0.00	3.37	46.95	71.66	51.30

Fig.1 Location map of District Lakhimpur Kheri

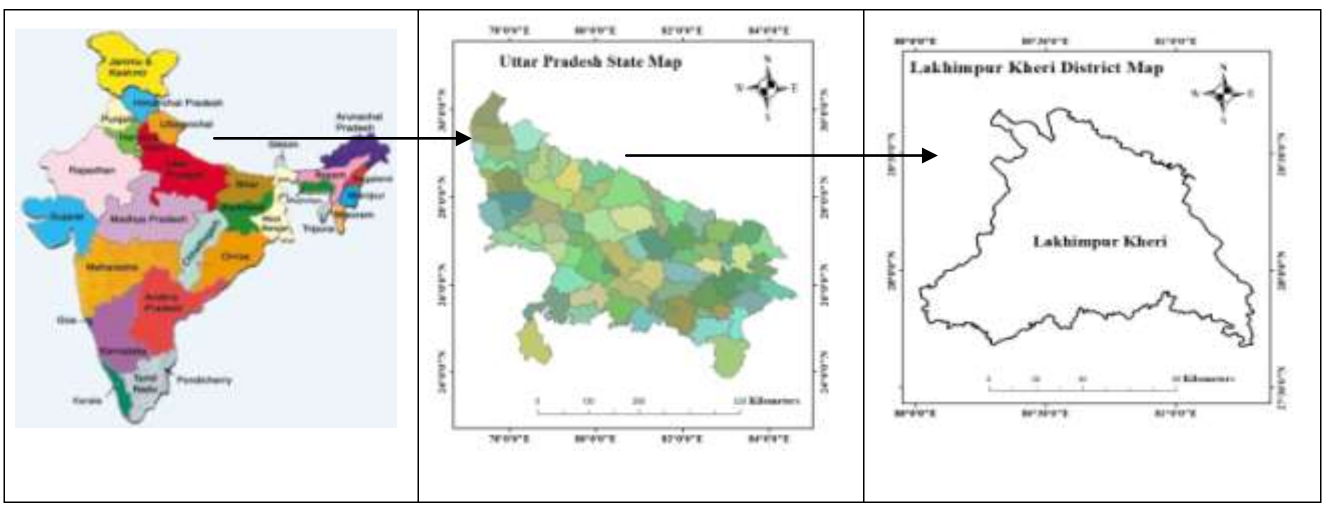


Fig.2 Reference evapotranspiration along with meteorological parameters of the study area

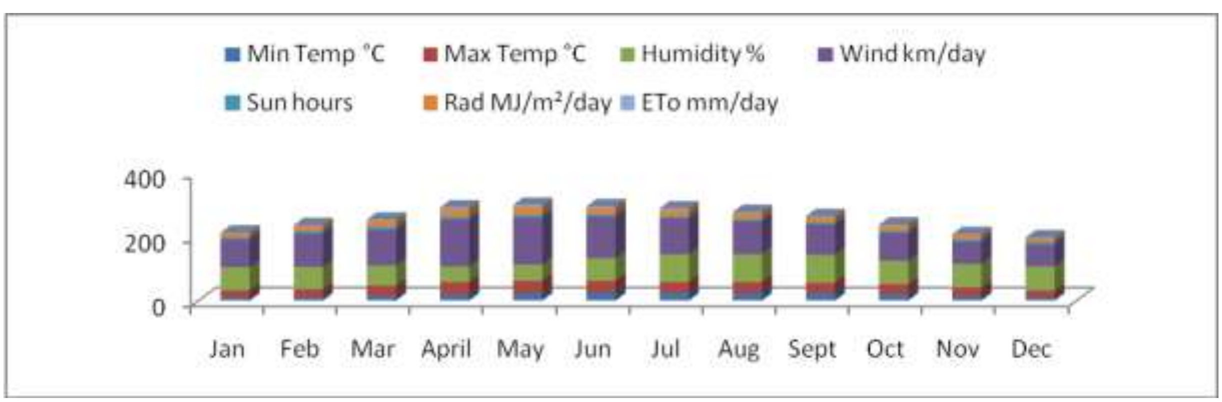


Fig.3 District-wise effective rainfall of Lakhimpur Kheri (UP, India) district

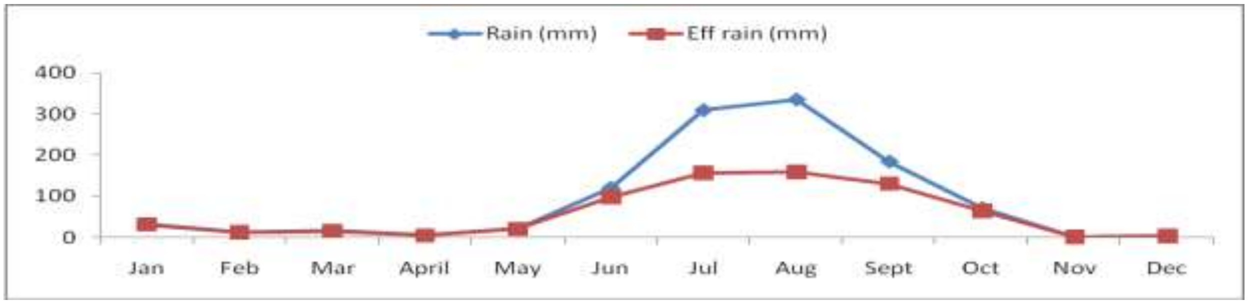


Fig.4 crop water requirement of sugarcane crop in Lakhimpur Kheri (UP,India) District

