Jurnal Kejuruteraan 35(5) 2023: 1119-1126
https://doi.org/10.17576/jkukm-2023-35(5)-12

Determination of Water Requirements for Major Crops in Sindh Using Cropwat Model

Ateeque Rehman[a], Ashfaque Ahmed Memon[a], Shafi Muhammad Kori[a] & Asadullah Sarki[b*]

[a]*Department of Civil Engineering, Mehran University of Engineering and Technology Jamshoro, Sindh, Pakistan*

[b]*Sindh Agriculture University, Tando Jam, Pakistan*

**Corresponding author: raja.sarki@gmail.com*

Received 16 February 2023, Received in revised form 15 March 2023
Accepted 15 April 2023, Available online 30 September 2023

ABSTRACT

Due to population growth and increasing urbanization trends, there is a shortage of water around the world. Irrigation systems are critical for increasing crop output and ensuring food security. Desertification caused by humans and water shortages have further exacerbated the world's regular water scarcity, putting a significant impact on food production. Water scarcity and rising food demands necessitate greater efficiency in water use, both in rain-fed and irrigated agriculture. Hence, it is the most demanding requirement for the farming community to use some type of irrigation planning to conserve the limited water resources. The purpose of this study is to calculate crop water requirements and irrigation scheduling for some major crops in Sindh using the CROPWAT model developed by FAO of United Nations. In this regard, selection from among the major crops cultivated in the Sindh province of Pakistan was made in such a way at least one crop from each category be included in this research. Accordingly, Wheat as Rabi, Rice as Kharif, Sugarcane as Perineal and Chili and Rape-seed Mustard as Cash Crops were selected. CROPWAT model calculates crop water requirements and irrigation scheduling from existing or new climatic- and crop-information. The Input crop data for CROPWAT software was obtained from various online resources and published information, whereas, climatic data incorporated in the CLIMWAT tool attached with CROPWAT was utilized. In addition, the software used average rainfall data of the particular years for each crop observed at DRIP Tandojam metrological station. The results of water requirements for the crops were obtained through CROPWAT model are: Wheat (352.1 mm); Rice (1662.5 mm); Sugarcane (2184.5 mm); Chili (714.4 mm); and Rape-seed Mustard (475.6 mm), while those by lysimeter were: Wheat (415 mm); Rice (1633 mm); Sugarcane 2150 mm); Chili (808.9 mm); and Rape-seed mustard (424.87 mm). These results delineate that there is decrease in crop water requirement of Wheat, Rice, Sugarcane and Chili to the tune of 15%, 1.5%, 11.6% and 1.7%, respectively, whereas an increase of 12% for Rape-seed mustard.

Keywords: Crop water requirement; irrigation requirement; irrigation scheduling; CROPWAT Model

INTRODUCTION

In many countries, water shortages are emerging, including in Pakistan, and water for agriculture is becoming scarce due to the growing demand for fresh water as a consequence of population growth.

In South Asia, Pakistan lies between 24° to 37° Northern latitude and 61° to 75° Eastern longitude. The average annual rainfall is 495 mm, most of which falls during the monsoon season. The country's total population is around 173.2 million, with nearly 64 percent of the population living in rural areas, where agriculture and allied industries are still the primary source of income (FAO 2010). Sindh has a total land area of around 14.09 million hectares, of which 5.18 million hectares (37 percent) are cultivated (Agriculture Statistics 2013-14). The summer season (Kharif), which begins in April-May and finishes in October-November, and the winter season (Rabi), which begins in October-November and ends in April-May, are the two major crop seasons in Pakistan. The main Rabi crops are wheat, gram, and barley, while main Kharif crops are corn, paddy, cotton, and maize.

The river Indus and its tributaries are the vital sources of surface water in the Indus Basin Irrigation System (IBIS) of Pakistan. The Indus River's total average annual flow is 146-million-acre feet (MAF), from which only 106 MAF is diverted to canals (WAPDA 2007). Pakistan receives around 50-80% of the overall annual flow of rivers from snow or glacial melting, while the remaining are collected from the monsoon rains. Approximately 35 MAF flows towards the coast, 36 million-acre-feet are lost as losses of transmission, including infiltration, evaporation, seepage, and spills, then 3 MAF is lost as .(transmission losses in rivers (WAPDA 2007

