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Determination of Crop water Requirement and Irrigation Scheduling for Major Crops of Surendranagar, Gujarat Using CROPWAT 8.0

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Abstract: Due to the growing need for water for uses such as hydropower, farming, and drinking purpose among others, water is becoming an endangered asset. Water is increasingly needed for a variety of reasons as the population grows. On the contrary, the accessibility of water resources is limited. To determine crop water requirement for any crop and evaluate irrigation scheduling for effective water management, crop coefficients and reference crop evapotranspiration must be calculated. The purpose of this research is to determine crop water requirement of Cotton, Wheat and Sesame for Surendranagar Region and Prepare Irrigation Scheduling using the FAO-56 Penman-Monteith Method using FAO CROPWAT 8.0 Software. Meteorological data for Surendranagar region such as maximum and minimum temperatures, mean relative humidity, sunshine hours, and wind speed, are obtained from Wadhwan taluka of Surendranagar used to calculate reference crop evapotranspiration. Crop water requirement for Cotton using CROPWAT 8.0 model is obtained 876.3 mm/dec Crop water Requirement for Wheat is obtained 543.9 mm/dec and Crop water Requirement for Sesame is obtained 529.6 mm/dec This finding may be helpful for agricultural planning and effective irrigation control in the growing of cotton, Wheat and Sesame.
Keywords: CROPWAT 8.0, Irrigation scheduling, Cropwater Requirement, Evapotranspiration, FAO-56 Penman-Monteith

I. INTRODUCTION

Water is becoming increasingly valuable as an agricultural activities' demand for it increases. Due to population increase, rapid urbanisation, and irrigation operations, the productivity of agriculture is a major issue across the world, particularly in emerging nations, and water demand is steadily rising as a result. Some of the causes of this are inefficient water management and the misuse of water resources. Due to the diverse variety of geological and climatic conditions, Indian agriculture is complex and diversified, with both irrigated and dry land regions, and is able to generate most of the food and agricultural goods in the world. To efficiently manage natural resources for planning reasons, stop environmental deterioration, and increase agricultural production for the nation's food and nutritional security given its continually expanding population. Depending on the crop type, different crops have different water requirements. The crop's water requirement is determined by how much water is required to make up for the cultivated field's evaporation loss. On the other hand, the amount of irrigation water needed for crop production is the amount of water that must be utilised in addition to precipitation to fulfil the plant's Evapotranspiration needs without significantly reducing output. The type of crop, its stage of growth, and the surrounding circumstances all have an impact on how much water is needed. Under the same weather conditions, different crops have different water usage requirements. In order to calculate crop evapotranspiration (ETc), also known as consumptive usage, at various growth stages of the crop using the waterbalance technique, the crop coefficients relevant to the individual crops are employed together with the values of reference evapotranspiration (ETo). When soil water is at field capacity, crops will transpire water the fastest.

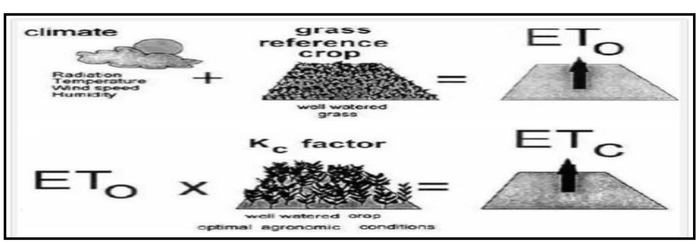

Figure 1 : The relationship between Reference Evapotranspiration (ETo) and standard Crop Evapotranspiration (ETc)
(Source: Allen, R.G. et al (1998) Crop evapotranspiration: guidelines for computing crop water requirements, FAO Irrigation and Drainage Paper 56.)

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The crop evapotranspiration (ETc) and the reference evapotranspiration (ETo) ratio is known as the crop factor,
Kc. Kc = ETc / ETo ……. (1)
Where, ETo = Reference evapotranspiration (mm/day)
ETc = Crop evapotranspiration (mm/day)
Both ETo crop and ETc are expressed in the same unit (mm per day)

The kind of crop, the stage of the crop's growth, and the climate are the key determinants of the crop coefficient, Kc. Crop traits, dates of (trans)planting, growth stage, and meteorological circumstances all affect the crop coefficient, which is dynamic in nature. With the help of irrigation and rainwater on the field, we may use model CROPWAT 8.0 to determine the crop's water needs throughout the growing season. The Penman-Monteith Equation of FAO is the basis of this application to determine ETo , which will also be useful for increasing crop production. This research aims to estimate the crop water requirement for the various crops in the Kutch district using CROPWAT 8.0.