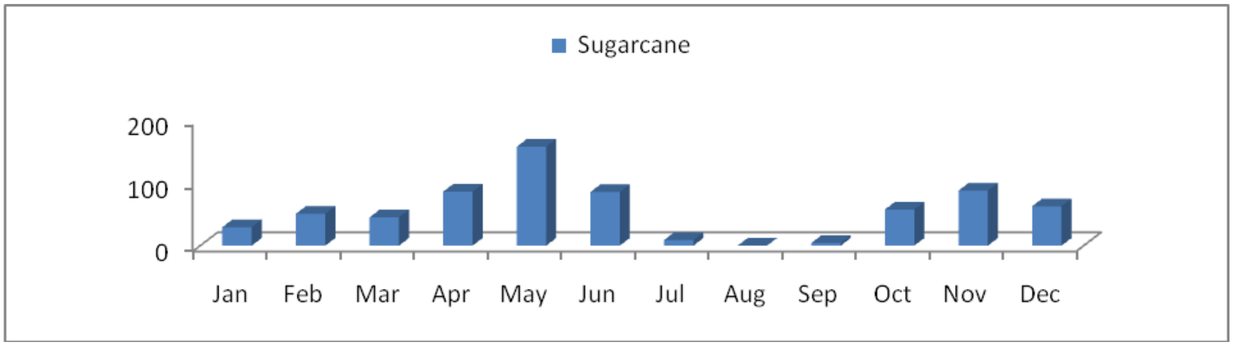


Fig.5 Net scheme irrigation required

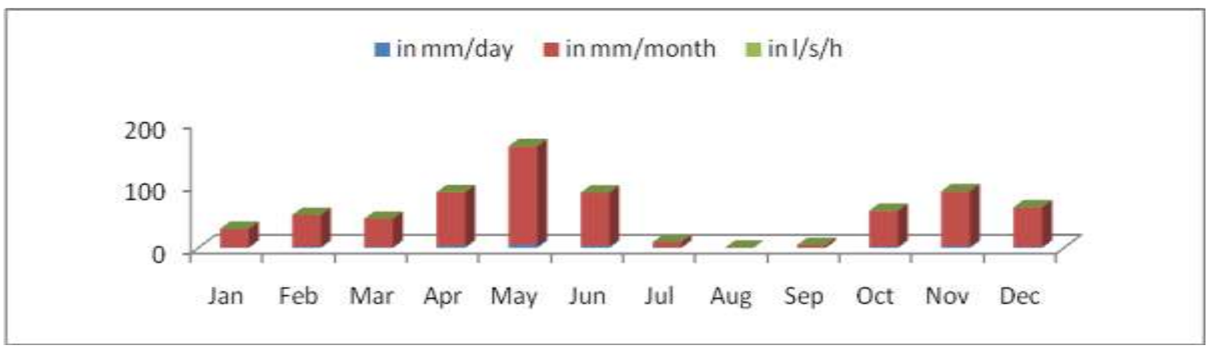
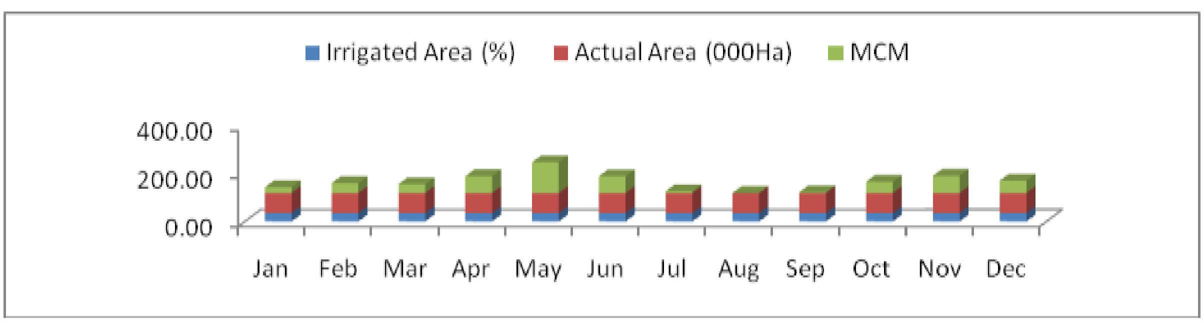


Fig.6 Net scheme irrigation required



Crop water requirement

The difference in the evapotranspiration and evaporation was considered as the water consumed by the Sugarcane and termed as crop water requirement. Estimated Crop water requirement of Sugarcane crops for Lakhimpur Kheri district has been presented in Table 5 and the water demand of crops presented in the Figure 4.

The results show that the crop water requirement of Sugarcane crop is more in the month of May followed by April month within the study area. This was happened due to nearly high reference evapotranspiration in the same months. Also, during the growing and developing period crops also need large quantity of water for various physiological functions.

The water requirement was calculated for Lakhimpur Kheri district of Uttar Pradesh State and it was found in the Sugarcane crop (672.3mm). Apart from sunshine and temperature, other climatic factors like wind velocity and humidity also influence the crop water need. By using the crop water requirement of Sugarcane crop, water demand has been calculated for Sugarcane Lakhimpur Kheri district of Uttar Pradesh State, which is shown in Table 5 and 6 and Figure 4 and 5. The water demand for Sugarcane crop will help in water management as well as in the irrigation scheduling in the study area.

This study will help in the calculation of net irrigation water requirement and understanding the behaviour of weather parameter on reference evapotranspiration (Fig. 6 and Table 7). The results clearly show that the crop water requirement during the summer period is very high as compared to the other periods. The results of this study may help in planning of efficient water management and ultimately in increasing the efficiency of available water.

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