In Pakistan, where irrigation is concerned, water resources are managed inefficiently. Previously, because of the abundance of water with relatively mild rainfall levels, this issue was not a major problem. Though, because of the recent shortage water scarcity, low amounts of precipitation, and a reduction of discharges in major canals, there appears to be a necessity to modernize the irrigation systems. Crop water requirements (CWRs) and irrigation scheduling are required to keep track of irrigation demand. Scientists can test CWR, evapotranspiration of crops, and irrigation scheduling using software modelling tools like AQUACROP and CROPWAT 8.0. The Food and Agriculture Organization (FAO) created these computer software applications to assist irrigation engineers and agronomists in doing routine calculations for irrigation water studies and, more specifically, for the management and design of irrigation schemes. Crop water requirements are influenced by a variety of factors, including agro-climatic conditions, soil type, crop type, soil structure and textural conditions, and, to some extent, cultural practices.

The criteria for irrigation water and the scheduling of irrigation for certain representative chosen crops for each crop season in Sindh is determined using the CROPWAT model in the current study: wheat for the Rabi season; paddy for the Kharif season; sugarcane as a perennial crop; chilly, rape-seed Mustard and sunflower as cash crops.

MATERIALS AND METHODS

THE STUDY AREA

The district Hyderabad, Sindh, Pakistan is chosen as the study area. The province of Sindh consists of an area of 140,900 sq km between latitude 23-29 ° N and longitude 67-71 ° E. With the exception of the Arabian Sea in the southwest, the state is largely surrounded by land in all directions. It has borders in south with Rann of Kachh, in the east by Rajasthan, in the northeast by the province of the geographic region, and by Balochistan in the north and west. The barren Kirthar Mountains are in the extreme west; and the Great Indian Desert on the east partly called the Thar Desert.

Agriculture of this region depends primarily on the water supplied by the river. The Sindh province falls within the subtropical region, with hot summer and cold winter. The maximum temperature from May to August is 46 °C, and the minimum temperature from December to January is 2 °C.

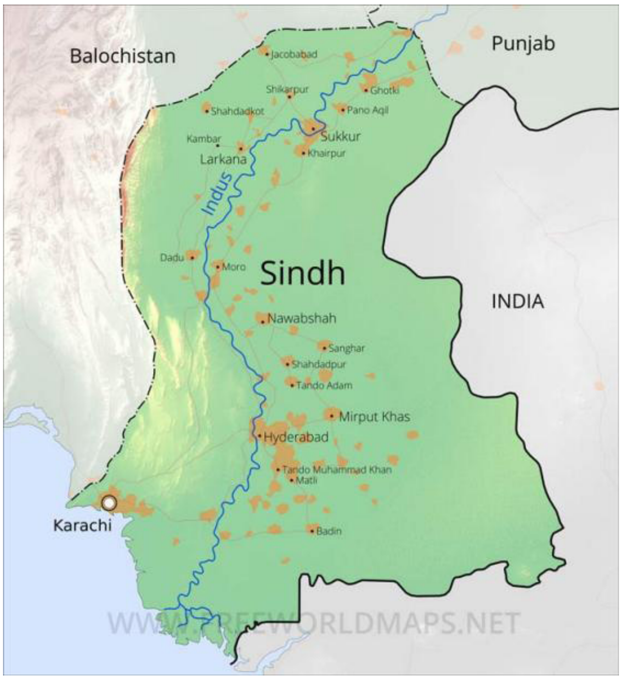

FIGURE 1. The Province of Sindh and its adjacent borders (Courtesy: Quora.com)

ESTIMATION OF WATER REQUIREMENT

In general, the crop water requirements are determined from the interrelations of the ET, the form of soil, the bulk density of the soil, the unit of volume and the permanent wilt point of soil, and effective root zone of the project site. The Penman-Monteith method was found to be the most accurate and consistent in all climatic conditions on both a monthly and daily basis by the Irrigation and Drainage Council of Environmental and Water Resources, based on the recommendation of the American Society of Civil Engineers (ASCE) Task committee, which was obtained after evaluating 19 estimating methods and carefully screened lysimeter data from 11 worldwide locations of different climates ranging from arid to humid conditions. Hence, Penman-Monteith equation, as illustrated below, as used in the CROPWAT model for the calculation of evapotranspiration of crop (ETc), will be used to estimate crop evapotranspiration.

$$ETc = Kc\ (ETo) \quad \text{(i)}$$

Where
ETc = Evapotranspiration of Crop
ETo = Reference Crop Evapotranspiration
Kc = Crop coefficient