II. STUDY AREA

Figure 2.1 : Map of Study Area (Surendranagar)

Surendranagar district is located in Gujarat's western Saurashtra area. The district is situated between 22.7115° N, Latitude 71.6733° E Longitude. It is the seventh biggest district in the state with a geographical area of 10489 square kilometres, or about 5.35% of the entire state. The region is bordered by the districts of Ran of Kutchch in the northwest, Patan in the north, Mahesana and Ahmedabad in the east and south-east, Botad in the south, and Rajkot in the west Surendranagar district falls in agro-climatic Zone-VI.

III.METHODOLOGY

A. Reference Crop Evapotranspiration

Apart from the water availability in the top soil, the evaporation from a cropped soil is mostly governed by the percentage of the solar radiation reaching the soil surface. Evaporation and transpiration occur concurrently and there is no easy method to discriminate between the two processes. Over the course of the growing season, this percentage falls as the crop matures and its canopy gradually covers more ground space. When the crop is small, soil evaporation accounts for the majority of water loss, but once the crop is mature and completely covers the soil, transpiration takes over as the primary process. According to the leaf area per unit soil surface in the figure below, the partitioning of evapotranspiration into evaporation and transpiration is shown on the graph. Nearly all of the energy transfer (ET) occurs during sowing, whereas more than 90% of ET occurs during full crop cover.

B. Penman-Monteith Method

In 1948 Penman developed an equation to calculate the evaporation from an open water surface using normal climatological observations of daylight, temperature, humidity, and wind speed by combining the energy balance with the mass transfer technique. By adding resistance variables, this so-called combination approach was further refined by other researchers and expanded to cropped surfaces. The equation may be understood as the greatest amount of water that might be absorbed by the system's surface and air owing to evapotranspiration caused by the system's solar and wind energy. Aerodynamic resistance and surface resistance variables are distinguished by the resistance nomenclature. The bulk surface resistance parameter, which works in series with the aerodynamic resistance, is a common combination of the surface resistance parameters. The resistance to vapour movement via stomata openings, the whole leaf surface, and the soil characterises the surface resistance. The term "aerodynamic resistance" refers to the upward resistance caused by vegetation and includes airflow friction across vegetative surfaces. Good correlations may be found between observed and computed evapotranspiration rates, especially for a uniform grass reference surface, even if the exchange mechanism in a plant layer is too complicated to be fully explained by the two resistance factors.

The Penman-Monteith form of the combination equation,

$$\mathrm{ET_o} = \frac{0.408\Delta\left(R_\mathrm{n} - G\right) + \gamma\frac{900}{T+273}U_2(e_\mathrm{s} - e_\mathrm{a})}{\Delta + \gamma(1 + 0.34U_2)},$$

Where,
ETo = reference evapotranspiration [mm day-1],
Rn =net radiation at the crop surface [MJ m-2 day-1]
G = soil heat flux density [MJ m-2 day-1]
T =mean daily air temperature at 2 m height [°C],
U2 = wind speed at 2 m height [m s-1],
es = saturation vapour pressure [kPa],
ea = actual vapour pressure [kPa],
es – ea = saturation vapour pressure deficit [kPa]
Δ = slope vapour pressure curve [kPa 0C-1]
γ = psychrometric constant [kPa 0C-1]

C. Crop Coefficient

The influence of traits that set one crop apart from the Reference crop is integrated by the Crop coefficient (kc). The reference evapotranspiration, ETo (millimetres per day), can be used to determine ETc by multiplying it by the dimensionless crop coefficient, Kc. Since ground cover, crop height, and leaf area change as the crop matures, the crop coefficient is primarily influenced by crop type, with only minor influences from the climate and soil evaporation. For the early stage, mid-season stage, and harvest stage, CROPWAT 8.0 demands k values. Interpolated k values are those from the development and late season stages.

D. Crop Evapotranspiration

The difference in evapotranspiration between the reference grass surface and the cropped grass surface is expressed by the coefficient kc, which is multiplied by ETo to compute crop evapotranspiration. The difference can be split into two variables that each describe the difference in transpiration and evaporation between the two surfaces, or it can be integrated into a single coefficient. The objective of the calculation, the level of precision necessary, the climatic data available, and the time step at which the calculation is performed all influence the technique that is used.

E. Calculation Procedure for crop Evapotranspiration (ETc)

Identifying, measuring, and choosing the appropriate kc coefficients for the various crop growth phases. adjusting the chosen k coefficient for the stage's climate or wetness occurrence rates. the crop coefficient curve's construction. figuring out ETc as the multiply of of ETo and Kc.

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F. Crop Water Requirement

Crop water need is the quantity of water needed to make up for the evapotranspiration loss from the planted fields. Crop water demand refers to the amount of water that must be provided, whereas crop evapotranspiration refers to the amount of water lost by evapotranspiration, even if the values for Crop evapotranspiration under standard condition (ETc) and crop water requirement are similar.

G. Irrigation Scheduling

When rainfall is insufficient, irrigation scheduling is necessary to ensure that the appropriate amount of water is applied via irrigation at the appropriate time and rate. The crop evapotranspiration under standard circumstances (ETc) and the effective rainfall contributions over the same time step are stated differently in the irrigation demand, which is determined over a certain amount of time and expressed in millimetres (mm). The percentage of the crop's water demands that must be partially met by irrigation contributions in order to ensure the crop's ideal growth circumstances is known as the irrigation need.

IV. DATA COLLECTION

A. Meteorological Data

Meteorological data of year 2021 and 2022 year was collected from State Water Data Centre located in Gandhinagar and NASA Power Web-portal. Latitude, longitude, and altitude of the station, maximum and minimum relative humidity (%), wind speed (km/day), and sunlight hours are the meteorological characteristics that were gathered and averaged before being utilised in the computation of ETo. The programme that will produce the effective rainfall data is fed additional rainfall data that was obtained from the same station.

B. Crop Data

Cotton, Wheat and Sesame are the major crops farmed in this area. CROPWAT needs crop data from FAO Irrigation and Drainage Paper 56, including crop coefficient, Kc values (initial, mid, and late development stages), rooting depth, and duration of plant growth stages, critical depletion, and yield response factor. Dates for sowing and harvesting were determined using information from nearby agricultural enterprises as a guide.

Crop Data

Sr.No	Crop	Sowing Date	Crop Coefficient			Duration	Crop Development Period (In Days)			
			Initial	Mid	Final		Initial	Develop ment	Mid Season	Late Season
1.	Cotton	25-June	0.35	1.15-1.20	0.70-0.50	180	30	50	55	45
2.	Wheat	25-Nov	0.30	1.15	0.30	130	30	30	40	30
3.	Sesame	25-June	0.35	1.10	0.25	110	20	30	40	20

Source : FAO-56

Table 4.1 Crop Data of Study Area (Surendranagar)

C. Soil Data

As per the observation and talking to farmers of this region the soil type in this area is Red(sandy) and Medium Black Soil. The software requires a few generic soil data points, including total soil moisture that is now available, the maximum rate of rain penetration, the maximum depth of roots, starting soil moisture depletion, and initial soil moisture that is currently accessible. This data was taken from FAO Manual 56.

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V. RESULTS AND DISCUSSION

A. Cropwater Requirement For Cotton, Wheat And Sesame

After entering following climate data of region in CROPWAT 8.0 model. Results of Cropwater requirement and Irrigation requirement for the selected crops are obtained as below.