CROPWAT MODEL DESCRIPTION

CROPWAT is a computer decision-support program that uses data from climate, crop, rain, and soil to calculate reference evapotranspiration (ETo), crop water requirement (CWR), irrigation scheduling, and irrigation water requirement (IR) using a set of equations developed by .(the Food and Agriculture Organization (FAO
The software provides detailed information on different crop characteristics, local environment and characteristics of soil, which helps to establish irrigation schedules and to calculate the water supply scheme under irrigated and rain conditions for different crop patterns. The Penman-Monteith model is utilized. Information of the environmental conditions, such as the min- and max- temperature, mean relative humidity (percent), wind velocity (km/hr), hours of sunshine (h), rainfall data (mm), and measurements used to measure effective rainfall (mm) are .utilized
The basic function of software is to compute the crop water requirements, reference evapotranspiration, and irrigation of crops and systems. The consumer can model varied water supply conditions through a daily water balance, and estimate yield reductions and efficiencies in ir-.rigation and rainfall

The FAO Penman-Monteith method relies on the measurement of reference evapotranspiration (ETo). The input file contains temperature (maximum and minimum), humidity, sunshine, and wind speeds monthly and ten daily. From ETo, crop water requirements (ET crops) are calculated over the growing season and crop evaporation rate estimates, expressed as crop coefficients (Kc), are assisted by well established procedures in accordance with the following equation:

$$ET\ crop = Kc \times ETo \quad \text{(ii)}$$

Updated values for crop coefficients have been provided by the FAO. Crop irrigation needs are determined by forecasts of successful rain-fall, assuming the best water system. Inputs on the cropping pattern will make it possible to estimate the needs of the subject irrigation.

The CROPWAT model will measure the root region's daily water balance. Root zone depletion at the end of the day is concerned with the following equation:

$$Dr_i = Dr_{i-1}(P_i - Ro_i) - l_i - CR_i) + ET_{ci} + D_{pi}$$

Where
Dr_i= depletion of the root region at the end of the day, i[th] (mm)
Dr_{i-1}= Water content at the end of the preceding day in the root zone (mm)
P_i= rainfall on the day i (mm)
Ro_i= surface soil runoff on day i (mm)
l_i= net depth of irrigation on day i which infiltrates the soil (mm)
CR_i= capillary rise from the groundwater TABLE on day i (mm)
ET_{ci}= crop evapotranspiration on day i (mm)
D_{pi}= Water wastage in the root region on the day i (mm)

SELECTED CROPS AND DATA COLLECTION

Representative crops of each season were selected for the research and wheat was selected for the Rabi season; paddy for the Kharif season; sugarcane as a perennial crop; chilly and rape-seed Mustard as cash crops.
The crop constant values (Kc) are taken from the published information of DRIP, FAO handbooks, etc. Kc values are used for annual and seasonal crops for the initial, development, middle, and late growth phases. The same Kc value will be used for the entire year in the case of .perennial crops

RESULTS AND DISCUSSION

The CROPWAT software utilizes climatic data from Pakistan, meteorological station data from Hyderabad, crop kinds, cultivation dates, and soil type (silt loamy) data for five crops. All relevant data was entered into the program, and meteorological characteristics such as ET0, effective rainfall, total irrigation requirements of crops, and their irrigation schedules were computed based on that data.

Other CROPWAT model outputs are shown in Tables and charts in the next section. The data for the five crops studied may be found in TABLE 1. TABLE 2 to TABLE 6 include climate data for each crop year in Hyderabad, Sindh.

Each TABLE shows the ET_0 values received by the CROPWAT model for various months.

It is higher in summer because of higher temperatures and the highest value was recorded in the month of May (11.19 mm).

It reduces in winter and the lowermost value was recorded in December (3.58 mm) because of lower temperatures and the annual average was (7.05 mm).

All four crops had lower ETc values at the start and end of their productive stages, and higher ETc values in the middle stages, with the exception of rapeseed Mustard, which had higher ETc values in the late stages.

The CWR is calculated using the portion of the rainfall that was effectively absorbed by the crops after losses due to surface runoff and deep percolation. The most significant aspects to consider are the amount, frequency, and intensity of rainfall. In order to design its greatest use, it is necessary to have a comprehensive grasp of these three major components.