MONTHLY ETO PENMAN-MONTEITH DATA
(File: C:\ProgramData\CROPWAT\data\climate\Surendranagar.PEM)

Country: INDIA   Station: SURENDRANAGAR-DIST
Altitude: 71 m.   Latitude: 22.71 °N   Longitude: 71.67 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m²/day	ETo mm/day
January	10.8	28.8	45	168	10.3	18.6	4.12
February	14.7	33.7	34	158	11.5	22.3	5.21
March	20.6	39.8	26	203	12.3	26.1	7.63
April	24.4	42.9	29	251	12.5	28.2	9.53
May	26.8	42.6	43	344	13.2	29.8	10.64
June	27.3	39.2	57	347	13.5	30.2	9.34
July	25.8	34.2	76	348	13.4	30.0	7.11
August	24.7	33.9	75	271	12.6	28.4	6.58
September	24.5	32.2	82	216	12.6	27.0	5.64
October	20.9	32.9	69	135	11.6	23.1	4.93
November	16.2	31.7	61	136	11.1	19.9	4.15
December	13.7	32.3	56	157	10.6	18.1	4.11
Average	20.9	35.4	54	228	12.1	25.1	6.58

Table 5.1: Climate Data of Wadhwan-Surendranagar

B. Crop Water Requirement for Cotton Wheat and Sesame

Following are the Results of Crop water requirement for Cotton , Sesame and Wheat crop for their planting dates during their entire crop period of its Initial, Development, Mid Season and Late Season stage.

Sr.No	**Name of Crop**	**Planting Date**	**Crop Water Requirement (in mm/dec)**	**Irrigation requirement (in mm/dec)**
1.	Cotton	25-June	876.3 mm/dec	512.6 mm/dec
2.	Sesame	25-June	529.6 mm/dec	152.2 mm/dec
3.	Wheat	25-November	543.9 mm/dec	538.2 mm/dec

Table 5.3 Cropwater requirement and Irrigation requirement for Cotton, Sesame and Wheat

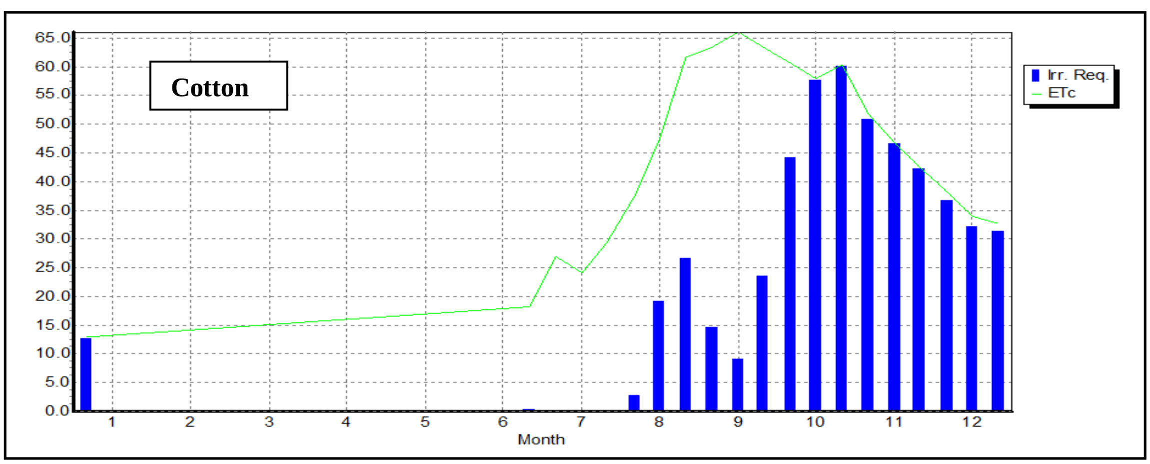

Table 5.4: Chart of Crop water requirement and Irrigation Requirement for Cotton

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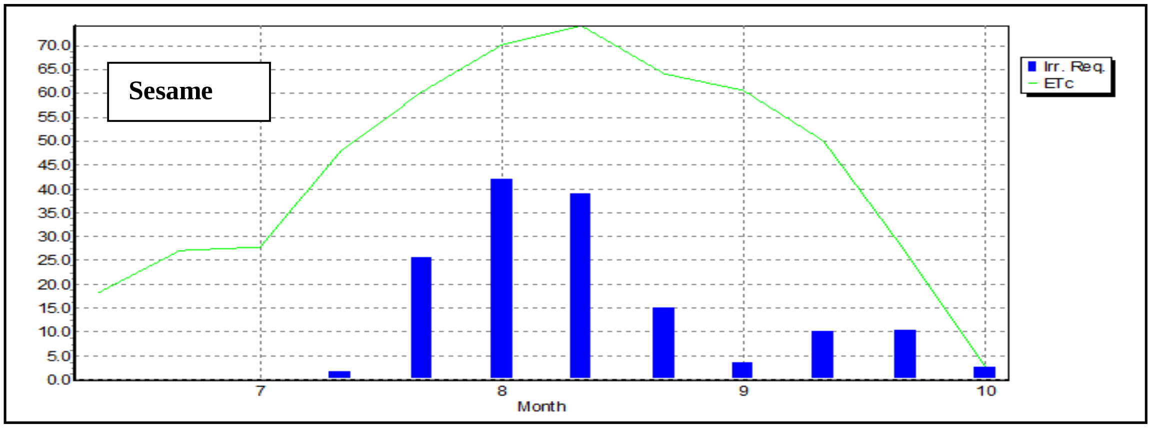

Table 5.5: Chart of Crop water requirement and Irrigation Requirement for Sesame

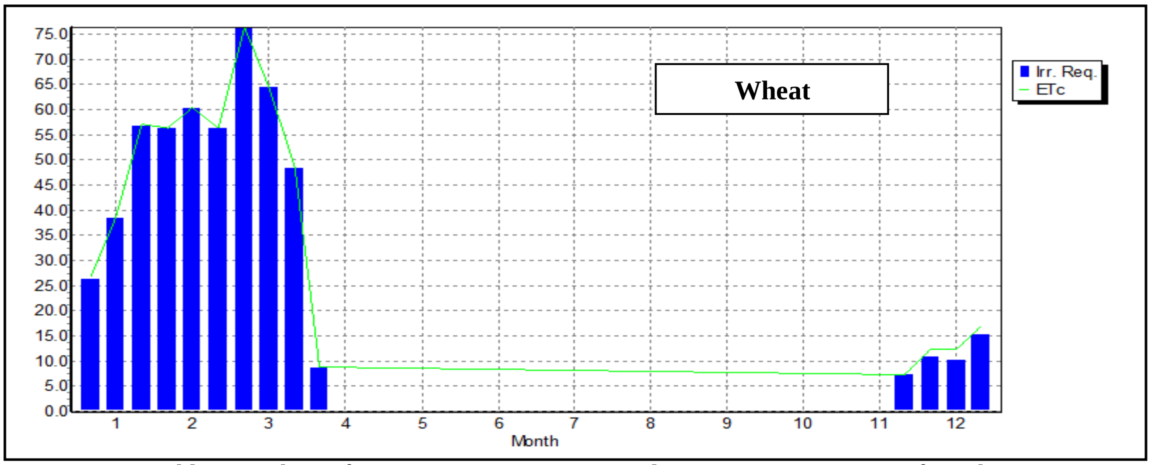

Table 5.6: Chart of Crop water requirement and Irrigation Requirement for Wheat

C. Irrigation Scheduling For Cotton , Sesame and Wheat

The main goals of irrigation scheduling are to choose when, how, and how much to irrigate. In order to maintain the water level in the root zone within the limits of readily available water (RAW), Major goal of Irrigation scheduling is to maintain an optimal water supply.

Crop irrigation schedule

ETo station SURENDRANAGAR-DI: Crop COTTON S Planting date 25/06 Yield red. 0.0 %
Rain station SURENDRANAGAR Soil RED SANDY Harvest date 05/01

Table format: Irrigation schedule / Daily soil moisture balance

Timing: Irrigate at critical depletion
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
8 Oct	106	Mid	0.0	1.00	100	66	92.3	0.0	0.0	131.8	0.14
24 Oct	122	Mid	0.0	1.00	100	66	91.9	0.0	0.0	131.3	0.95
11 Nov	140	Mid	0.0	1.00	100	67	93.9	0.0	0.0	134.2	0.86
7 Dec	166	End	0.7	1.00	100	78	109.9	0.0	0.0	156.9	0.70
5 Jan	End	End	0.0	1.00	0	61					