Determination of the Crop Water Requirements

Crops require varied amounts of water demands based on their location, temperature, soil type, cultivation method, effective rain, and so on, and the total amount of water required by a crop over its life cycle is not evenly distributed. The irrigation water requirements (IRs) for the five crops under the study is in the following order according to the (mm/dec) unit:

Sugarcane (2184.5) > Rice (1662.5) > Chili (714.4) > Rape-seed Mustard (475.6) > Wheat (352.1)

TABLE 1. Data of the five selected crops for the study

					Crop Growth Period (Days)			
Crop Name	Scientific Name	Planting and Harvesting Date	Critical Depletion Fraction	Rooting Depths (cm)	Initial	Development	Mid-season	Late Season
Wheat	Triticum	10 Nov-29 Mar	0.55	30	30	40	40	30
Rice	Oryza sativa	15 June-12 oct (transplanting)	0.20	40	20	30	40	30
Sugarcane	Saccharum officinarum	10 Oct-9 Oct	0.65	100	30	60	180	95
Rape-seed Mustard	Brassica Napus	10 Nov-9 Mar	0.62	50	30	40	30	20
Chilli	Capsicum frutescens	15 Apr-1 Sept	0.60	20	30	30	40	40

TABLE 2. Climatic data used for calculating crop water requirements and irrigation schedule of Wheat (1995)

Month	Temp (^{0}C) Min	Temp (^{0}C) Max	Humidity (%)	Wind (km/day)	Sun (h)	Rad (Mj/m^2/day)	ET_o (mm/day)	Rain (mm)	Eff. Rain (mm)
January	5.6	19.6	67	131	8.5	15.6	2.55	0.0	0.0
February	7.2	23.1	63	142	9.0	18.4	3.33	0.0	0.0
March	10.2	26.3	52	211	9.1	21.0	4.72	0.0	0.0
April	17.5	32.8	58	284	9.2	23.0	6.23	0.0	0.0
May	20.2	37.7	52	451	10.0	25.0	9.16	0.0	0.0
June	23.5	36.0	67	594	10.1	25.2	8.21	0.0	0.0
July	22.9	33.0	77	553	7.0	20.4	5.82	89.5	71.6
August	22.8	33.4	75	542	8.2	21.7	6.16	0.0	0.0
September	20.0	34.0	73	454	10.0	22.8	6.32	0.0	0.0
October	16.1	31.5	65	221	9.2	19.2	4.88	0.0	0.0
November	9.7	27.2	51	151	8.6	16.1	3.67	0.0	0.0
December	7.6	21.3	71	163	7.8	14.1	2.46	0.0	0.0
Average	**15.3**	**29.7**	**64**	**324**	**8.9**	**20.2**	**5.29**	**89.5**	**71.6**

TABLE 3. Climatic data used for calculating crop water requirements and irrigation schedule of Rice (2021)

Month	Temp (^{0}C)		Humidity (%)	Wind (km/day)	Sun (h)	Rad (Mj/m^2/ day)	ET_o	Rain (mm)	Eff. Rain (mm)
	Min	Max							
January	10.9	25.2	45	190	7.5	14.5	3.62	1.0	0.8
February	13.7	29.0	43	190	8.1	17.3	4.44	4.3	3.4
March	18.9	34.7	39	233	9.0	20.8	6.41	0.2	0.2
April	23.0	39.3	36	294	8.4	21.9	8.43	4.7	3.8
May	26.3	42.4	42	467	9.7	24.5	11.19	3.8	3.0
June	28.2	40.9	53	613	8.3	22.5	10.74	9.7	7.8
July	28.0	38.4	60	570	8.0	21.9	9.00	43.3	34.6
August	27.2	37.1	62	553	7.3	20.3	8.16	46.1	36.9
September	25.9	37.4	58	467	8.4	20.5	8.06	23.3	18.6
October	22.4	37.6	43	233	9.0	18.9	6.57	6.0	4.8
November	17.0	32.5	42	156	8.1	15.5	4.43	0.5	0.4
December	12.2	26.8	48	173	8.1	14.4	3.58	3.9	3.1
Average	**21.1**	**35.1**	48	345	8.3	19.4	7.05	146.8	117.4

TABLE 4. Climatic characteristics used for calculating crop water requirements and irrigation schedule of Chili (2003)

Month	Temp (^{0}C)		Humidity (%)	Wind (km/day)	Sun (h)	Rad (Mj/m2/day)	ETo (mm/day)	Rain (mm)	Eff. Rain (mm)
	Min	Max							
January	10.5	25.0	59	124	9.0	16.2	3.30	0.0	0.0
February	12.8	27.2	57	144	8.1	17.2	3.84	0.0	0.0
March	17.8	33.1	51	218	9.1	21.0	5.71	0.0	0.0
April	23.6	39.0	38	284	10.1	24.4	8.59	0.0	0.0
May	26.2	40.4	50	463	9.1	23.6	9.91	0.0	0.0
June	29.3	38.8	63	609	8.1	22.2	9.08	0.0	0.0
July	28.0	34.1	77	492	5.1	17.6	5.74	89.5	71.6
August	27.5	34.3	74	596	8.1	21.5	6.51	0.0	0.0
September	26.3	34.6	68	433	8.2	20.2	6.63	0.0	0.0
October	19.5	36.2	43	254	9.2	19.2	6.39	0.0	0.0
November	14.4	29.1	55	138	9.1	16.7	3.85	0.0	0.0
December	11.7	25.4	56	137	8.1	14.4	3.20	0.0	0.0
Average	**20.6**	**33.1**	**58**	**323**	**8.4**	**19.5**	**6.06**	**89.5**	**71.6**

TABLE 5. Climatic characteristics used for calculating crop water requirements and irrigation schedule of Rape-seed mustard (2003)

Month	Temp (^{0}C)		Humidity (%)	Wind (km/day)	Sun (h)	Rad (Mj/m^2/ day)	ET_o (mm/ day)	Rain (mm)	Eff. Rain (mm)
	Min	Max							
January	11.0	23.8	45	124	9.2	16.4	3.60	0.0	0.0
February	14.1	25.9	43	144	8.5	17.7	4.19	60.0	48.0
March	17.0	33.0	39	218	9.9	22.1	6.27	0.0	0.0
April	24.1	36.4	36	284	11.2	26.0	8.46	0.0	0.0
May	28.1	42.3	42	463	10.8	26.2	11.46	0.0	0.0
June	28.4	38.4	53	609	11.1	26.7	10.74	3.5	2.8
July	29.1	35.5	60	492	6.5	19.7	8.22	89.5	71.6

continue ...

... cont.

August	27.6	34.3	62	596	9.2	23.2	8.05	215.0	172.0
September	26.3	35.4	58	433	9.1	21.5	7.83	56.0	44.8
October	23.5	35.6	43	254	10.2	20.5	6.51	0.0	0.0
November	17.7	31.1	42	138	9.0	16.6	4.39	0.0	0.0
December	11.8	25.9	48	137	9.3	15.7	3.56	0.0	0.0
Average	21.6	33.1	48	323	9.5	21.0	6.94	334.5	267.6

TABLE 6. Climatic characteristics used for calculating crop water requirements and irrigation schedule of Sugarcane (1995)

Month	Temp (^{0}C)		Humidity (%)	Wind (km/day)	Sun (h)	Rad (Mj/m2/day)	ETo (mm/day)	Rain (mm)	Eff. Rain (mm)
	Min	Max							
January	5.6	19.6	67	131	8.5	15.6	2.55	0.0	0.0
February	7.2	23.1	63	142	9.0	18.4	3.33	0.0	0.0
March	10.2	26.3	52	211	9.1	21.0	4.72	0.0	0.0
April	17.5	32.8	58	284	9.2	23.0	6.23	0.0	0.0
May	20.2	37.7	52	451	10.0	25.0	9.16	0.0	0.0
June	23.5	36.0	67	594	10.1	25.2	8.21	0.0	0.0
July	22.9	33.0	77	553	7.0	20.4	5.82	89.5	71.6
August	22.8	33.4	75	542	8.2	21.7	6.16	0.0	0.0
September	20.0	34.0	73	454	10.0	22.8	6.32	0.0	0.0
October	16.1	31.5	65	221	9.2	19.2	4.88	0.0	0.0
November	9.7	27.2	51	151	8.6	16.1	3.67	0.0	0.0
December	7.6	21.3	71	163	7.8	14.1	2.46	0.0	0.0
Average	**15.3**	**29.7**	**64**	**324**	**8.9**	**20.2**	**5.29**	**89.5**	**71.6**