Totals

Total gross irrigation	554.2	mm	Total rainfall	619.3	mm
Total net irrigation	388.0	mm	Effective rainfall	450.2	mm
Total irrigation losses	0.0	mm	Total rain loss	169.1	mm
Actual water use by crop	873.7	mm	Moist deficit at harvest	85.2	mm
Potential water use by crop	873.7	mm	Actual irrigation requirement	423.5	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	72.7	%
Deficiency irrigation schedule	0.0	%			

Table 5.7 : Irrigation Schedule for Cotton as per CROPWAT model

Crop irrigation schedule

ETo station SURENDRANAGAR-DI: | Crop SESAME | Planting date 25/06 | Yield red. 0.0 %
Rain station SURENDRANAGAR | Soil RED SANDY | Harvest date 12/10

Table format: Irrigation schedule / Daily soil moisture balance

Timing: Irrigate at critical depletion
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
22 Aug	59	Mid	0.0	1.00	100	60	90.5	0.0	0.0	129.3	0.25
12 Oct	End	End	0.0	1.00	100	29					

Totals

Total gross irrigation	129.3	mm	Total rainfall	613.3	mm
Total net irrigation	90.5	mm	Effective rainfall	444.0	mm
Total irrigation losses	0.0	mm	Total rain loss	169.3	mm
Actual water use by crop	528.3	mm	Moist deficit at harvest	43.4	mm
Potential water use by crop	528.3	mm	Actual irrigation requirement	84.3	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	72.4	%
Deficiency irrigation schedule	0.0	%			

Table 5.8 : Irrigation Schedule for Sesame as per CROPWAT model

Crop irrigation schedule

ETo station SURENDRANAGAR-DI: | Crop Wheat Surendran | Planting date 25/11 | Yield red. 0.0 %
Rain station SURENDRANAGAR | Soil RED SANDY | Harvest date 03/04

Table format: Irrigation schedule / Daily soil moisture balance

Timing: Irrigate at critical depletion
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
2 Jan	39	Dev	0.0	1.00	100	56	49.8	0.0	0.0	71.1	0.21
21 Jan	58	Dev	0.0	1.00	100	56	65.1	0.0	0.0	93.0	0.57
3 Feb	71	Mid	0.0	1.00	100	57	68.7	0.0	0.0	98.2	0.87
15 Feb	83	Mid	0.0	1.00	100	58	69.8	0.0	0.0	99.7	0.96
26 Feb	94	Mid	0.0	1.00	100	60	72.5	0.0	0.0	103.6	1.09
8 Mar	104	End	0.0	1.00	100	63	75.3	0.0	0.0	107.6	1.25
21 Mar	117	End	0.0	1.00	100	70	84.2	0.0	0.0	120.3	1.07
3 Apr	End	End	0.0	1.00	100	42					

Totals

Total gross irrigation	693.5	mm	Total rainfall	5.7	mm
Total net irrigation	485.4	mm	Effective rainfall	5.4	mm
Total irrigation losses	0.0	mm	Total rain loss	0.3	mm
Actual water use by crop	540.9	mm	Moist deficit at harvest	50.1	mm
Potential water use by crop	540.9	mm	Actual irrigation requirement	535.5	mm
Efficiency irrigation schedule	100.0	%	Efficiency rain	94.7	%
Deficiency irrigation schedule	0.0	%			

Table 5.9 : Irrigation Schedule for Sesame as per CROPWAT model

The table 5.7,5.8 and 5.9 represents the output window obtained from CROPWAT model for irrigation scheduling of Cotton, Sesame and Wheat crop at critical depletion. It was found that for Cotton the total gross irrigation was about 554.2 mm, NIR was 388 mm and the efficiency of rain was 72.7%. For Sesame the total gross irrigation was about 129.3 mm, NIR was 90.5 mm and the efficiency of rain was 72.4%. For Wheat the total gross irrigation was about 693.5 mm, NIR was 485.4 mm and the efficiency of rain was 94.7%

VI. CONCLUSIONS

The study's findings might serve as a reference for farmers as they decide when to schedule irrigation and what practices and methods to apply. The study's findings may be extended into the future, and probability analysis can be used to estimate how much water crops would need in the future. Additionally, it can be determined if the anticipated rainfall will be sufficient to meet the crops' future water needs. CROPWAT is an effective and user friendly tool for finding Cropwater requirement and prepare Irrigation Scheduling. From the results Crop water requirement for Cotton using CROPWAT 8.0 model is obtained 876.3 mm/dec Crop water Requirement for Wheat is obtained 543.9 mm/dec and Crop water Requirement for Sesame is obtained 529.6 mm/dec. The results of this study may be useful for optimal irrigation management and agricultural planning for growing cotton, sesame, and wheat.