TABLE 7. Crop Water Requirements for Wheat

Month	Decade	No of days in decade	Stage	Kc (Coeff)	ETc (mm/day)	Etc (mm/dec)	Eff. Rain (mm/dec)	Irr. Req. (mm/dec)
Nov	1	1	Init	0.30	1.22	1.22	0.0	1.2
Nov	2	10	Init	0.30	1.10	11.00	0.0	11.0
Nov	3	10	Init	0.30	0.98	9.80	0.0	9.8
Dec	1	10	Dev	0.30	0.84	8.40	0.0	8.4
Dec	2	10	Dev	0.44	1.04	10.40	0.0	10.4
Dec	3	11	Dev	0.67	1.63	17.93	0.0	17.9
Jan	1	10	Dev	0.90	2.28	22.80	0.0	22.8
Jan	2	10	Mid	1.12	2.85	28.50	0.0	28.5
Jan	3	11	Mid	1.18	3.31	36.41	0.0	36.4
Feb	1	10	Mid	1.18	3.62	36.20	0.0	36.2
Feb	2	10	Mid	1.18	3.93	39.30	0.0	39.3
Feb	3	8	Late	1.17	4.46	35.68	0.0	35.7
Mar	1	10	Late	0.99	4.20	42.00	0.0	42.0
Mar	2	10	Late	0.70	3.28	32.80	0.0	32.8
Mar	3	9	Late	0.42	2.18	19.62	0.0	19.6
Total =						352.1	0.0	352.1

TABLE 8. Crop Water requirements for Chili

Month	Decade	Days in decade	Stage	Kc (Coeff)	ETc (mm/day)	Etc (mm/dec)	Eff: Rain (mm/dec)	Irr. Req. (mm/dec)
Apr	2	6	Init	0.60	5.22	31.3	0.0	31.3
Apr	3	10	Init	0.60	5.46	54.6	0.0	54.6
May	1	10	Init	0.60	5.76	57.6	0.0	57.6
May	2	10	Dev	0.61	6.21	62.1	0.0	62.1
May	3	11	Dev	0.68	6.64	73.0	0.0	73.0
Jun	1	10	Dev	0.75	7.16	71.6	0.0	71.6
Jun	2	10	Mid	0.80	7.48	74.8	0.0	74.8
Jun	3	10	Mid	0.80	6.53	65.3	0.1	65.2
Jul	1	10	Mid	0.80	5.22	52.2	20.4	31.7
Jul	2	10	Mid	0.80	4.19	41.9	30.7	11.3
Jul	3	11	Late	0.79	4.49	49.3	20.4	28.9
Aug	1	10	Late	0.77	4.79	47.9	0.1	47.8
Aug	2	10	Late	0.74	4.83	48.3	0.0	48.3
Aug	3	11	Late	0.71	4.69	51.5	0.0	51.5
Sep	1	1	Late	0.70	4.62	4.6	0.0	4.6
			Total =			786.2	71.8	714.4

NET IRRIGATION REQUIREMENT (NIR) AND IRRIGATION SCHEDULE

Irrigation management in the field is improved by understanding crop irrigation water requirements and irrigation time plans. Irrigation water management is the process of efficiently regulating the amount, pace, and timing of irrigation. Tables 2 to 7 shows the crop water requirements for wheat, rice, sugarcane, chili, and rapeseed crops in the field.

The Net Irrigation Requirement (NIR) is the amount of water required for crop development, or the amount of water required to achieve the soil's field capacity. Cropping patterns and climate have an impact on NIR. To transform the NIR into a Gross Irrigation need, data on irrigation efficiency is also necessary (GIR). During the application and transfer of irrigation water, various losses such as runoff, evaporation, seepage, and percolation occur. Leaching, ground preparation, and transplanting all need a certain quantity of water. As a result, CWR includes ET, as well as losses incurred during the application of water required for these objectives, as shown in Equation (iv).

$$NIR = ETc - Eff.\ rain \qquad (iv)$$

This computation aids farmers in deciding which crops to produce based on water availability.

CONCLUSION AND SUGGESTIONS

CONCLUSIONS

Based on the above results of crop water requirements and irrigation schedules computed by the software following conclusions can be made:

1. The use of FAO CROPWAT model provided precise results pertaining to crop water requirements and irrigation schedules specific to the selected study area based on the seasonal and meteorological features of the area

2. According to the model results 15%, 1.5%, 11.6% and 1.7% less water is required compared to those determined by Lysimeter method for Wheat, Sugarcane and Rice crops, respectively. Whereas 12% increase in water requirement for Rape-seed mustard crop only.

3. Hence, better management strategies can be framed using precise results of the crop water requirements of the major crops under consideration

4. Scientific technologies like CROPWAT can accurately measure CWRs and offer crop patterns and crop rotations that farmers can practice.

SUGGESTIONS

It is further suggested that:

1. The results of this study may be utilized by water resource planners for long term planning, allowing them save some water while achieving CWRs, and by farmers when determining how much and how often to irrigate the crops under investigation.

2. A strategy should be prepared to estimate the CWRs for the remaining crops cultivated all over Pakistan.

A strategy like this might be used as the foundation for agricultural operations. Practical testing, on the other hand, are required to certify the usage of these software tools.

ACKNOWLEDGEMENT

The authors would like to thank Mehran University of Engineering & Technology and Sindh Agriculture University, Pakistan for their support throughout the research work.

DECLARATION OF COMPETING INTEREST

None

REFERENCES

Awais. 2016. Modeling the water and nitrogen productivity of sunflower using OILCROP-SUN model in Pakistan. *Field Crops Research* 205: 67-77. 10.1016/j.fcr.2017.01.013.

B. Mason, Marti Rufi-Salis, Felipe Parada, Xavier Gabarrell & Cyndee Gruden. 2019. Intelligent urban irrigation systems: Saving water and maintaining crop yields. *Journal of Agricultural Water Management* 226.C.

B.A George, S.A Shende, N.S Raghuwanshi. 2000. Development and testing of an irrigation scheduling model. *Agricultural Water Management* 46(2): 121-136.

Bahadur, A., Bazai, Z. A., Khair, S. M., F., & Bokhari, S. M. A. 2021. Modeling crop water requirement of grapes by using FAO-CROPWAT model in Quetta district, Balochistan. *Journal of Agro Meteorology* 23(4): 468-470.

CROPWAT for Windows: User Guide. 2001. University of Southampton, Southampton, UK.

CROPWAT Software, FAO, Land and Water Division.

CROPWAT Software, FAO, Land and Water Division. 2018. http://www.fao.org/landwater/databases-and-software/cropwat/en/

English, Zhe Gu, Zhiming Qi, Gary Feng & Annandale, Singh. 2017. Development of an irrigation scheduling software based on model predicted crop water stress. *Computers and Electronics in Agriculture* 143: 208-221.

Ewaid, S. H., Abed, S. A. & Al-Ansari, N. 2019. Crop water requirements and irrigation schedules for some major crops in Southern Iraq. *Water* 11(4): 756. https://doi.org/10.3390/w11040756.

Jensen, M.E., R.D. Burman and R.G. Allen. 2016. *Handbook of Evaporation and Irrigation Water Requirements*. American Society of Civil Engineers.

Kang Shaozhong, B. Guc, T. Dua, and J. Zhang. 2003. Crop coefficient and ratio of transpiration to evapotranspiration of winter wheat and maize in a semi-humid region. *Journal of Water Management* 59(3): 239-254.

Levidow, Daniele Z., R. Maia, E. Vivas, Mladen T., A. Scardigno. 2014. Improving water-efficient irrigation: Prospects and difficulties of innovative practices. *Journal of Agricultural Water Management* 146: 84-94.

M. Nazeer. 2009. Simulation of Maize crop under irrigated and rainfed conditions with CROPWAT model. *Asian Research Publishing Network ARPN, Journal of Agriculture and Biological Science* 4(2): 68-73.

Michael, A. M. 2009. *Irrigation Theory and Practice*. 2nd edition. Vikas Publishing House Pvt Limited.

National Engineering Handbook, Part 652. 2008. Irrigation guide. United States Department of Agriculture (USDA).

Rao, Muhammad & Ashraf, M. & Bhatti, Ahmad & Abdul Salam, Hafiz & Gul, Nazar. 2016. *Water Requirements of Major Crops in Sindh*. Pakistan Council of Research in Water Resources (PCRWR).

Stancalie, Adriana Marica, Leonidas Toulios & Doorenbos, Pruitt. 2010. Using earth observation data and CROPWAT model to estimate the actual crop evapotranspiration. *Physics and Chemistry of The Earth - PHYS CHEM EARTH* 35: 25-30. 10.1016/j.pce.2010.03.013.