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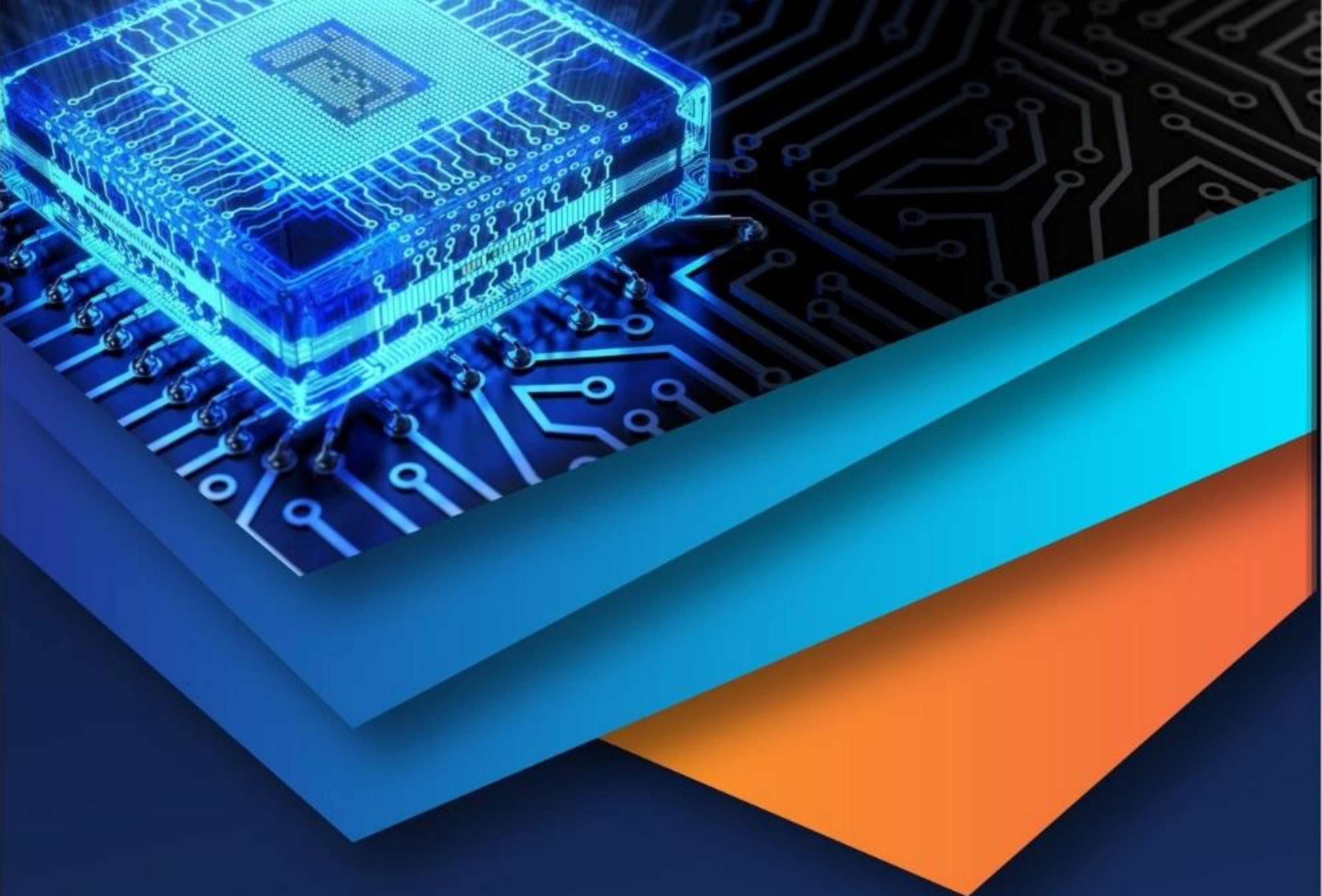

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